

# Resting Brain and Mind

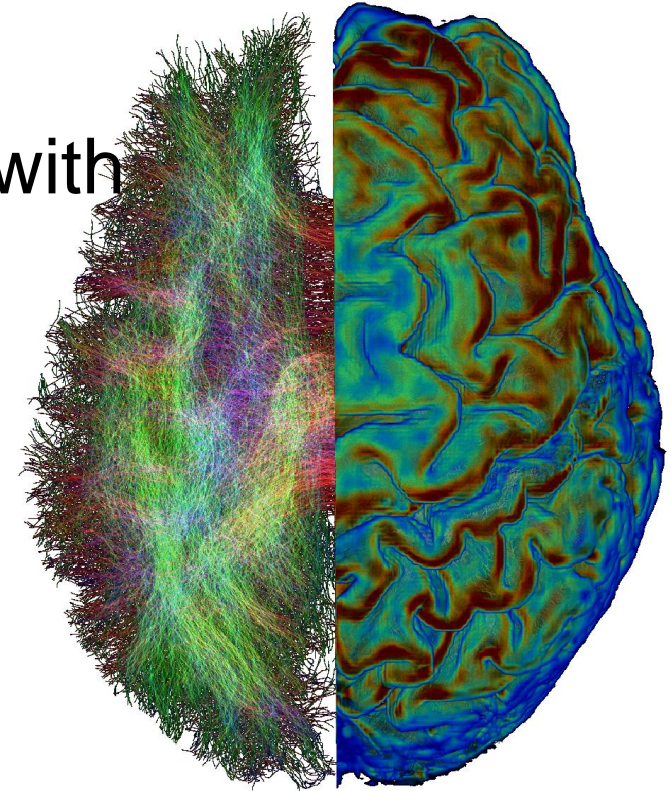
How brain dynamics are associated with ongoing cognition

**Sepehr MORTAHEB**

FNRS Research Fellow (Aspirant)  
Physiology of Cognition Lab  
GIGA CRC In vivo imaging  
University of Liège

University of Crete

April 24 2023





# Studying Mind and Brain

## Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

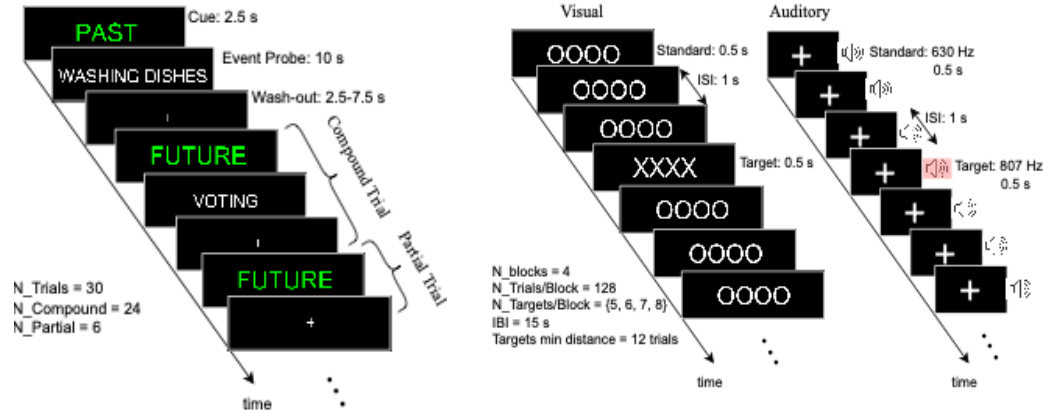
Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

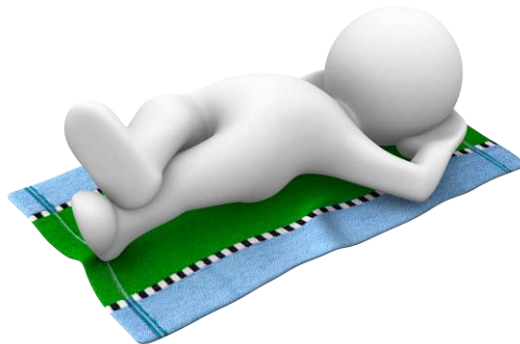
Discussion  
and  
Perspectives

## Mind

### Performing Cognitive Tasks

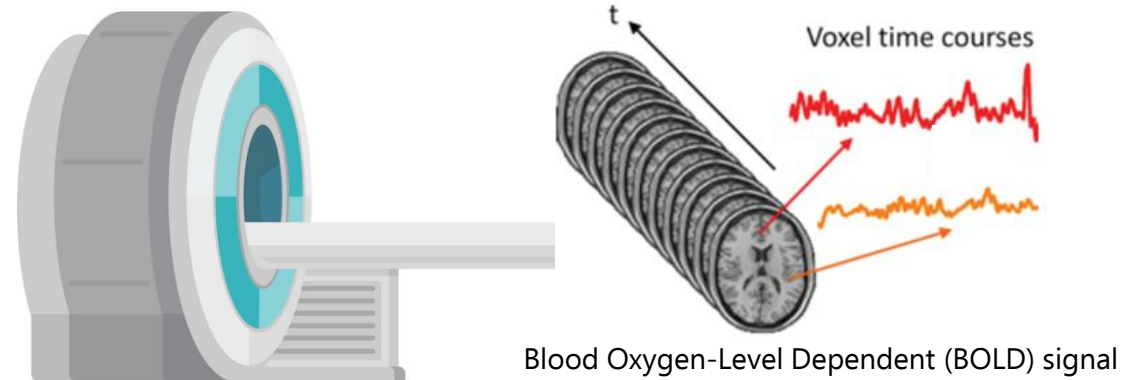


### Resting State

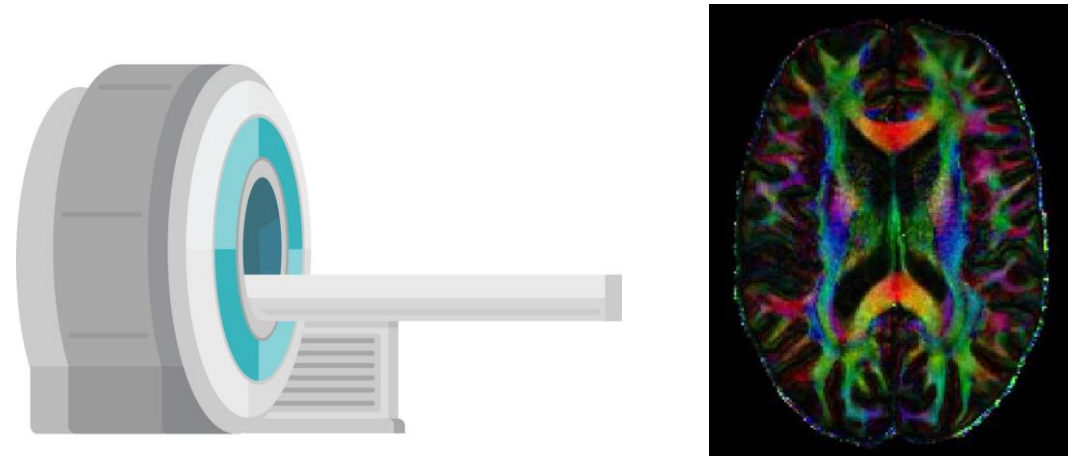


## Brain

### Functional MRI (fMRI)



### Diffusion Weighted Imaging (DWI)





# Resting State

## Introduction

Study I:  
Mind Blanking

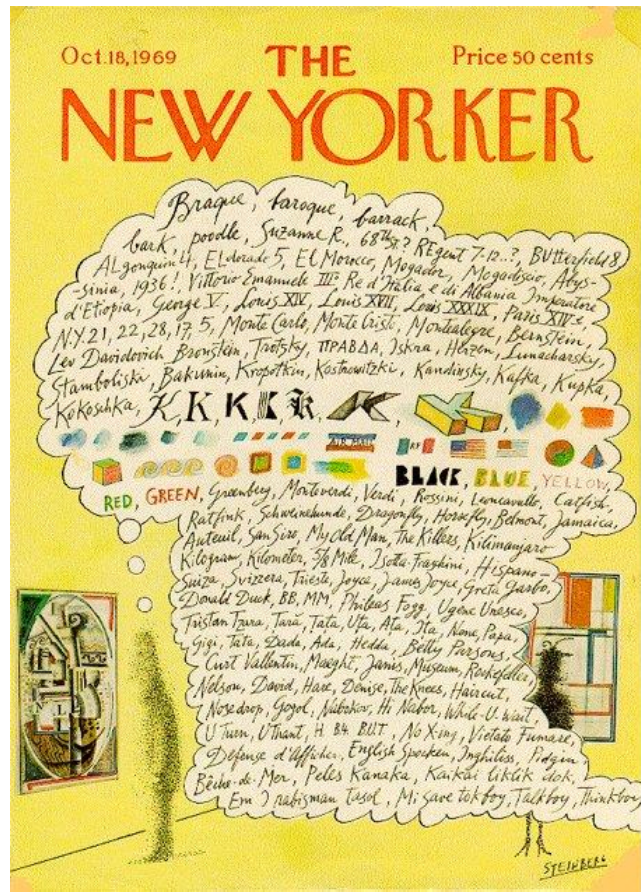
Study II:  
Psychedelics

Study III:  
Spaceflight

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Discussion  
and  
Perspectives

## Mind



Content

Dynamism

## Brain



Structure

Function





# The brain as a network

## Introduction

Study I:  
Mind Blanking

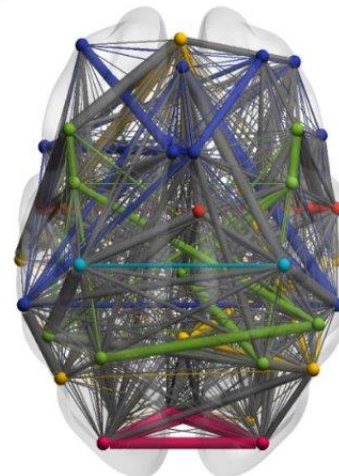
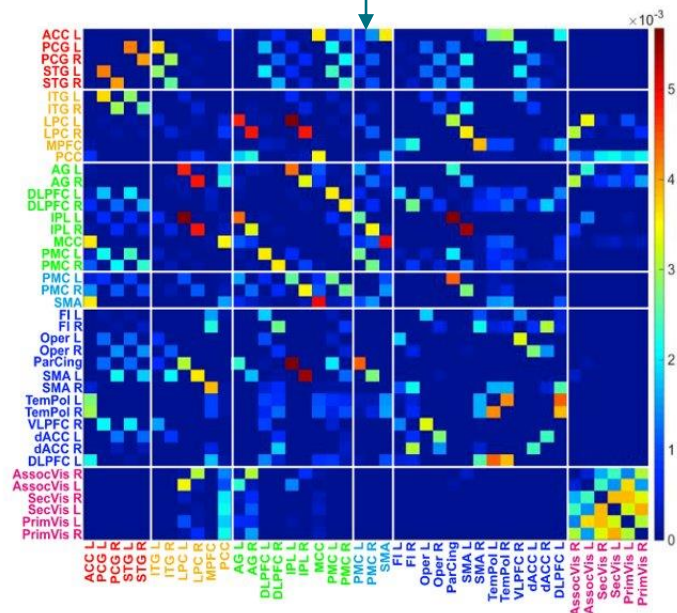
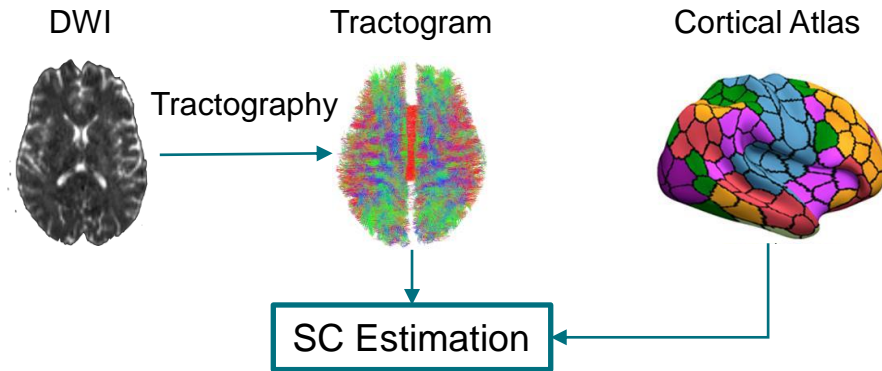
Study II:  
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and  
Perspectives

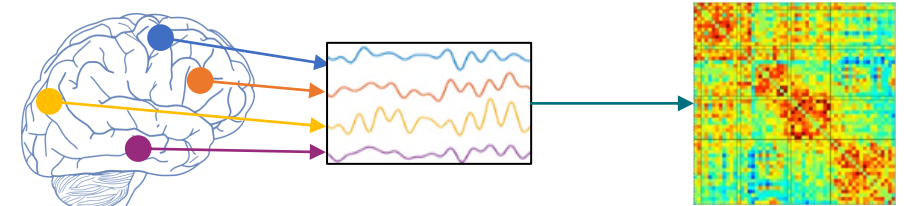
## Structural connectome



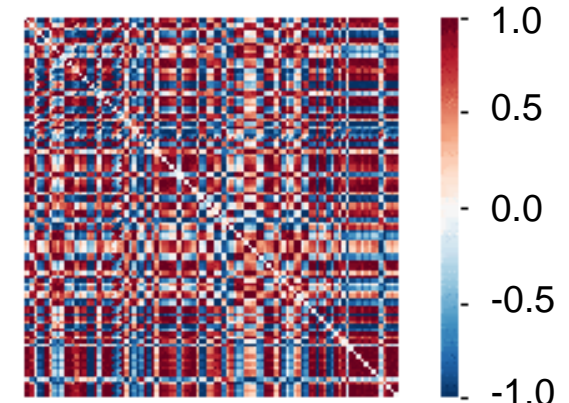
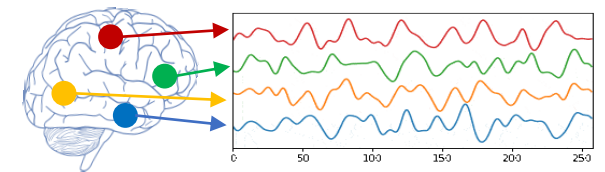
Aud Mot DMN Sal FP Vis

## Functional connectome

### Static FC Estimation



### Dynamic FC Estimation



Phase-based coherence matrices



# How rigid structure and dynamic function support the richness of the mind?

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## Special Conditions

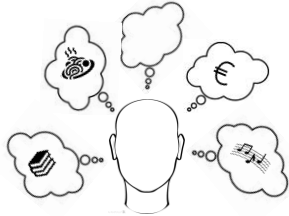
Typical  
Wakefulness

Altered States of  
Consciousness

Extreme  
Environments

### Study I:

Spontaneous occurrences  
of mind blanking



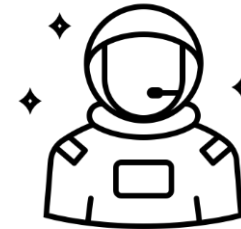
### Study II:

Psilocybin as an external  
pharmacological agent



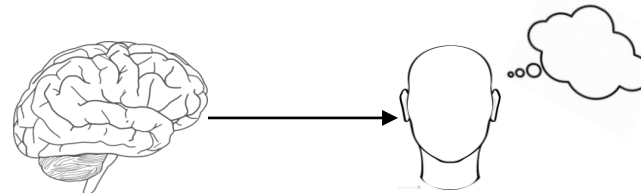
### Study III:

Effect of spaceflight on  
the brain's structure and function



### Study IV:

Toward mental state decoding at rest



Introduction

**Study I:  
Mind Blanking**

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Discussion  
and  
Perspectives

# Study I:

## “Spontaneous occurrences of mind blanking”



### Based on:

**Mortaheb, S.**, Van Calster, L., Raimondo, F., Klados, M.A., Boulakis, P.A., Georgoula, K., Majerus, S., Van De Ville, D. and Demertzi, A. Mind blanking is a distinct mental state linked to a recurrent brain profile of globally positive connectivity during ongoing mentation. *Proceedings of the National Academy of Sciences*, 119(41), p.e2200511119. (2022)



# Mental states during rest

Introduction

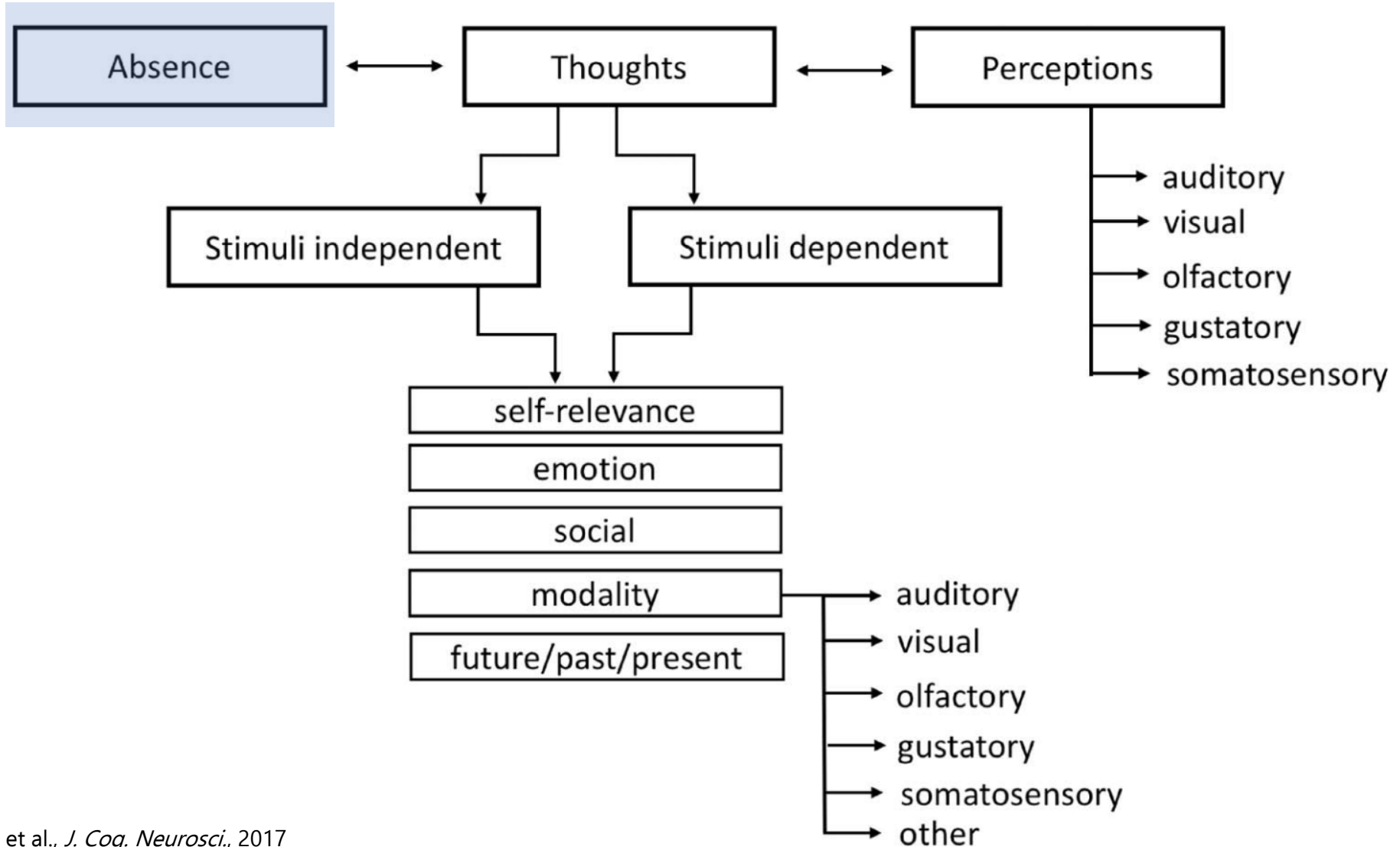
**Study I:**  
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# Methods

Introduction

Study I:  
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Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

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and  
Perspectives

## Participants

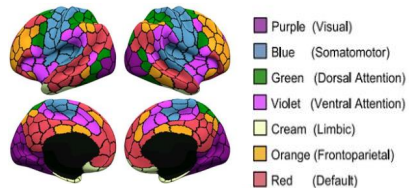
n = 36 typical  
27 Women, 9 Men  
23 ± 2.9 years old

## Paradigm

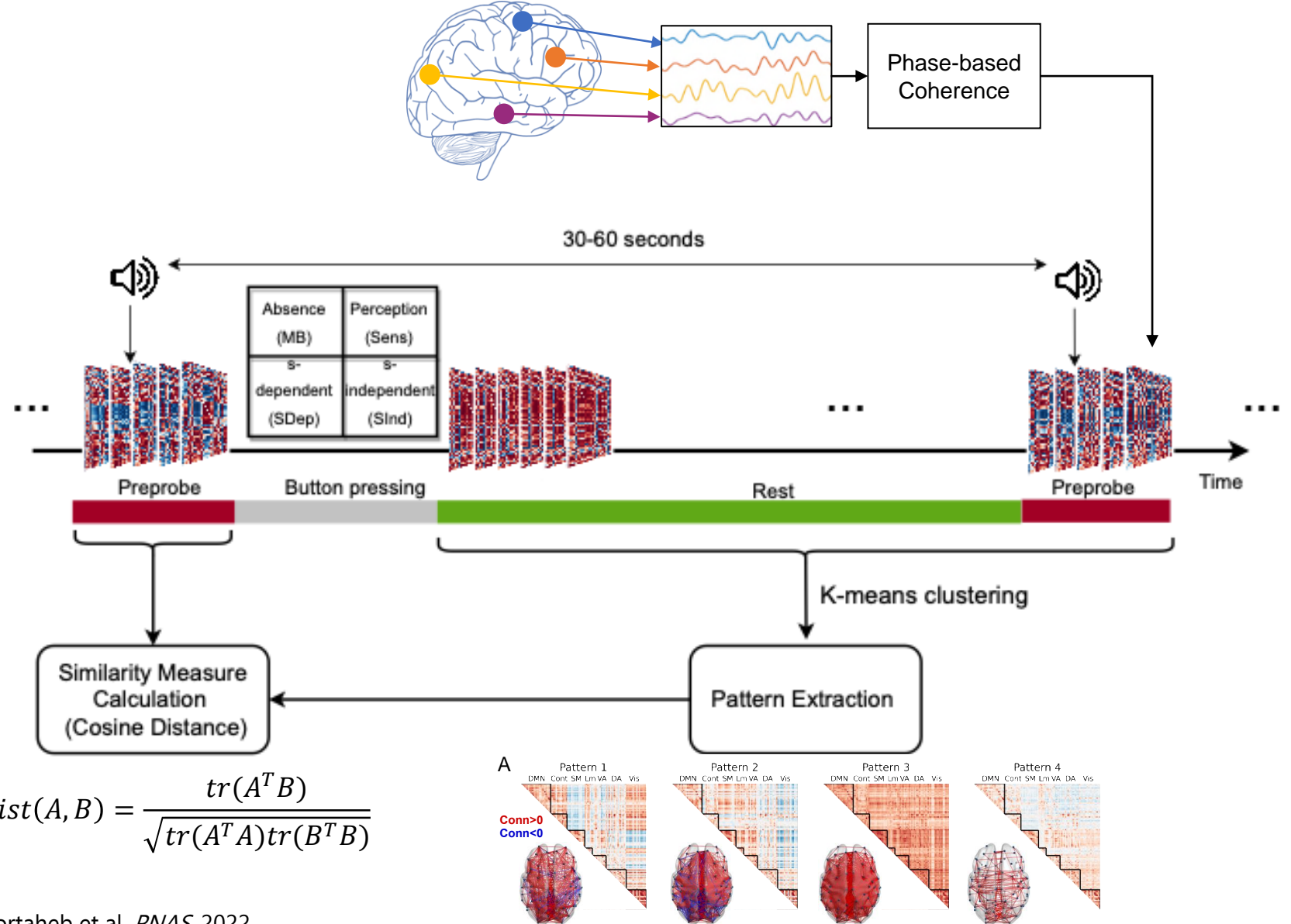
Experience-sampling  
Functional MRI (3T)  
TR = 2.04 sec

## Analysis

Schaefer Atlas (100 ROIs)



Phase-based coherence  
K-means clustering  
Cosine similarity



Mortaheb et al, *PNAS*, 2022

Data originally shared by S. Majerus, Psychology and Neuroscience of Cognition Research Unit, University of Liège, Belgium





# MB is characterized by a distinct behavioral profile

Introduction

**Study I:  
Mind Blanking**

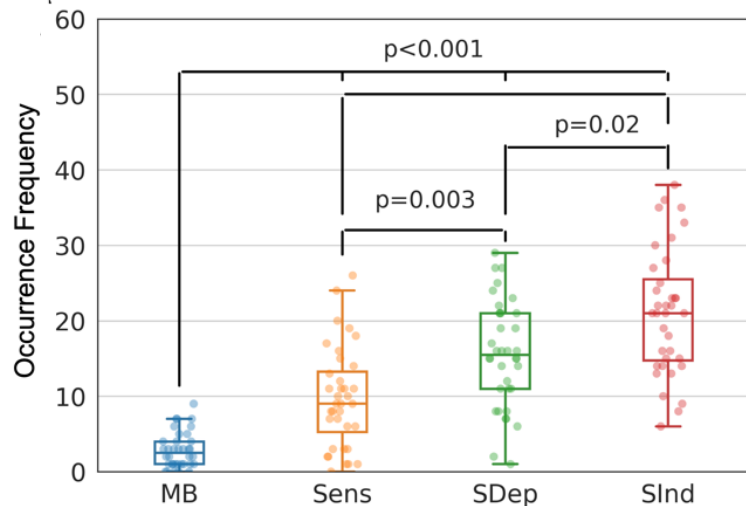
Study II:  
Psychedelics

Study III:  
Spaceflight

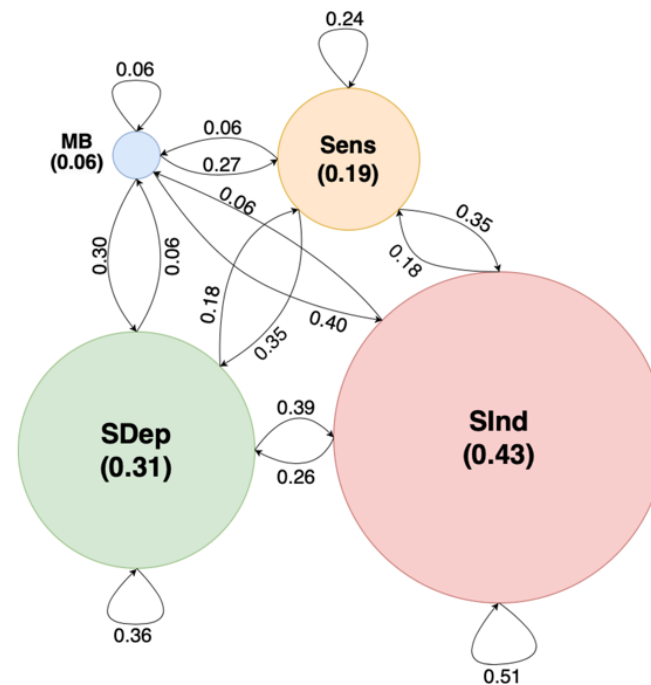
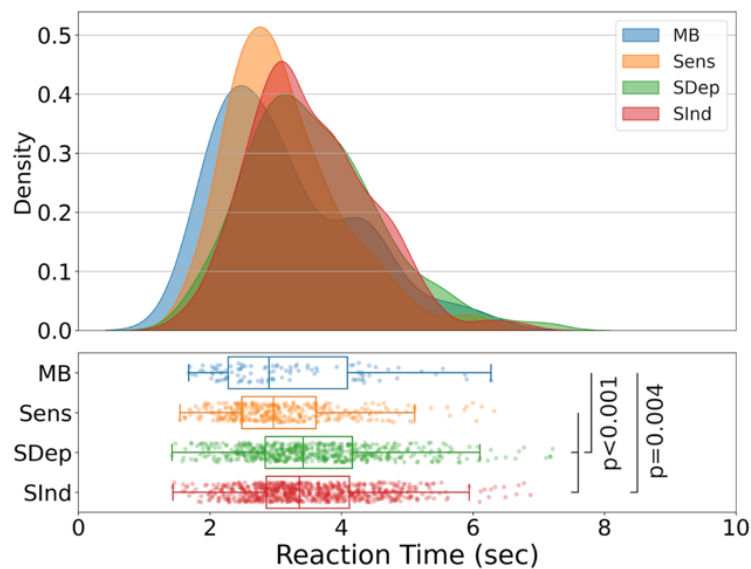
Study IV:  
Mental State  
Decoding

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and  
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**Rare**

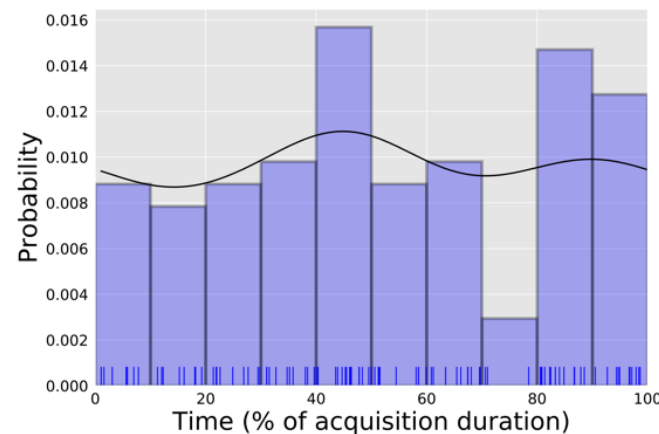


**Fast**



**Less visited**

**Equiprobable**





# MB is characterized by distinct neural profiles

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

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MB reports classification based on phased-based coherence matrices

	BALANCED ACCURACY	RECALL	PRECISION
MB VS. SENS	0.97	0.95	0.99
MB VS. SDEP	0.96	0.92	1
MB VS. SIND	0.94	0.88	1
MB VS. OTHERS	0.90	0.81	1
MB VS. OTHERS (DUMMY)	0.50	0.05	0.06

$$Precision = \frac{TP}{TP + FP} \quad Recall = \frac{TP}{TP + FN}$$

$$Balanced Accuracy = \frac{1}{2} \left( \frac{TP}{TP + FN} + \frac{TN}{TN + FP} \right)$$

*TP: True Positive*  
*FP: False Positive*  
*TN: True Negative*  
*FN: False Negative*

*Positive: MB Reports*



# MB is associated with functional hyper-connectivity pattern

Introduction

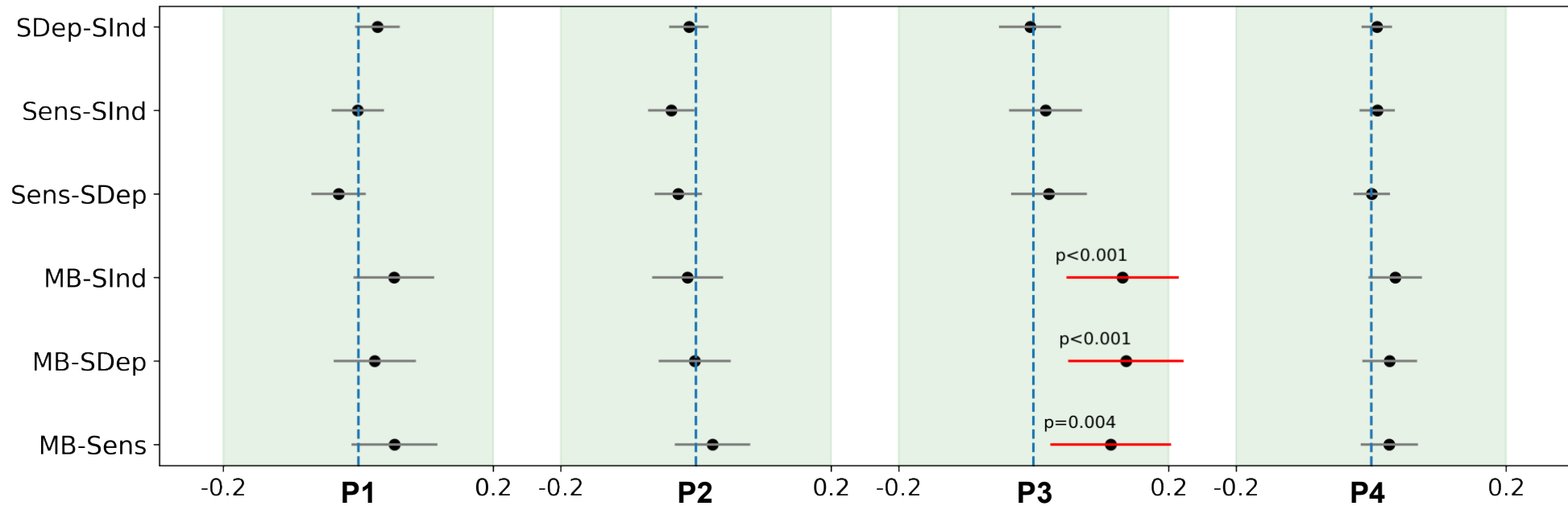
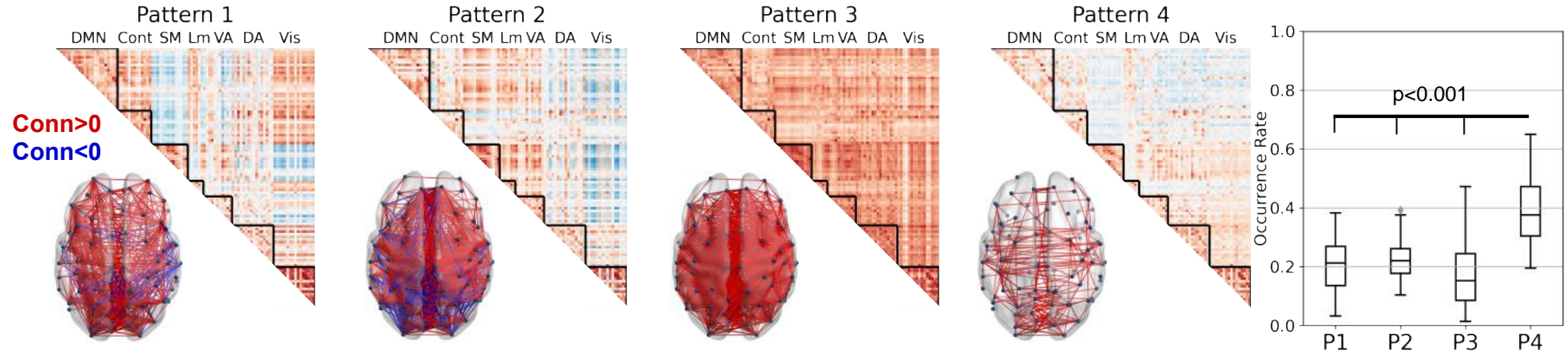
Study I:  
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# Is this an effect of Global Signal (GS)?

Introduction

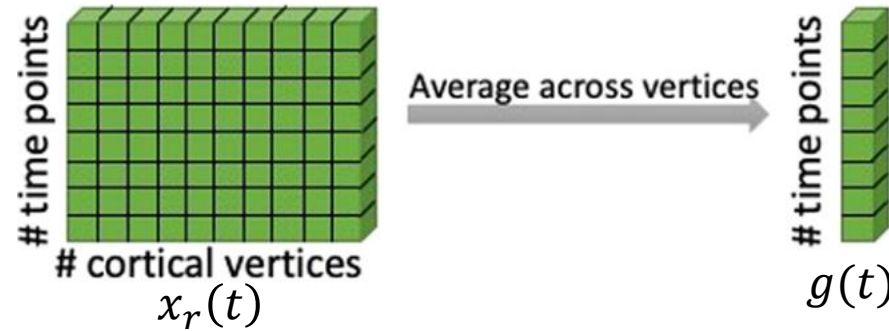
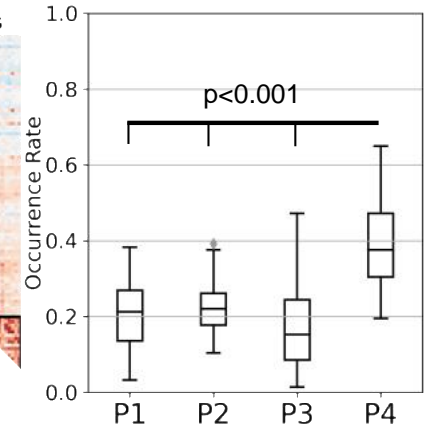
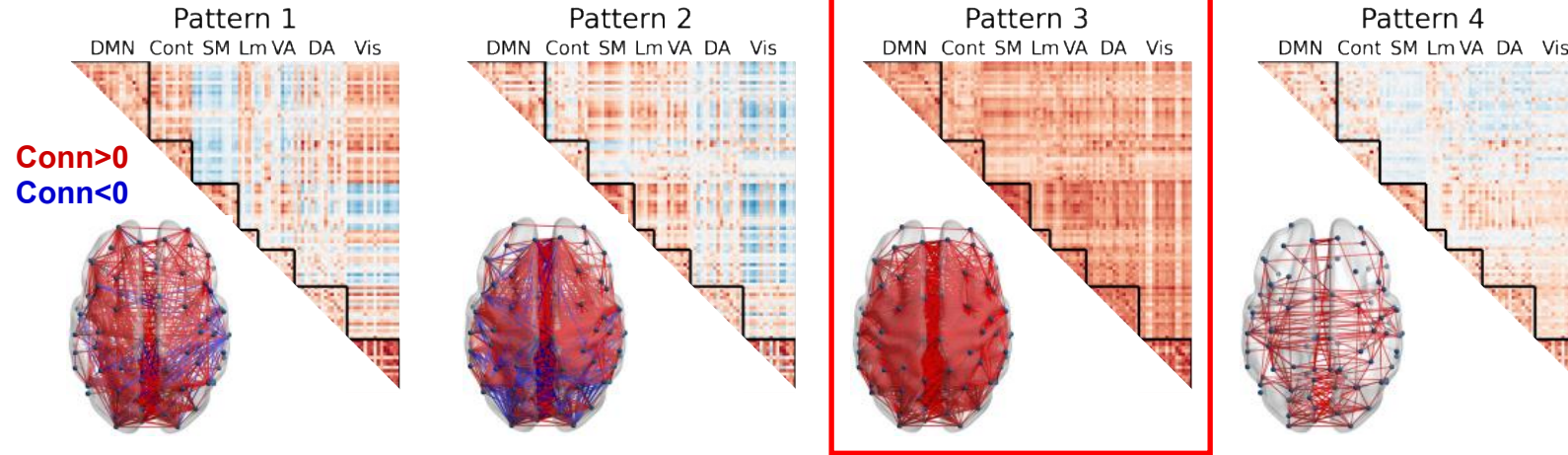
Study I:  
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Global Signal Regression (GSR): 
$$x'_r(t) = x_r(t) - \frac{\|x_r(t)\|}{\|g(t)\|} \cdot \text{corr}(x_r(t), g(t)) \cdot g(t)$$



# Effects of GSR on dynamic connectivity patterns

Introduction

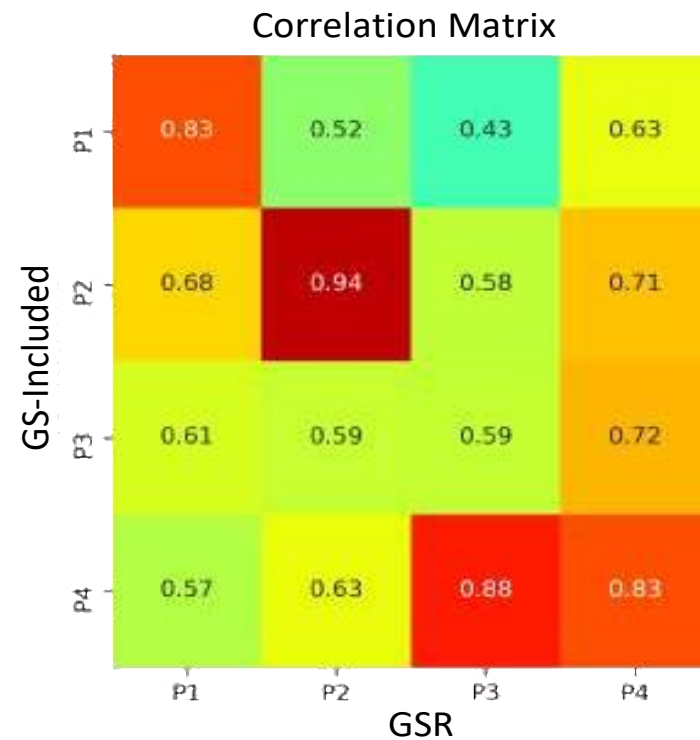
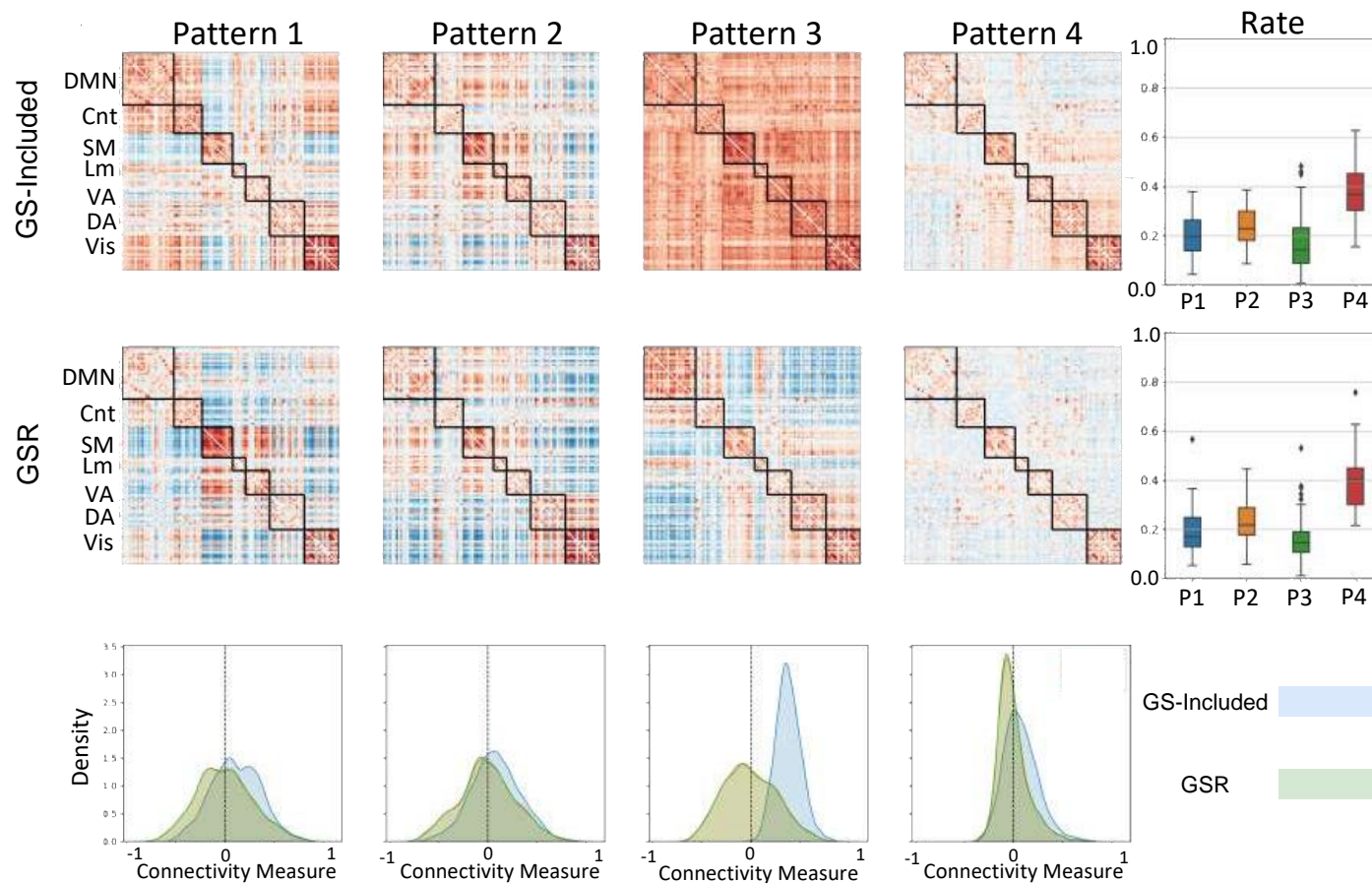
Study I:  
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# MB is characterized by high amplitudes of global signal

Introduction

**Study I:  
Mind Blanking**

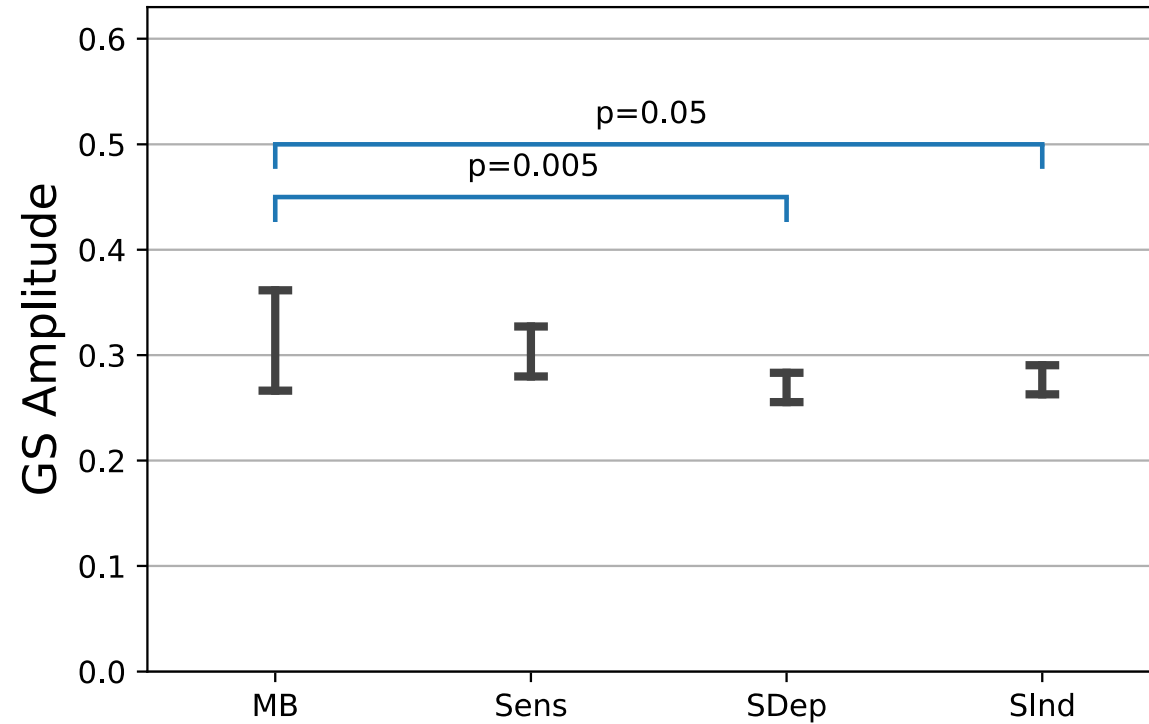
Study II:  
Psychedelics

Study III:  
Spaceflight

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and  
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MB is associated with higher global signal amplitude





# Discussion

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

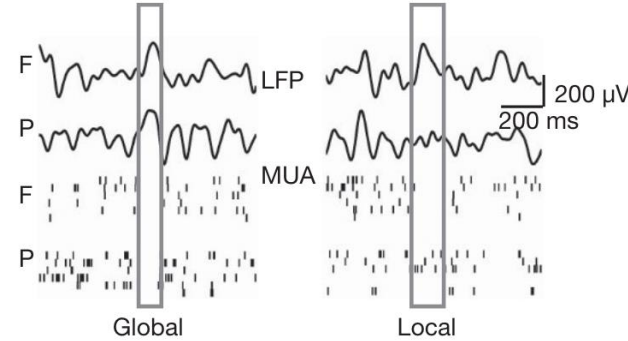
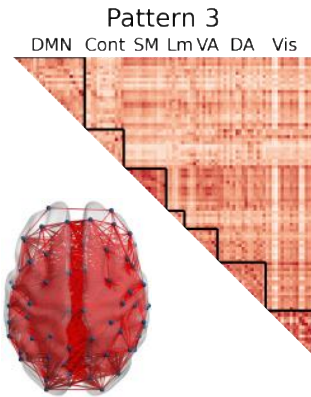
Study III:  
Spaceflight

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and  
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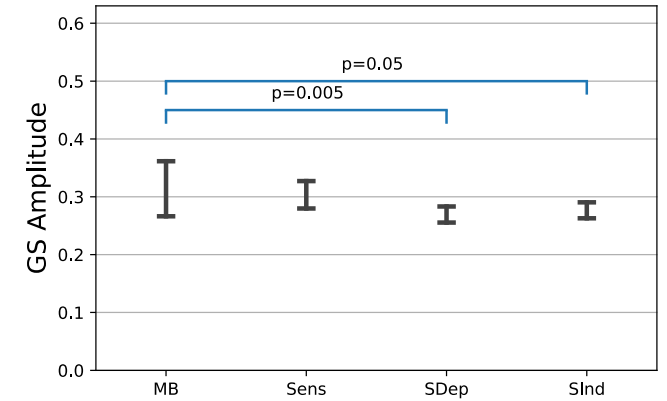
## Mind Blanking

### Hyper-Connectivity

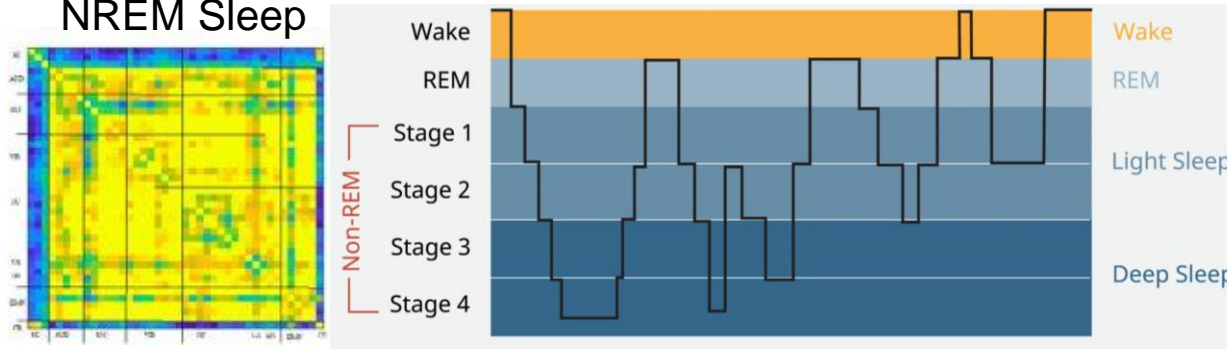


Vyazovskiy et al, *Nature* 2011  
**Neural Silencing**

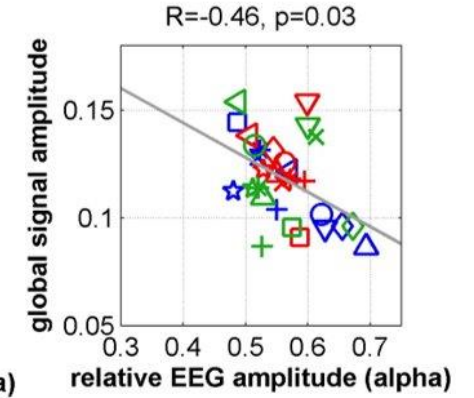
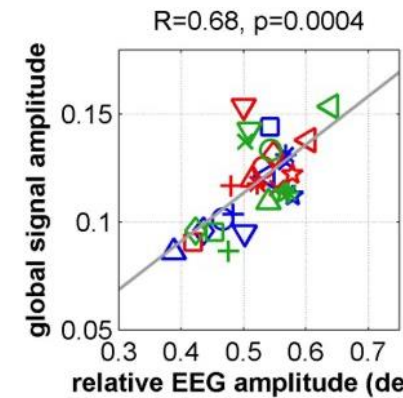
### High Global Signal Amplitude



### NREM Sleep



El-Baba et al, *PLOS One* 2019



Wong et al, *Neuroimage* 2013

## Slow Wave Activity

## Reduced Arousal

Introduction

Study I:  
Mind Blanking

**Study II:  
Psychedelics**

Study III:  
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and  
Perspectives

## Study II:

*"Effects of external perturbation on the brain and the mind"*







# How do psychedelic drugs affect the neurobehavioral profile?

Introduction

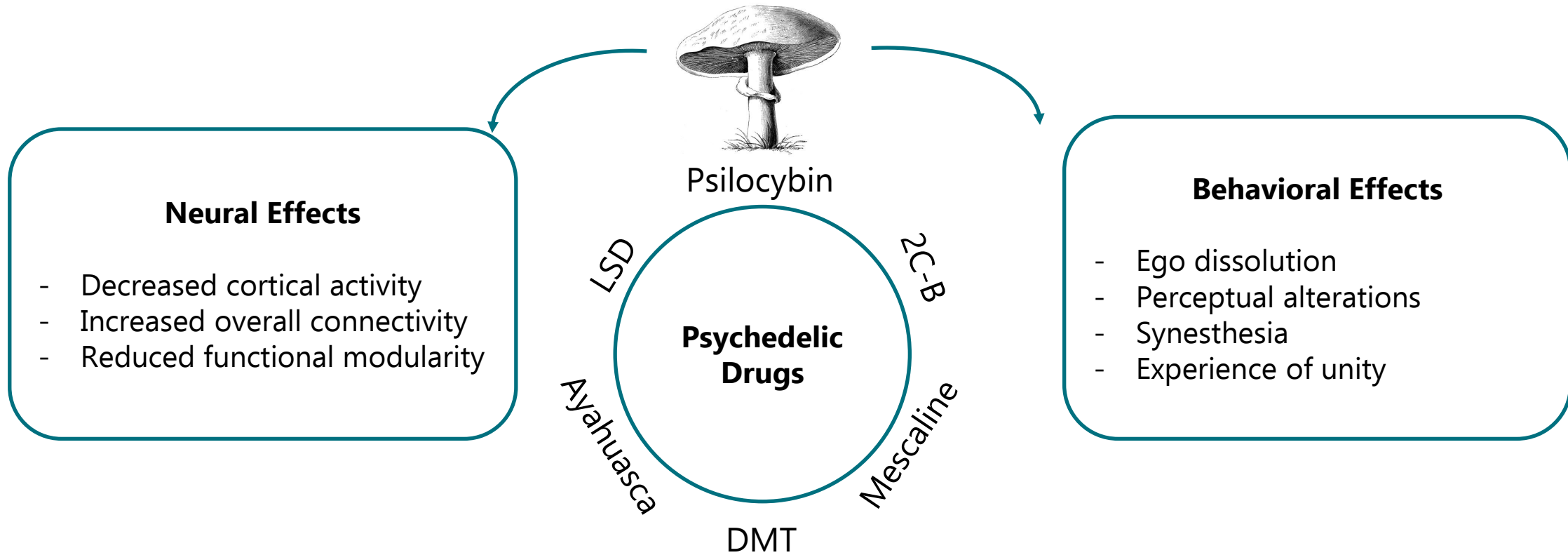
Study I:  
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# Methods

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## Participants

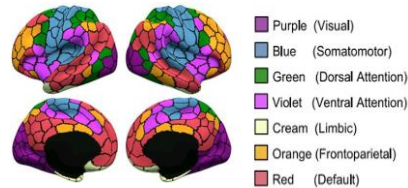
n = 49 typical  
22 Women and 27 Men

## Paradigm

Resting State  
functional MRI (7T)  
TR = 1.4 sec

## Analysis

Schaefer Atlas (100 ROIs) with 7  
Networks



## Static Connectivity:

- ROI-ROI Correlation

## Dynamic Connectivity:

- Phase-based coherence
- K-means clustering
- Markov Chain

## Neurobehavioral:

- Canonical Correlation  
Analysis

**Psilocybin Group:**  
10 Women and 12 Men  
Age:  $23 \pm 2.9$   
Dose: 0.17 mg/Kg

**Placebo Group:**  
12 Women and 15 Men  
Age:  $23.1 \pm 3.8$

Drug  
Intake

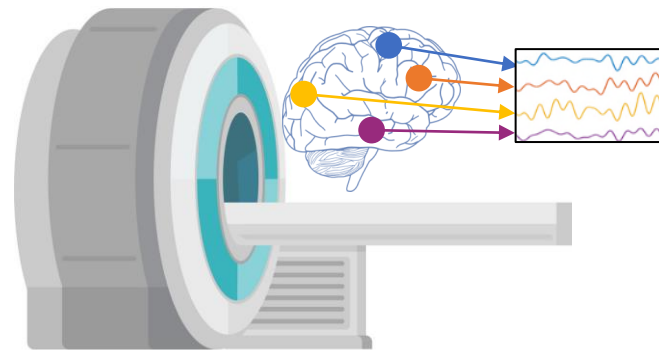
102 min

360 min

time

Neuroimaging

Behavioral  
Assessment



## Questionnaires:

### 5D-ASC (Altered States of consciousness)

- Auditory Alteration (AA)
- Anxious Ego Dissolution (AED)
- Oceanic Boundlessness (OB)
- Reduction of Vigilance (RV)
- Visionary Restructuralization (VR)

### EDI (Ego Dissolution Inventory)

Mason et al., *Neuropsychopharmacology*, 2020

Data originally shared by J. Ramaekers, Faculty of Psychology and Neuroscience, Maastricht University, Netherland



# Profound alterations in subjective experience

Introduction

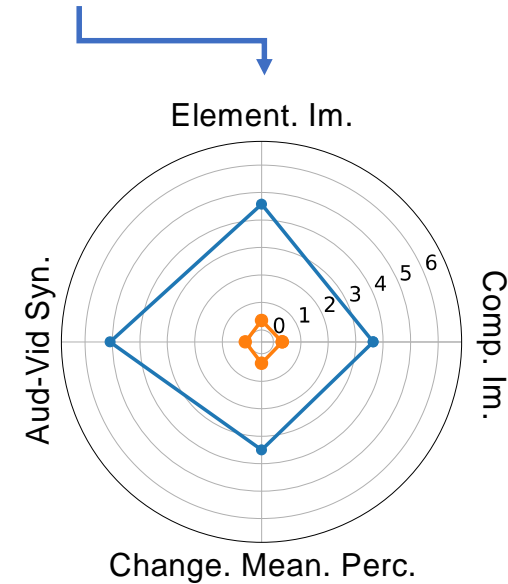
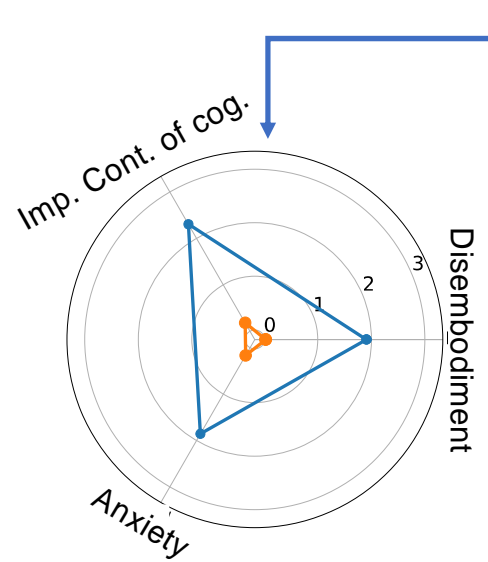
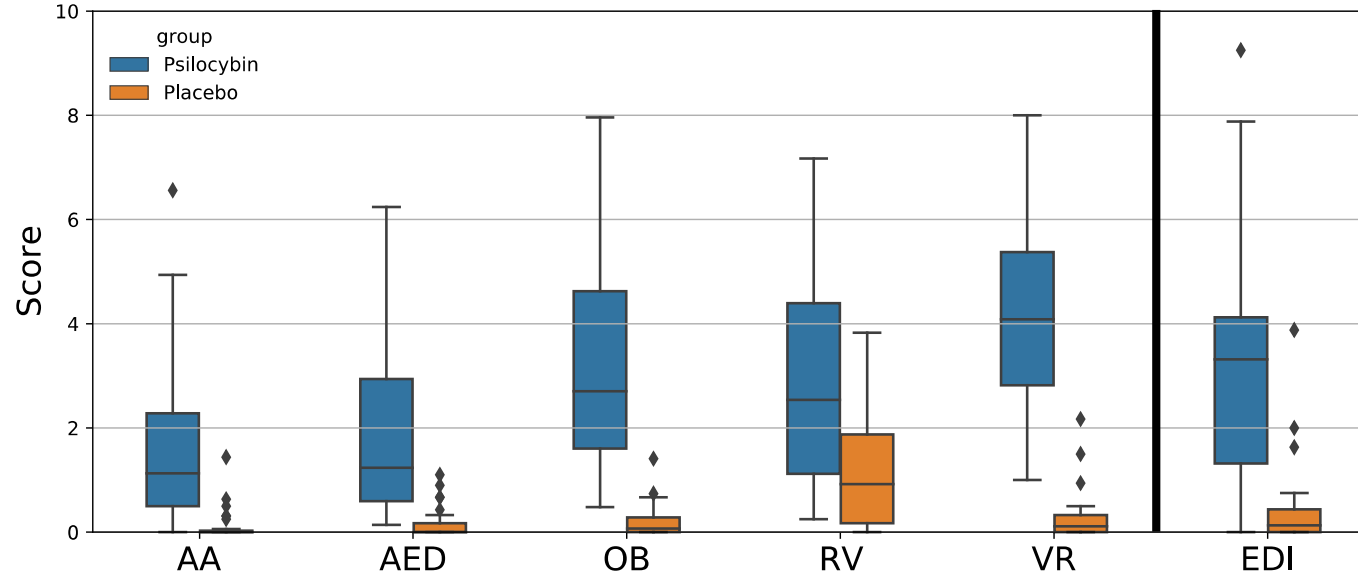
Study I:  
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# Overall increase in the whole-brain functional connectivity

Introduction

Study I:  
Mind Blanking

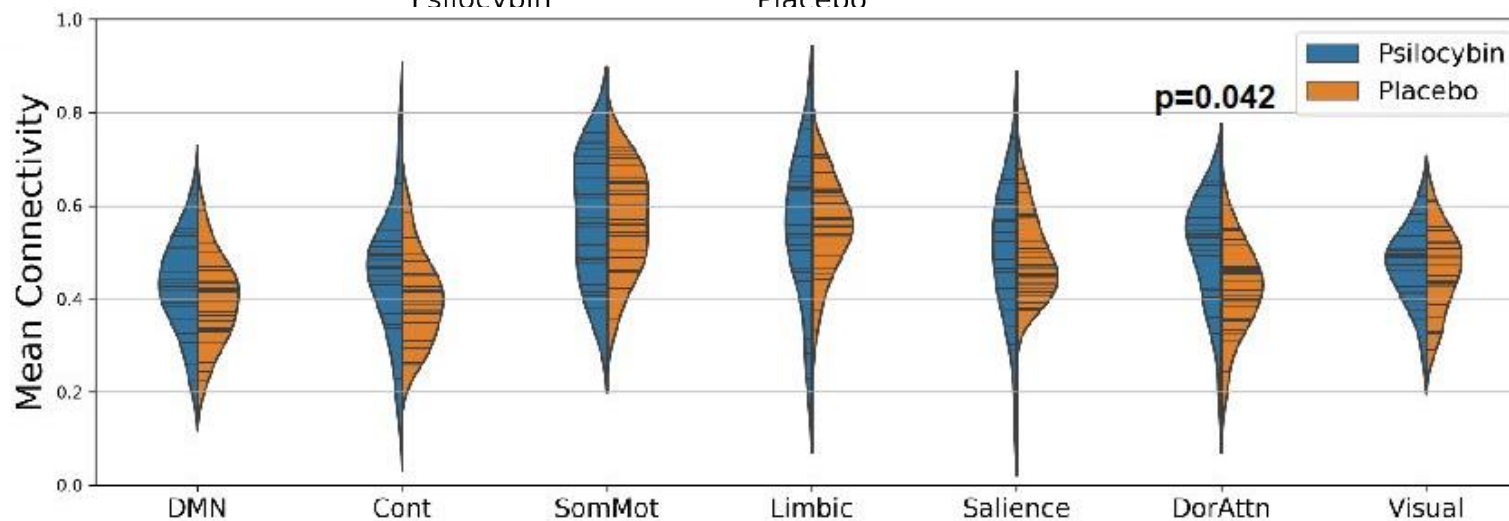
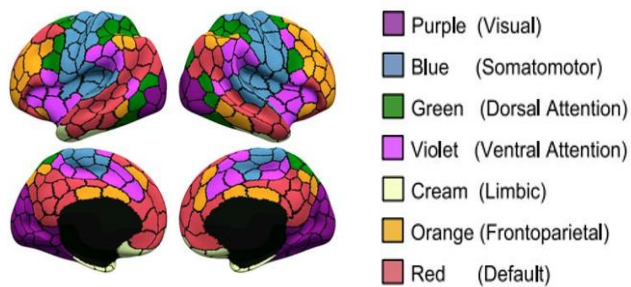
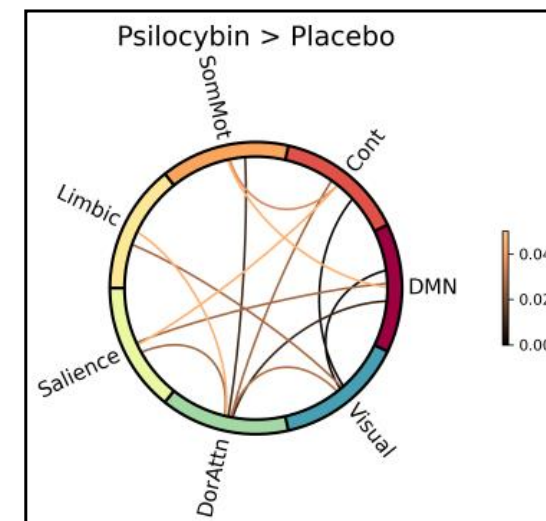
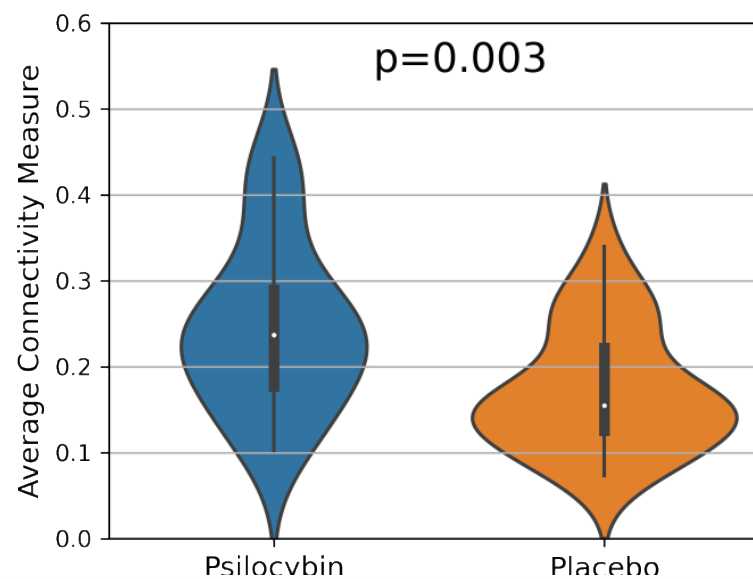
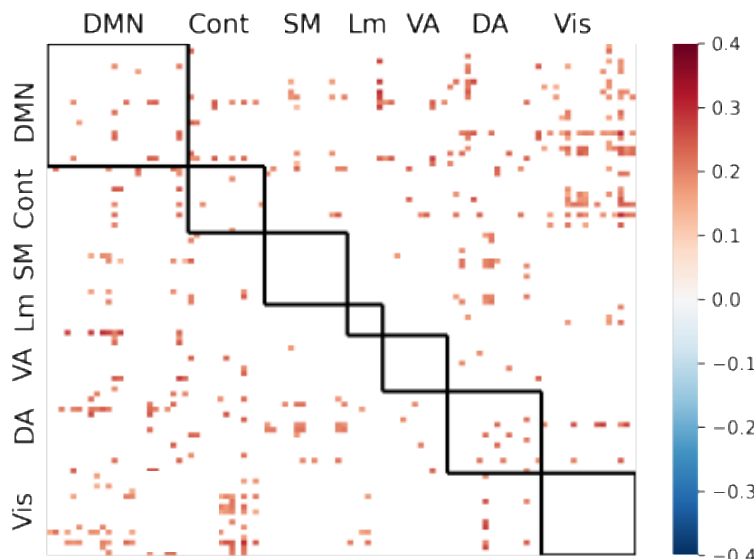
Study II:  
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## Psilocybin - placebo





# Overall tendency of the brain to return to a hyper-connectivity state

Introduction

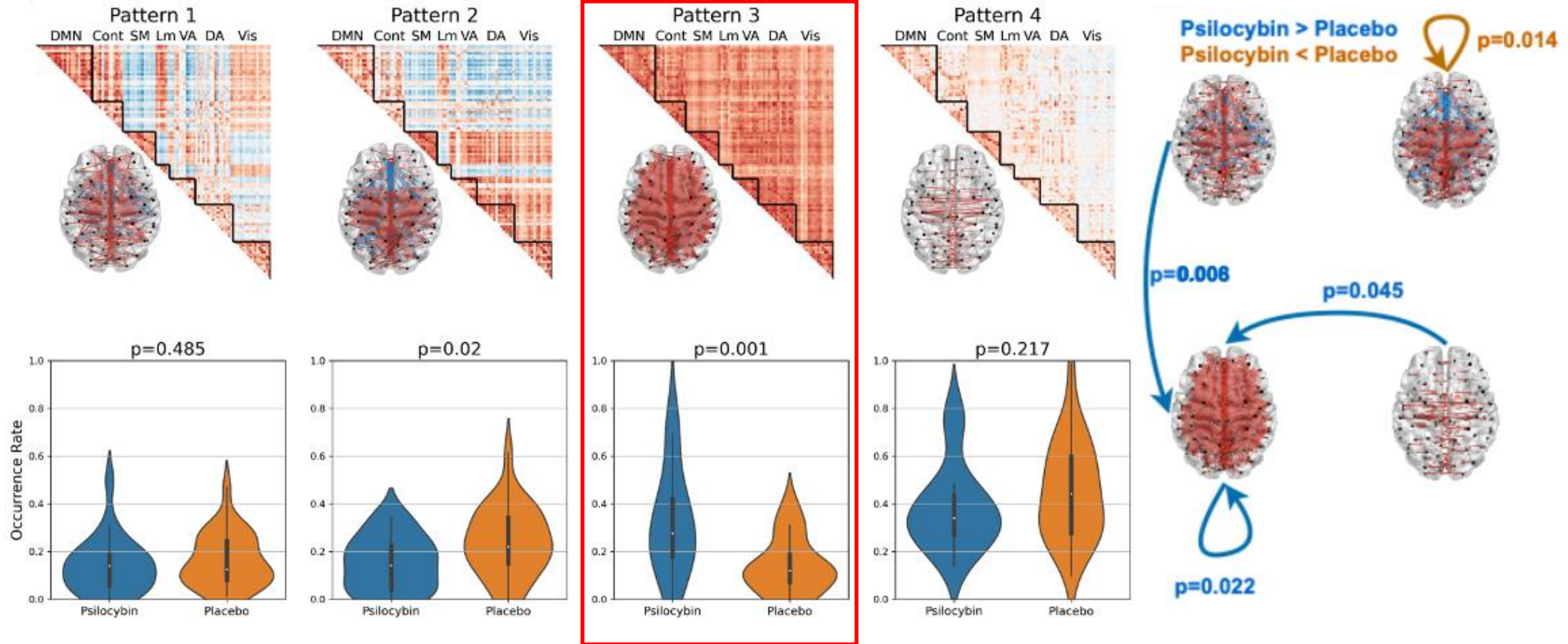
Study I:  
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# Overall decrease in regional BOLD signal amplitude

Introduction

Study I:  
Mind Blanking

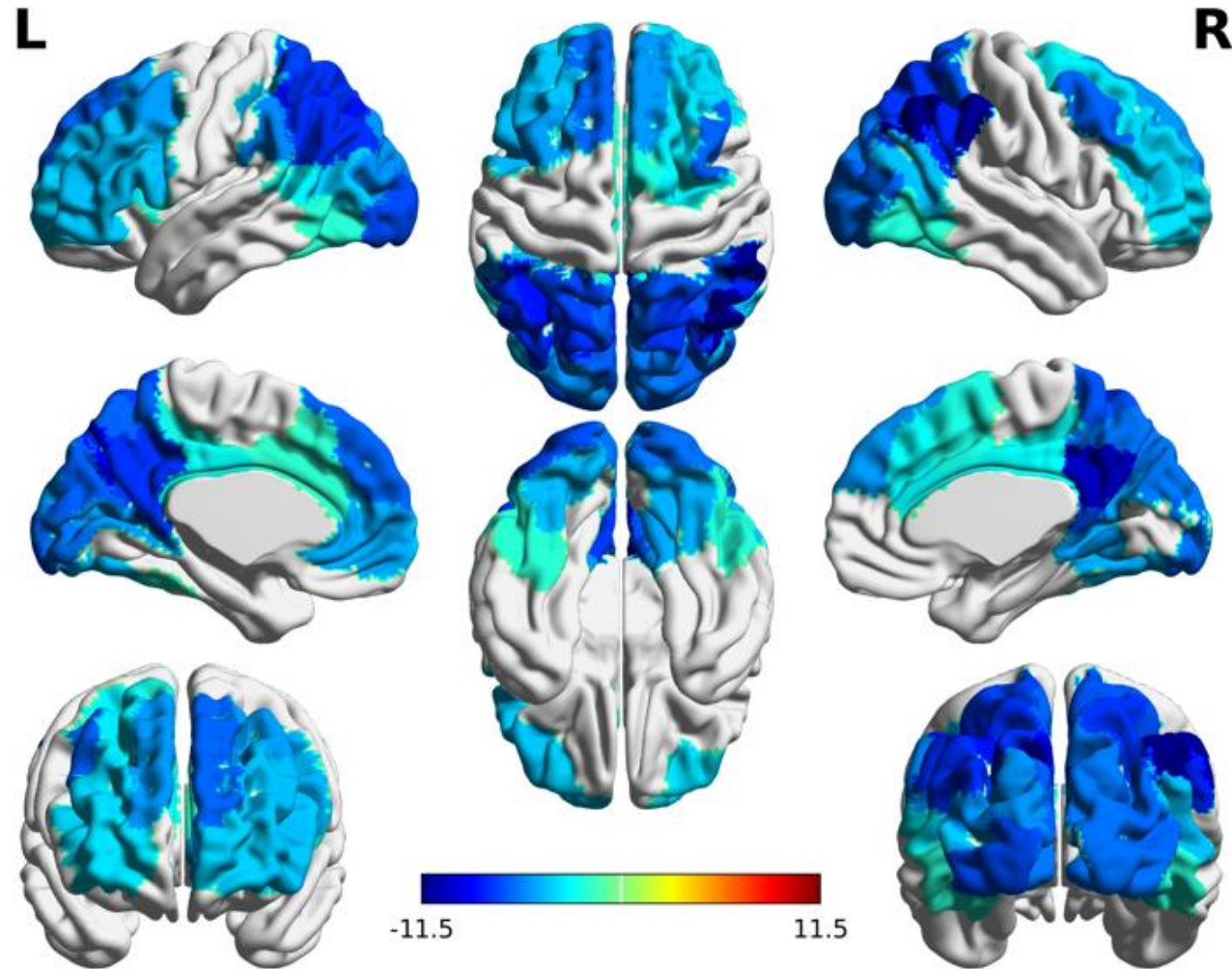
**Study II:  
Psychedelics**

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## Psilocybin vs Placebo





# Functional hyper-connectivity state is associated with feelings of depersonalization

Introduction

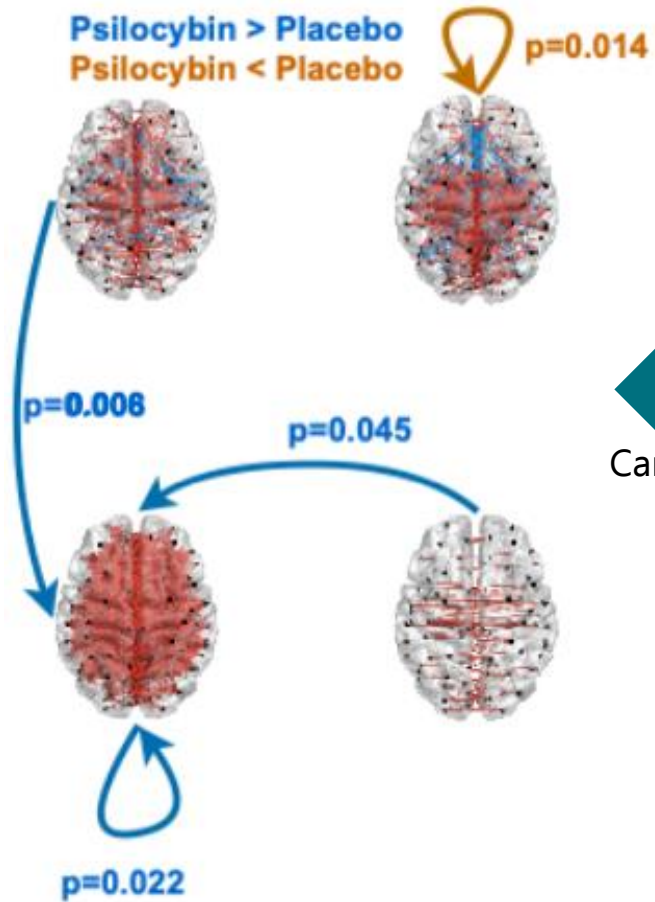
Study I:  
Mind Blanking

**Study II:  
Psychedelics**

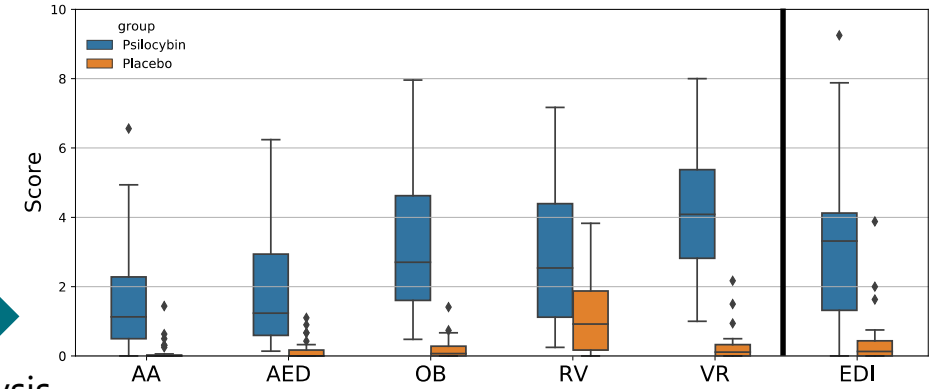
Study III:  
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Canonical Correlation Analysis (CCA)





# Functional hyper-connectivity state is associated with feelings of depersonalization

Introduction

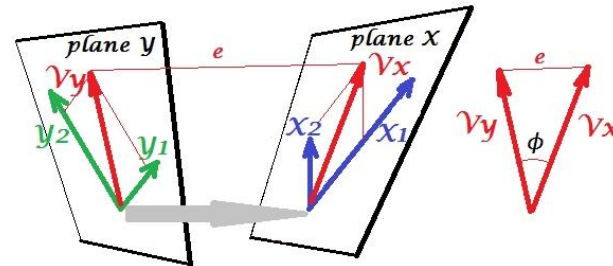
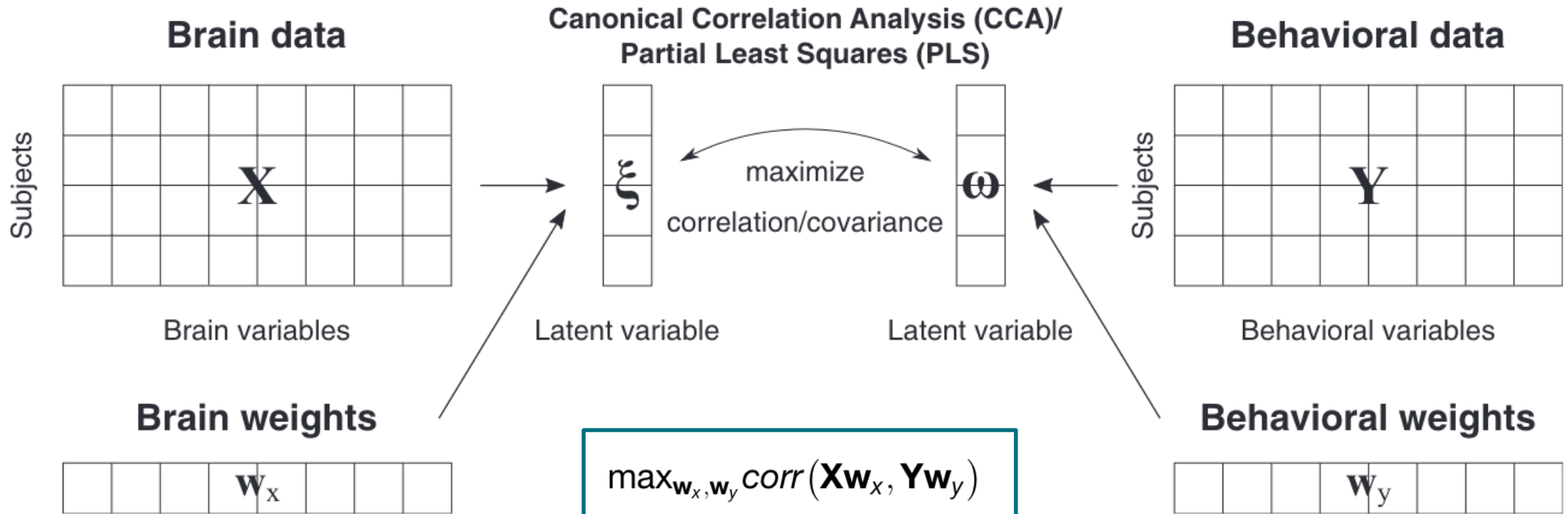
Study I:  
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# Functional hyper-connectivity state is associated with feelings of depersonalization

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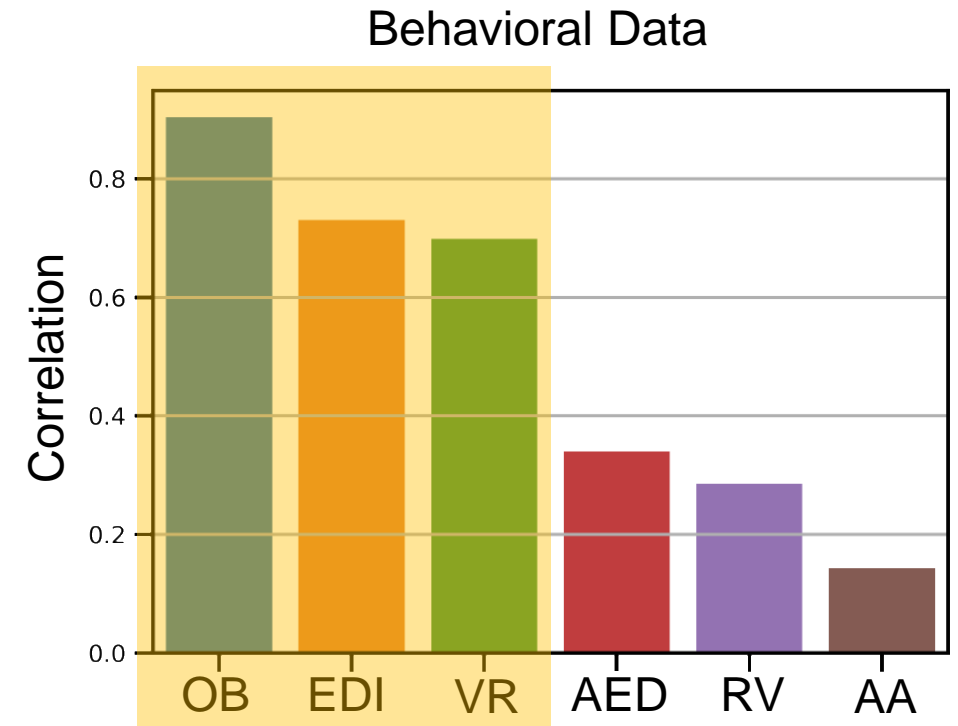
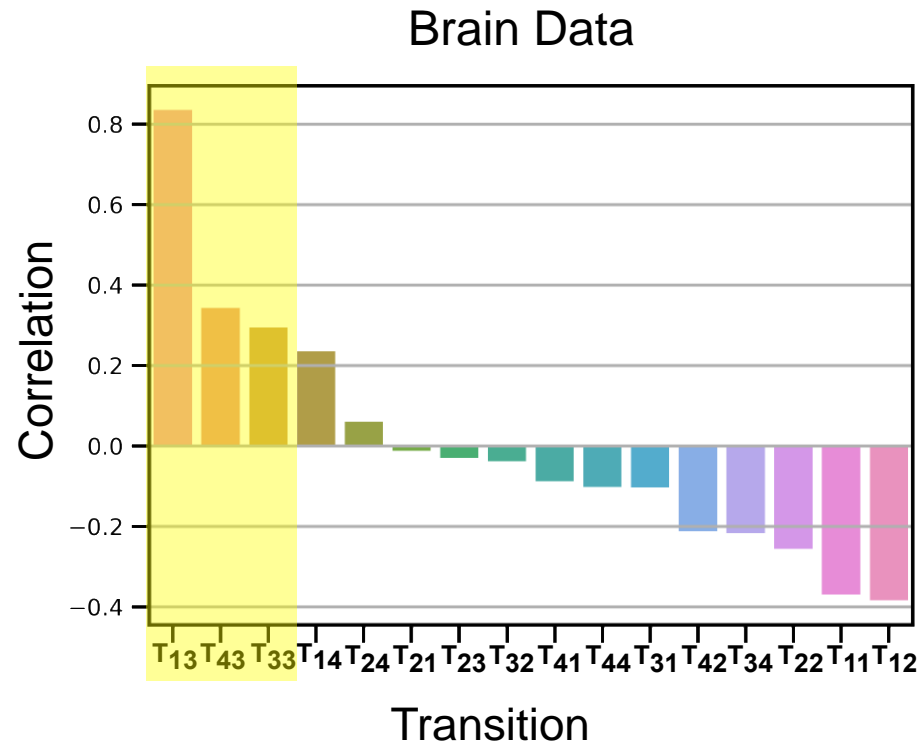
Study I:  
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# Discussion

Introduction

Study I:  
Mind Blanking

Study II:  
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Study III:  
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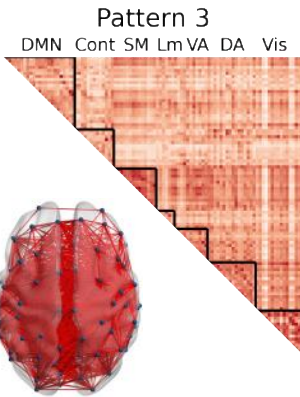
Study IV:  
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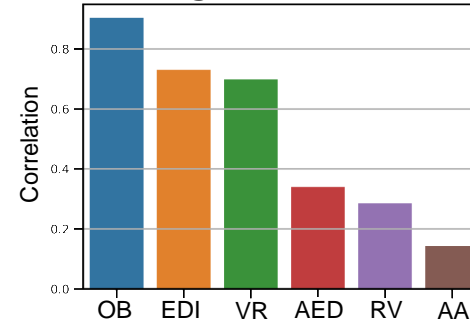
Slide: 26/48

## Psychedelic State

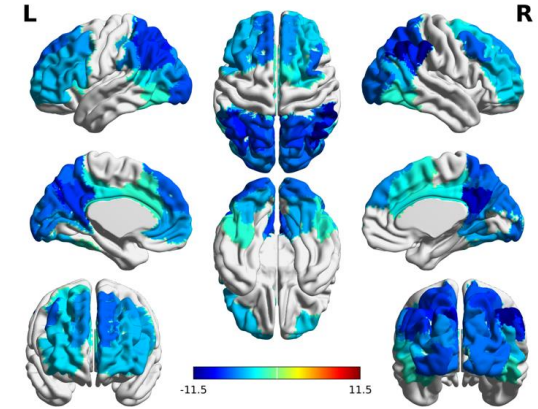
### Hyper-Connectivity



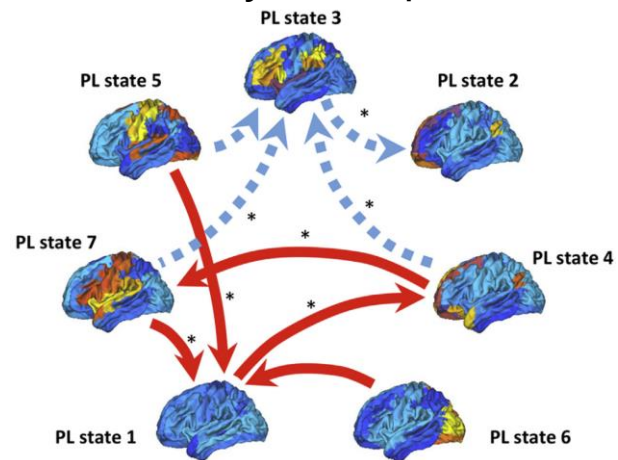
### Depersonalization and ego dissolution



### Low BOLD signal amp.

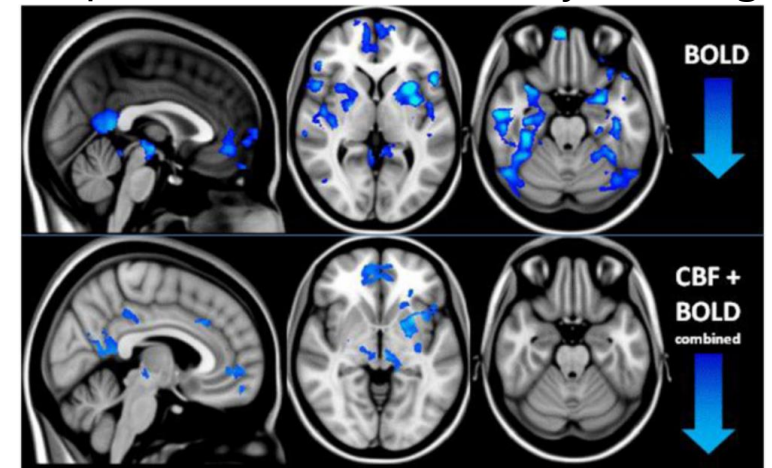


### Functionally non-specific state



Lord et al., *Neuroimage*, 2019

### BOLD amplitude reduction in key hub regions

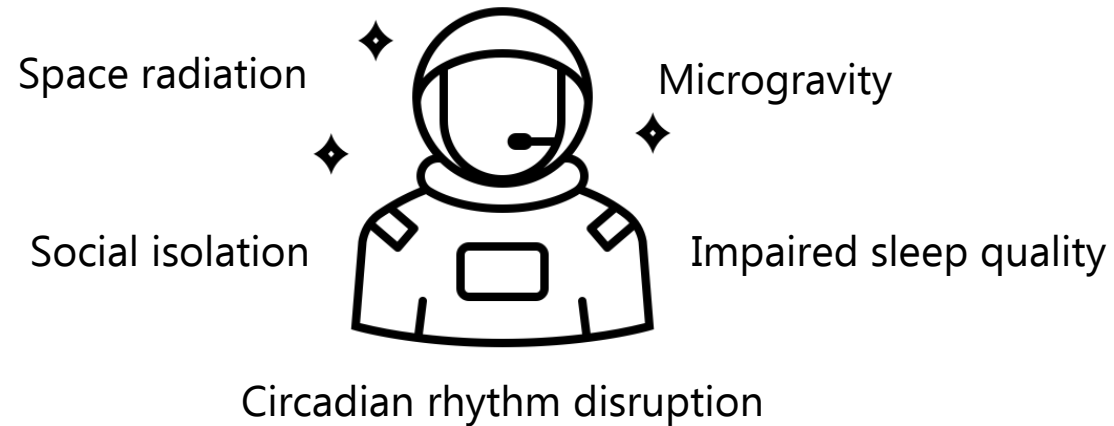


Carhart-Harris et al., *PNAS*, 2012

Introduction
Study I: Mind Blanking
Study II: Psychedelics
<b>Study III: Spaceflight</b>
Study IV: Mental State Decoding
Discussion and Perspectives

## Study III:

*"Effects of spaceflight on the brain's structure and function"*





# How does structure-function change after spaceflight?

Introduction

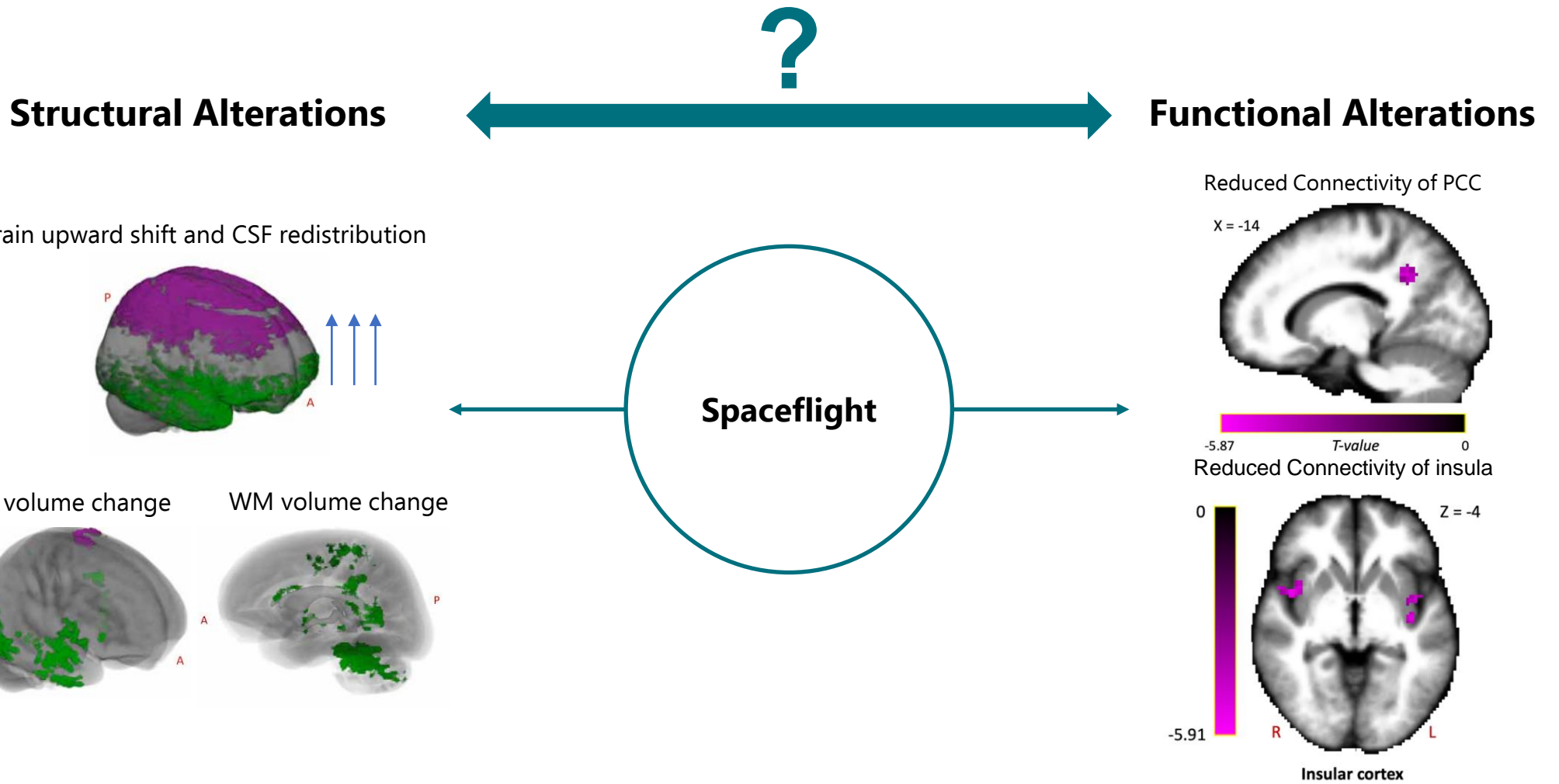
Study I:  
Mind Blanking

Study II:  
Psychedelics

**Study III:  
Spaceflight**

Study IV:  
Mental State  
Decoding

Discussion  
and  
Perspectives





# Methods

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

Discussion  
and  
Perspectives

## Participants

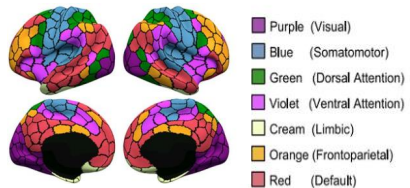
$n_1 = 18$  male cosmonauts  
 $n_2 = 13$  matched controls

## Paradigm

Resting State  
functional MRI (3T)  
TR = 1.4 sec  
DWI

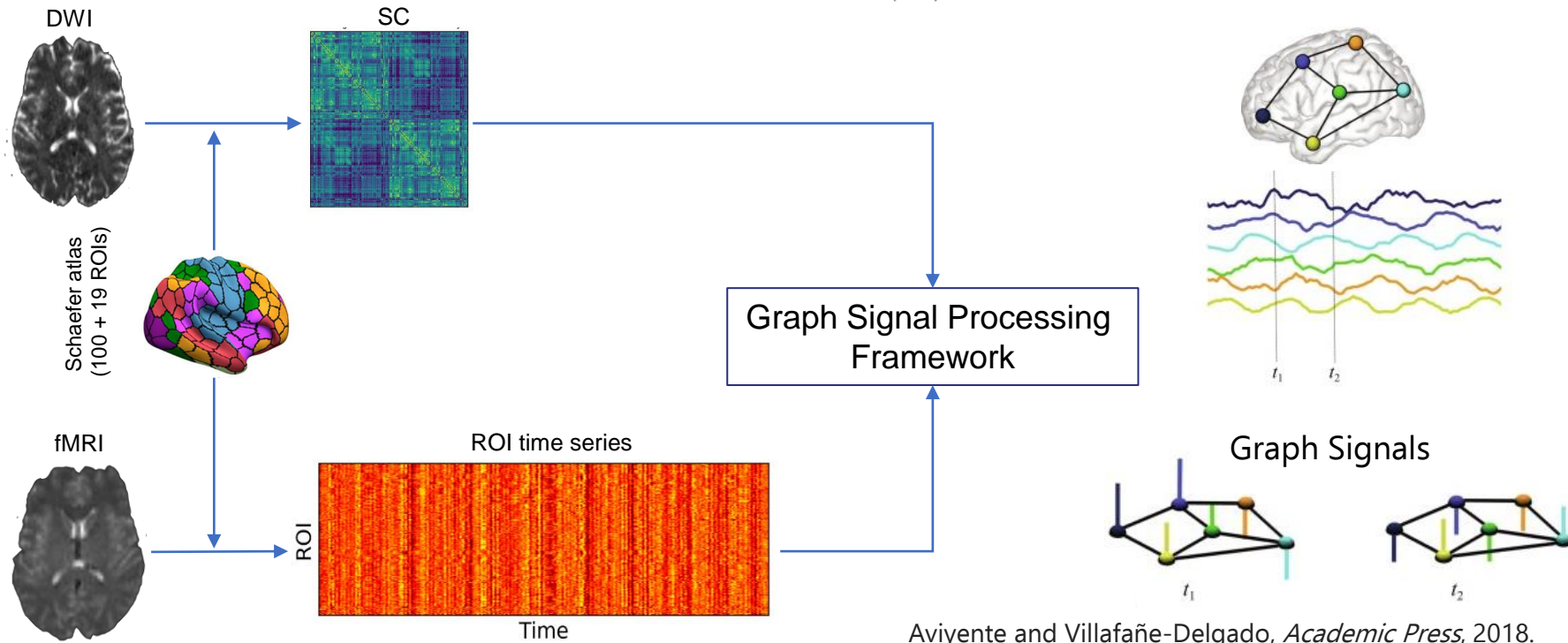
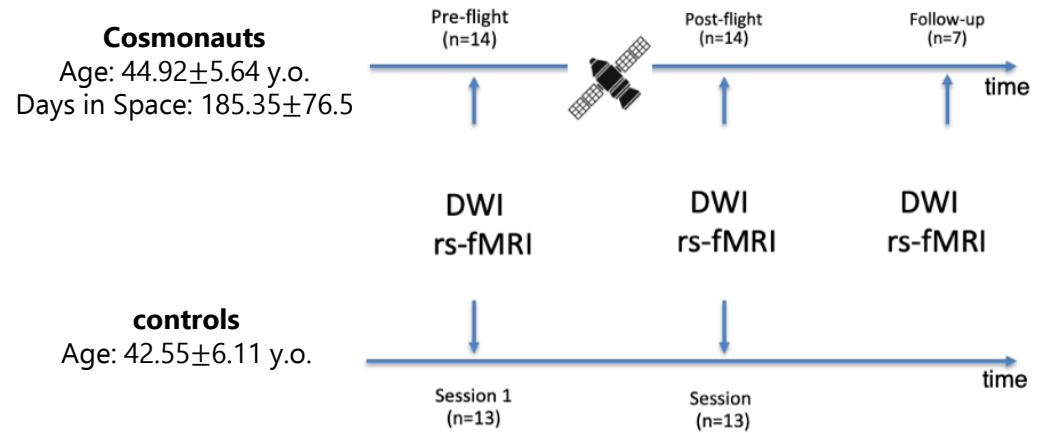
## Analysis

Schaefer Atlas (100 ROIs) with 7  
Networks



## Structure-function

- Graph Signal Processing (GSP)
- Structural Decoupling Index (SDI)



Aviyente and Villafañe-Delgado, *Academic Press*, 2018.

Data originally shared by F. Wuyts, Lab for Equilibrium Investigations and Aerospace, University of Antwerp, Antwerp, Belgium



# Methods

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

Discussion  
and  
Perspectives

## Participants

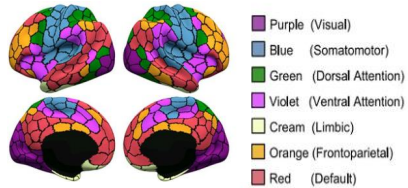
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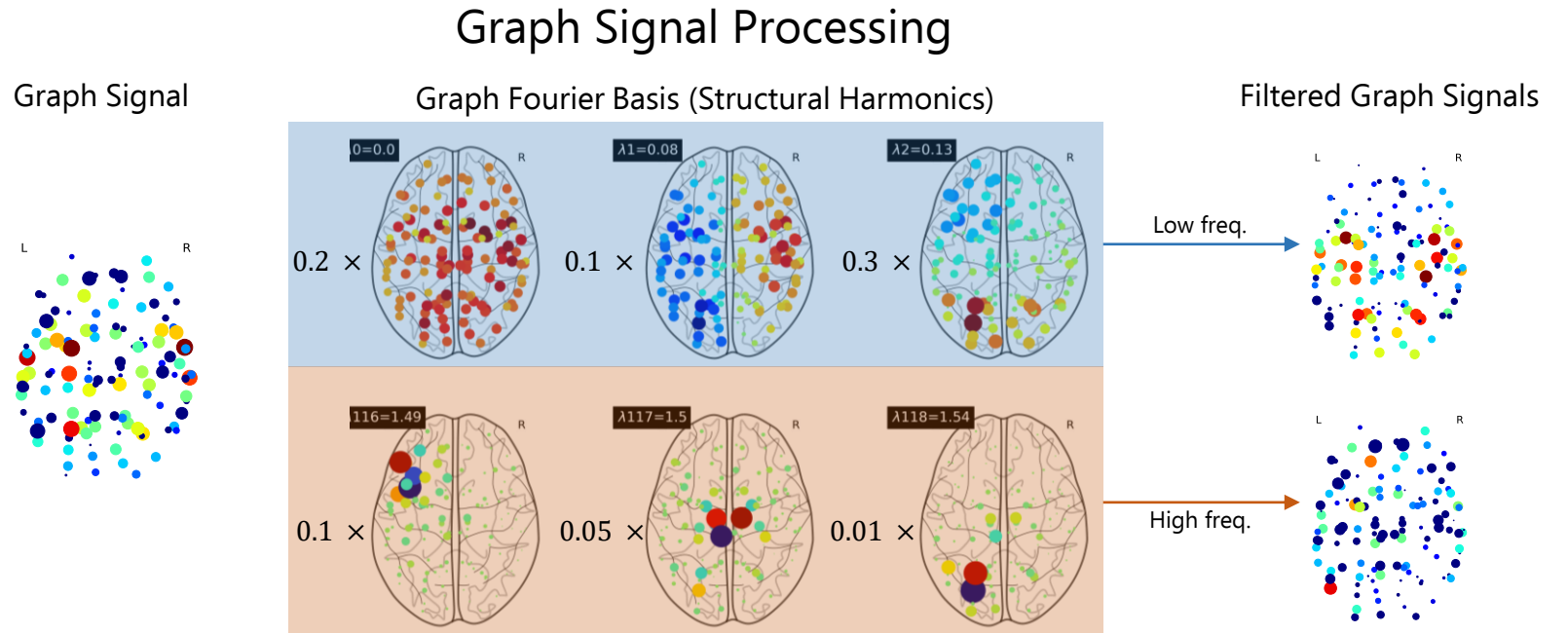
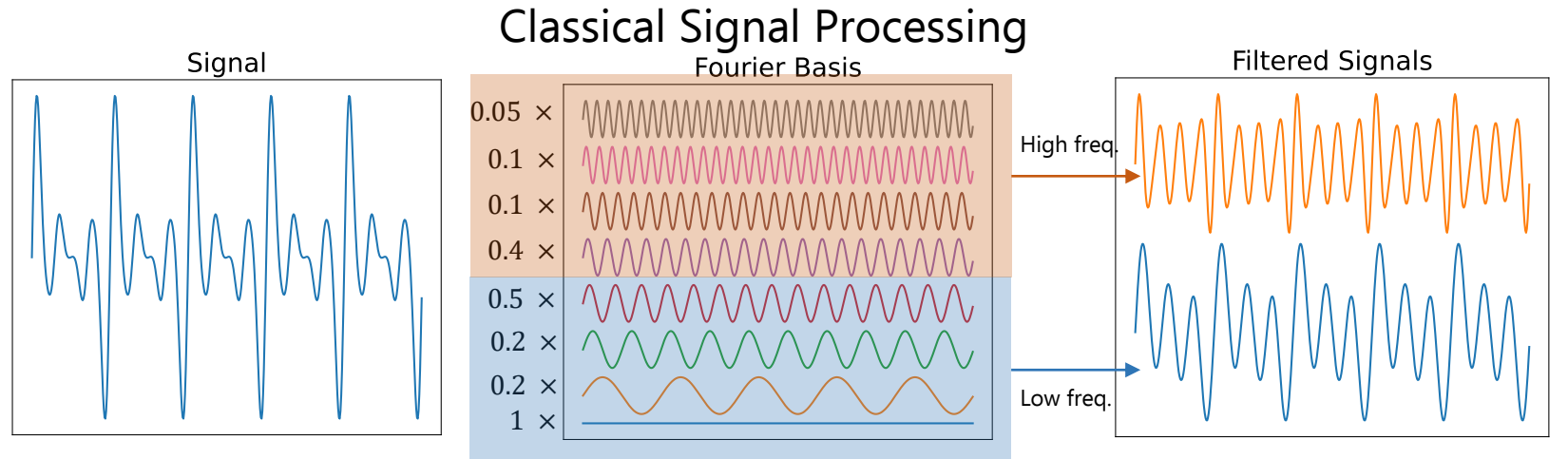
## Analysis

Schaefer Atlas (100 ROIs) with 7  
Networks



## Structure-function

- Graph Signal Processing (GSP)
- Structural Decoupling Index (SDI)





# Graph Adjacency Eigenvectors as Graph Fourier Basis

Introduction

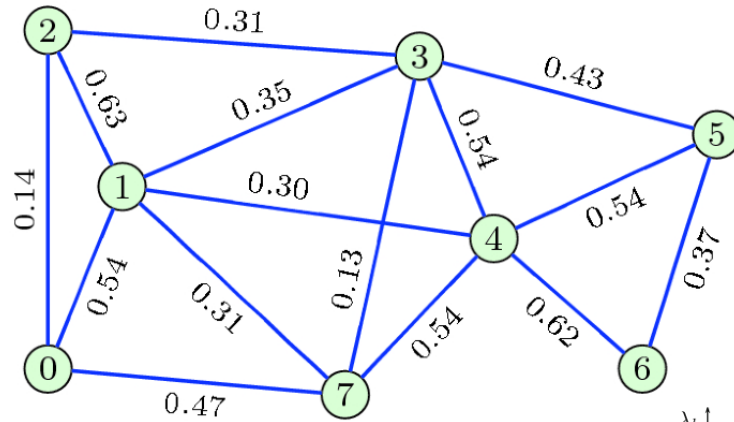
Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

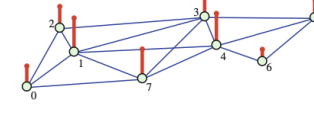
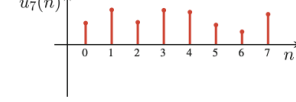
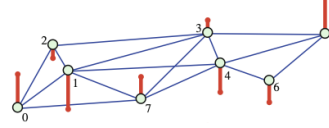
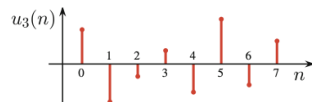
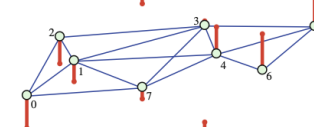
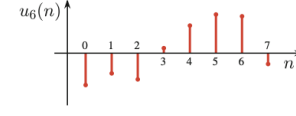
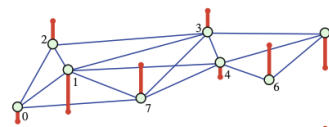
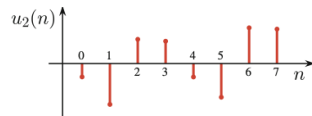
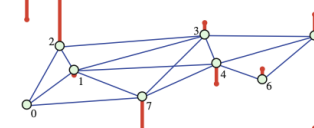
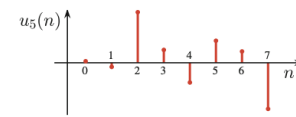
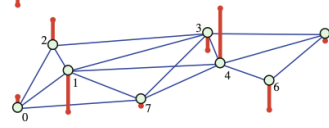
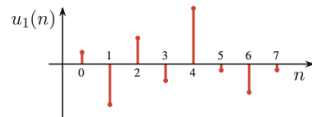
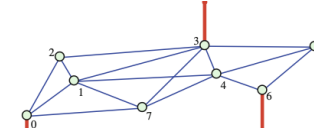
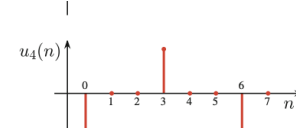
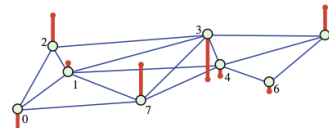
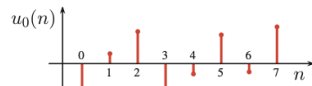
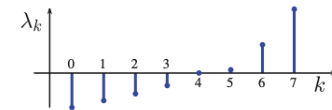
Discussion  
and  
Perspectives



$S$ : Adjacency Matrix

$$S = U\Lambda U^{-1}$$

Eigen  
Decomposition





# Graph Normalized Laplacian Eigenvectors as Graph Fourier Basis

Introduction

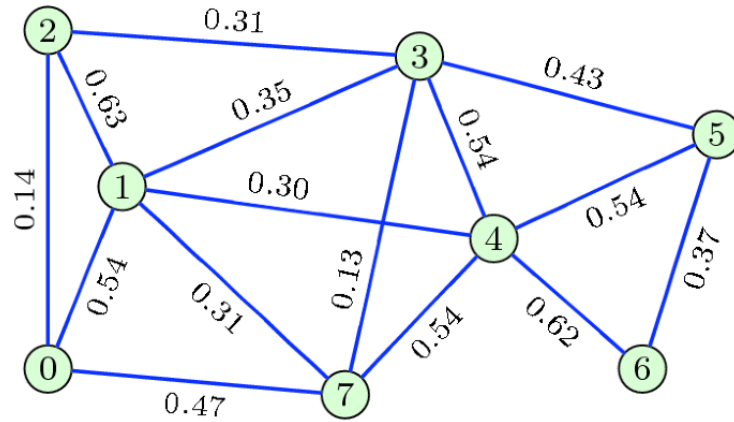
Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

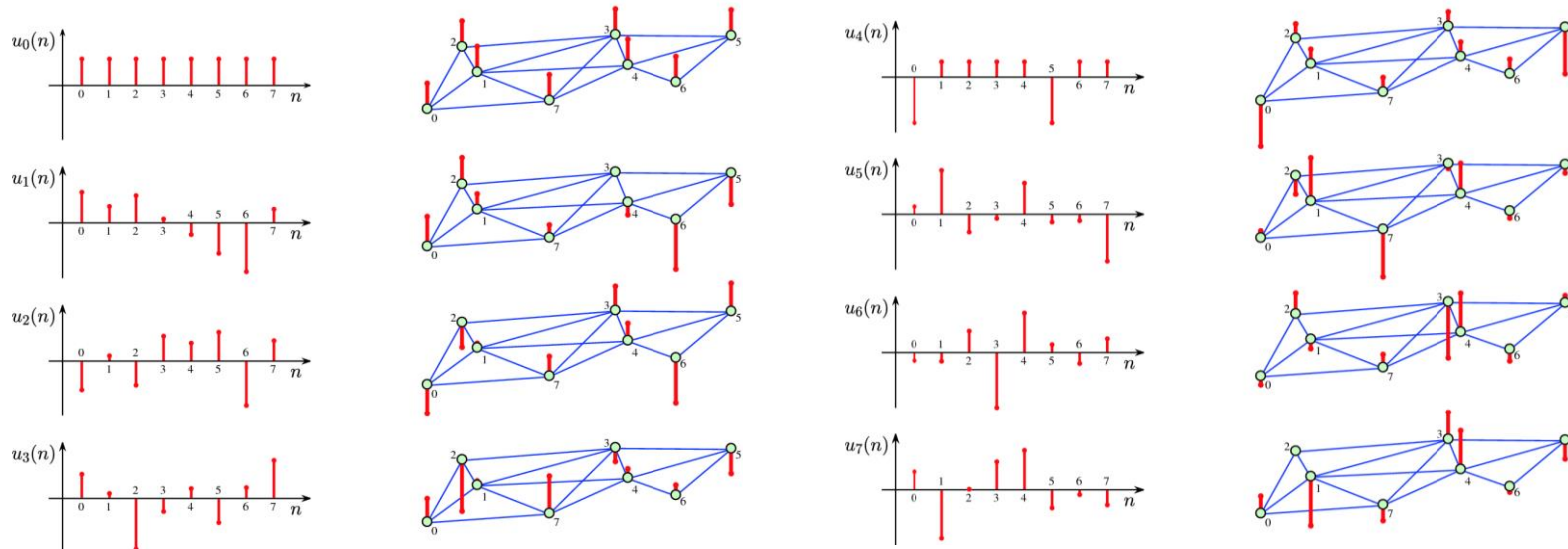
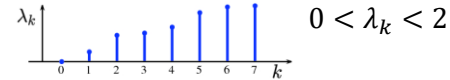
Discussion  
and  
Perspectives



$D$ : Degree Matrix  
 $S$ : Adjacency Matrix

$$\mathcal{L}(S) = D^{-1/2}(D - S)D^{-1/2} = U\Lambda U^{-1}$$

Eigen Decomposition







# Graph Normalized Laplacian Eigenvectors (Structural Harmonics) in the Brain

Introduction

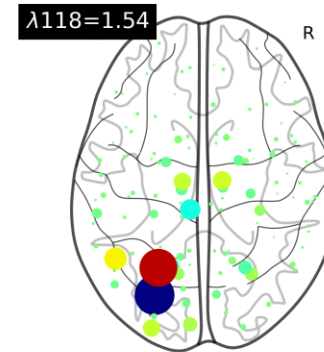
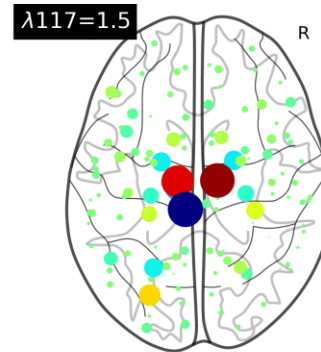
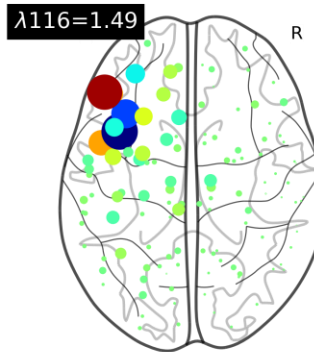
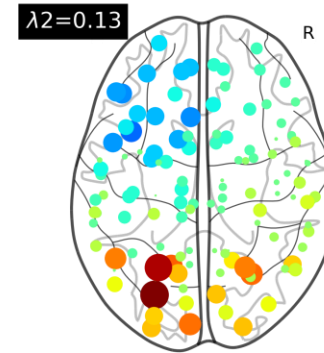
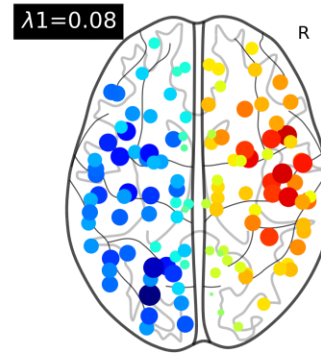
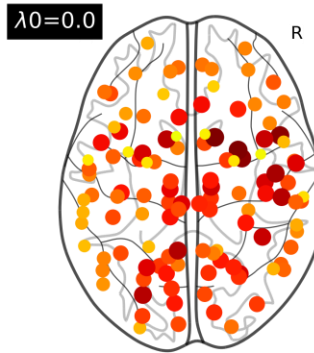
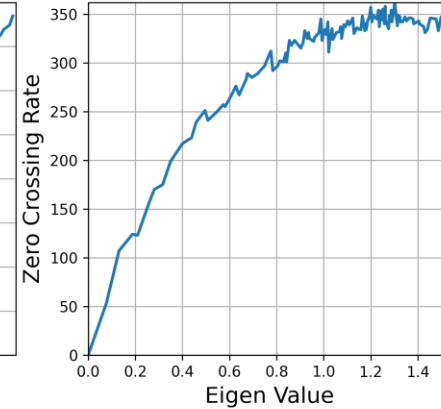
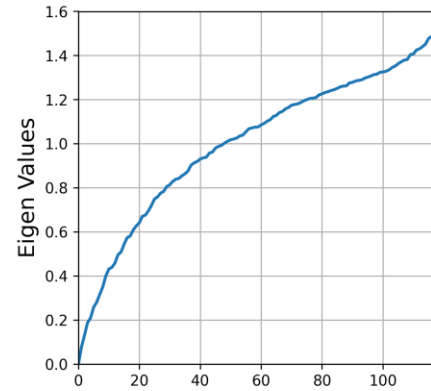
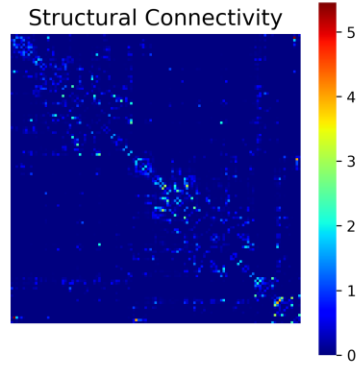
Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
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# Methods

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Mind Blanking

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Psychedelics

Study III:  
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Perspectives

## Participants

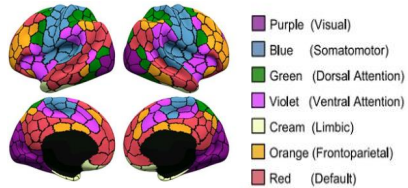
$n_1 = 18$  male cosmonauts  
 $n_2 = 13$  matched controls

## Paradigm

Resting State  
functional MRI (3T)  
TR = 1.4 sec  
DWI

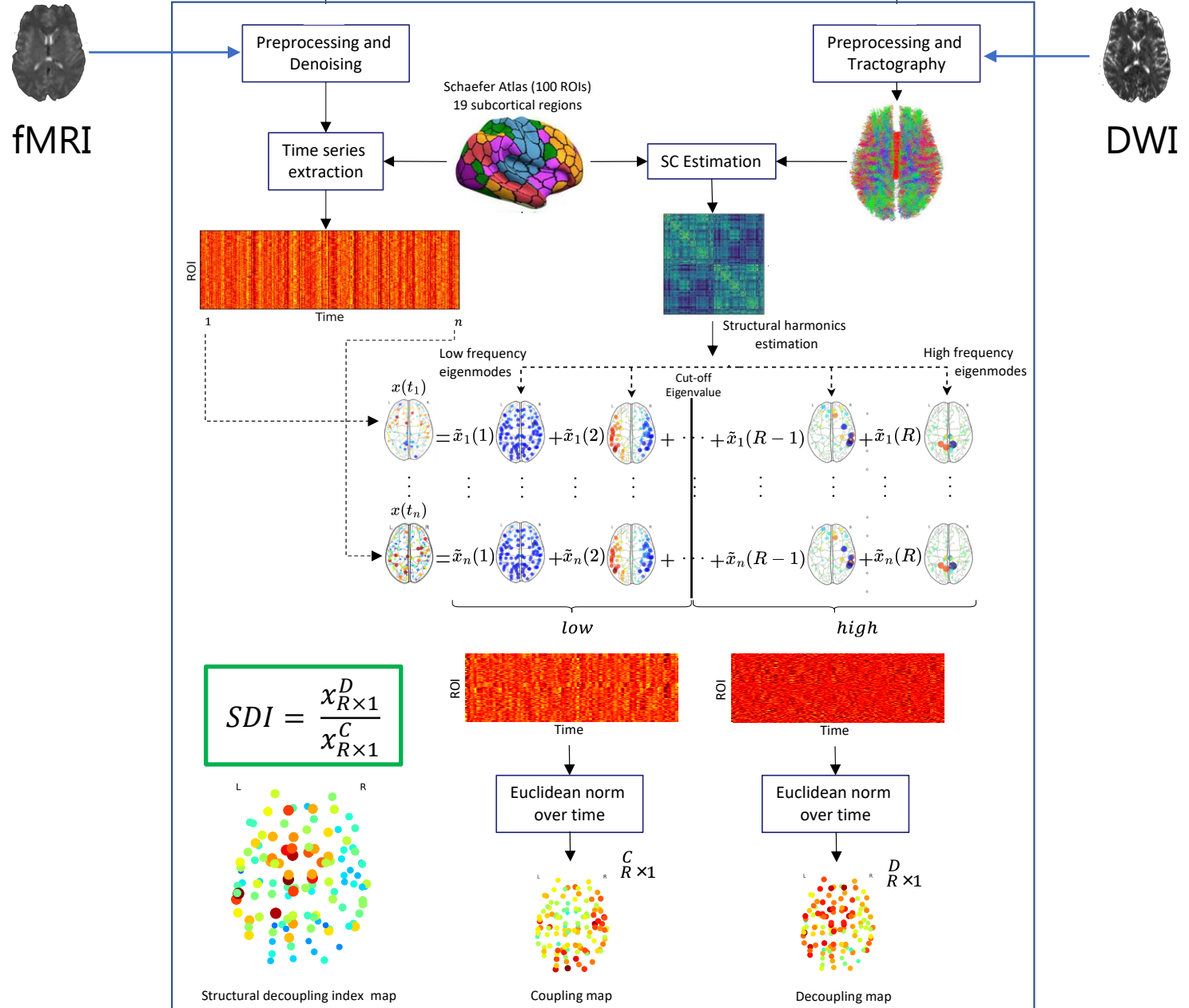
## Analysis

Schaefer Atlas (100 ROIs) with 7  
Networks



## Structure-function

- Graph Signal Processing (GSP)
- Structural Decoupling Index (SDI)





# Structural-functional decoupling alterations in multisensory integration regions

Introduction

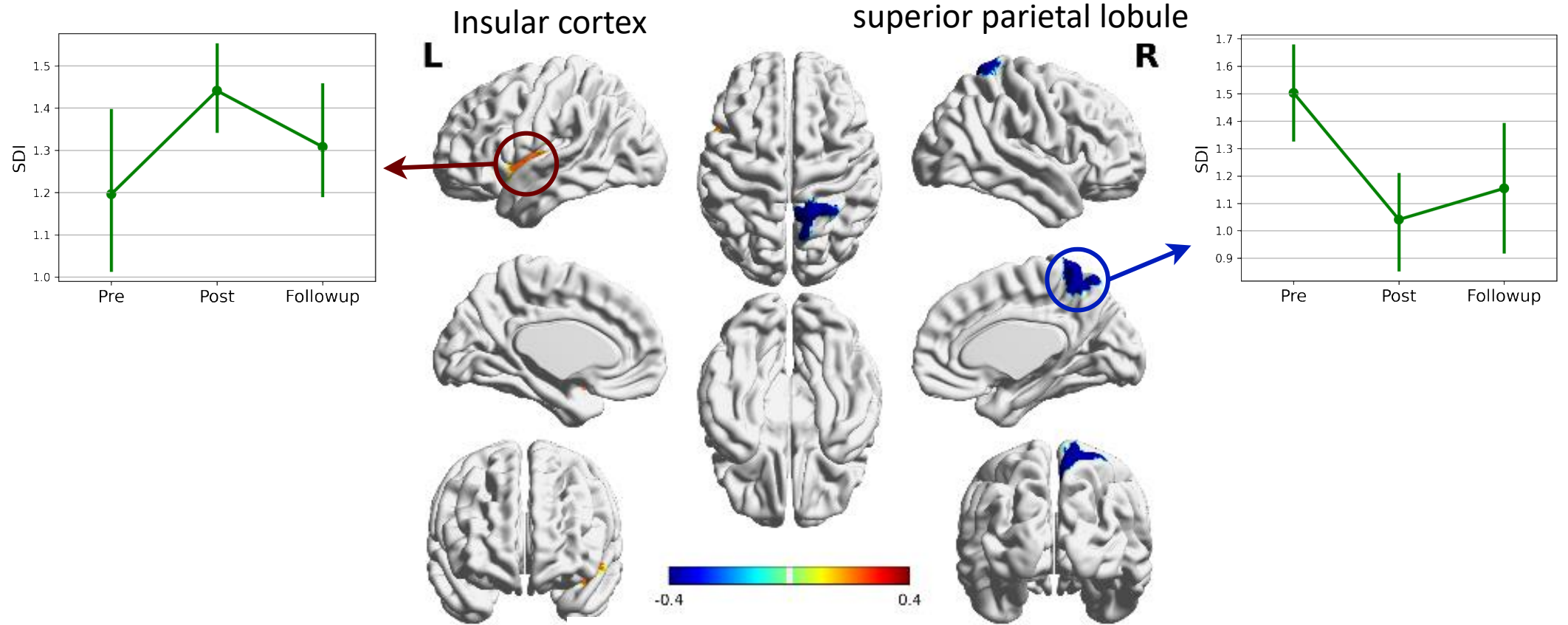
Study I:  
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Decoding

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and  
Perspectives





# No dynamic functional alterations due to exposure to prolonged microgravity after spaceflight

Introduction

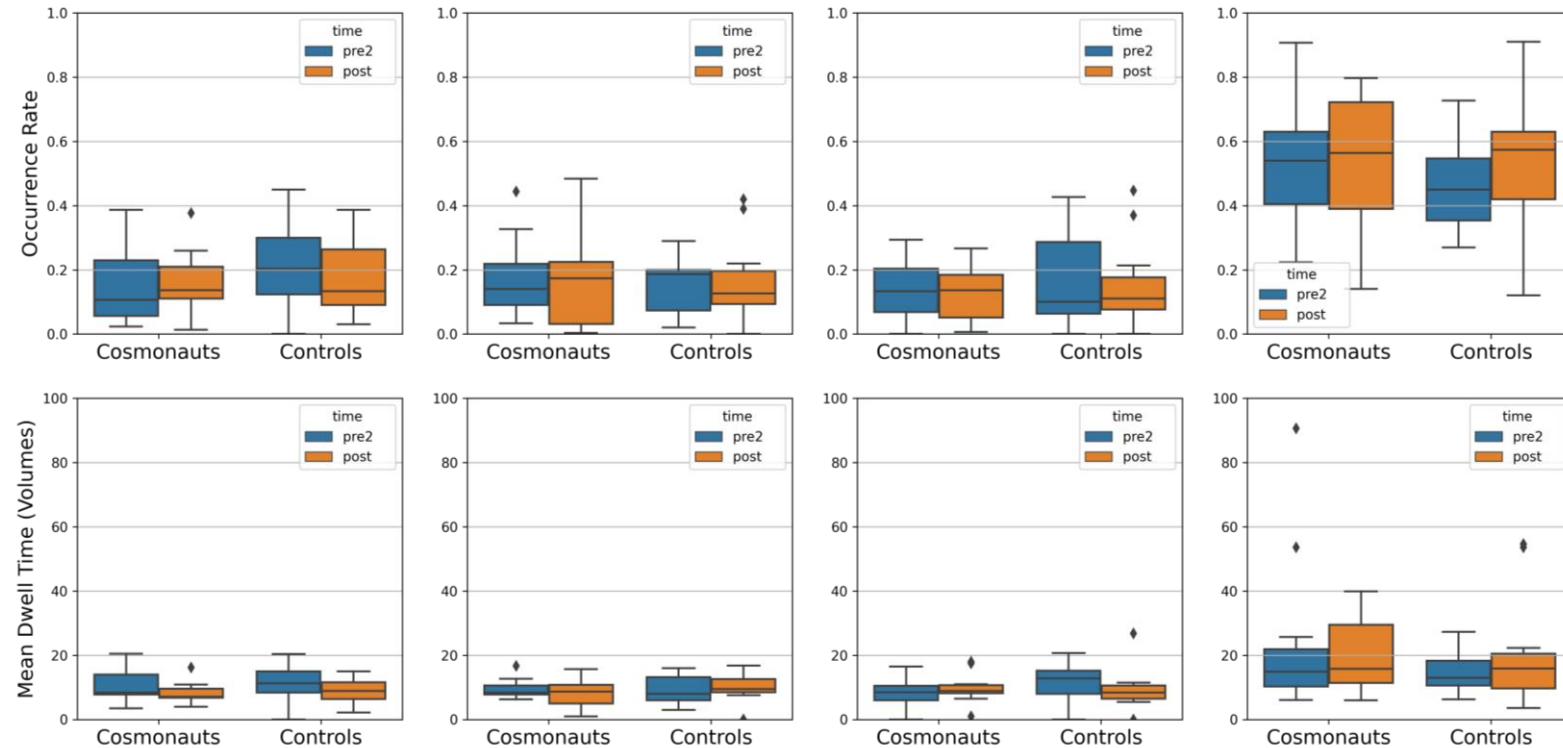
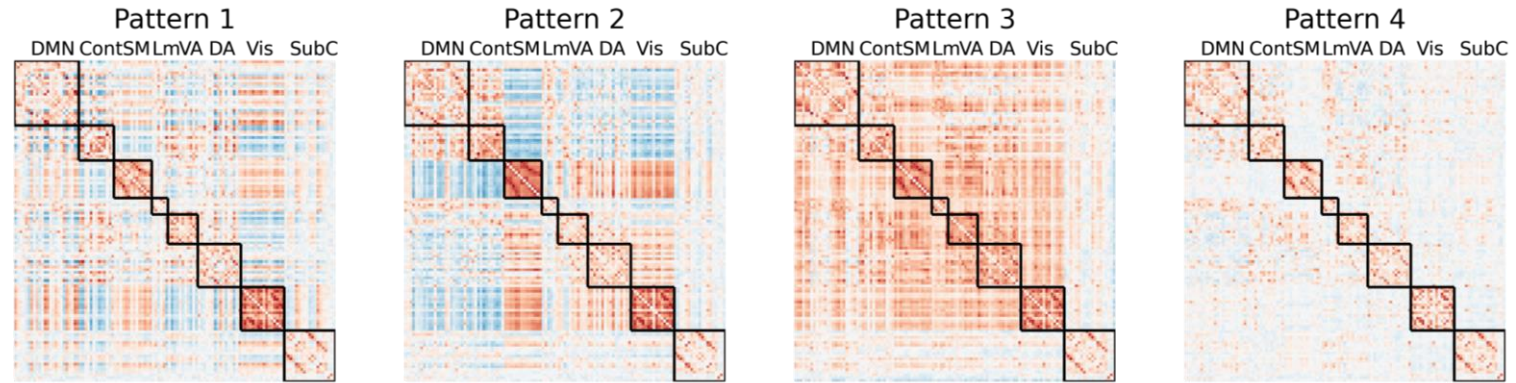
Study I:  
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Psychedelics

**Study III:  
Spaceflight**

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Mental State  
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and  
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# Structural connectivity alterations after space flight

Introduction

Study I:  
Mind Blanking

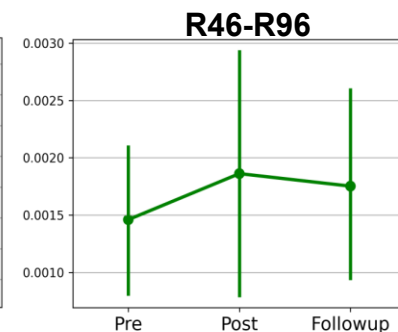
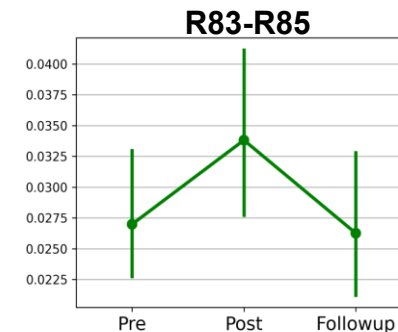
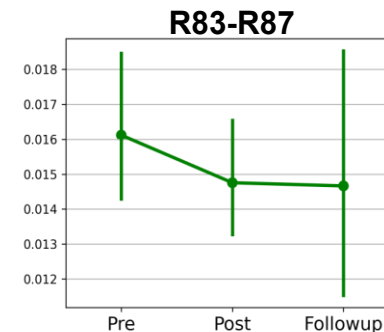
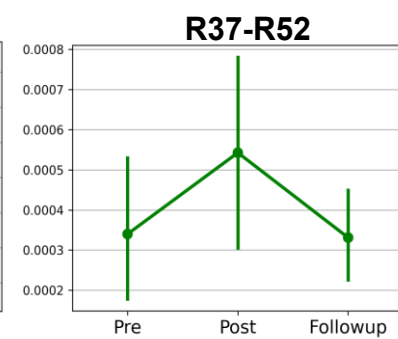
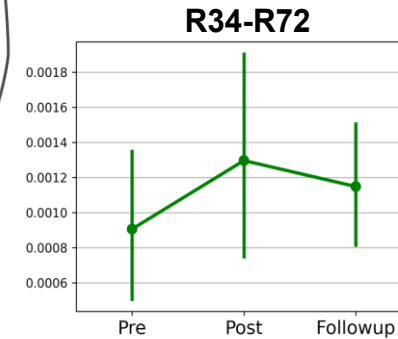
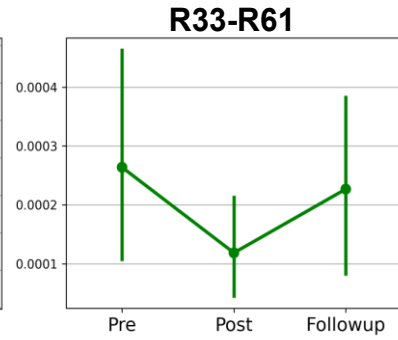
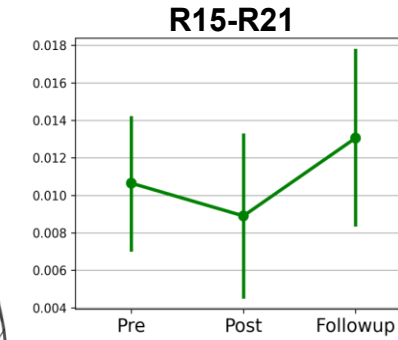
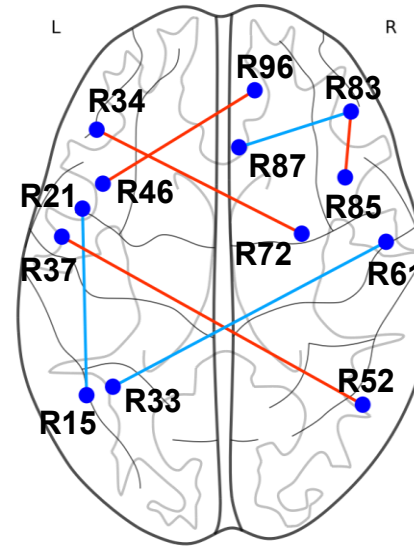
Study II:  
Psychedelics

Study III:  
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Perspectives

Connection	Regions
R15-R21	LH_DAN_Post_1 – LH_DAN_PrCv_1
R33-R61	LH_Cont_Par_1 – RH_SomMot_4
R34-R72	LH_Cont_PFCI_1 – RH_DAN_FEF_1
R37-R52	LH_DMN_Temp_1 – RH_Vis_3
R46-R96	LH_DMN_PFC_6 – RH_DMN_PFCdPFCm_2
R83-R85	RH_Cont_PFCI_2 – RH_Cont_PFCI_4
R83-R87	RH_Cont_PFCI_2 – RH_PFCmp_1





# Discussion

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

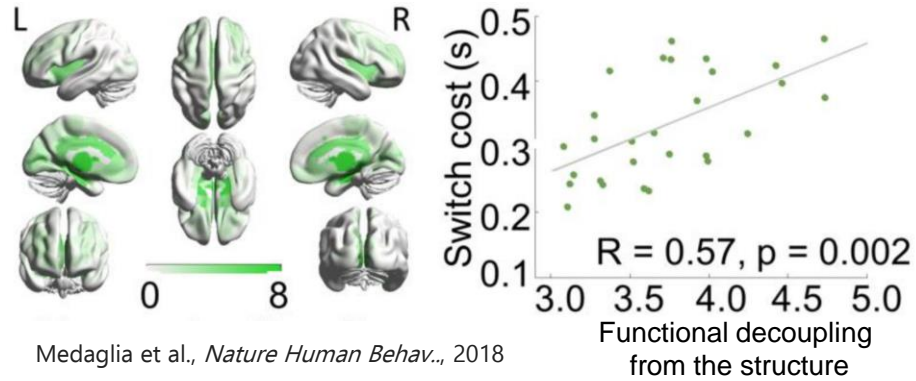
Study IV:  
Mental State  
Decoding

Discussion  
and  
Perspectives

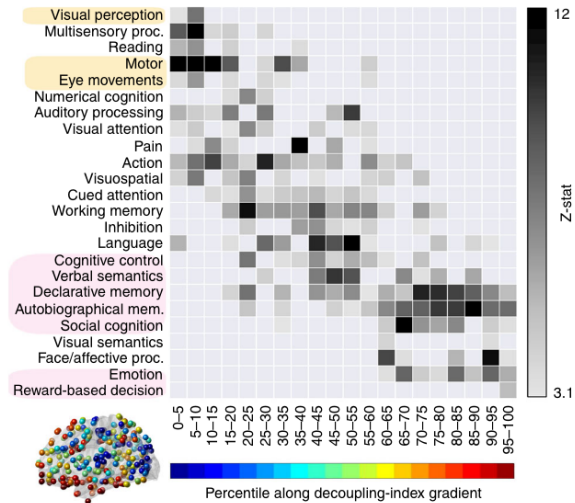
## Spaceflight

structure-function decoupling alterations

Structure-function decoupling and cognition

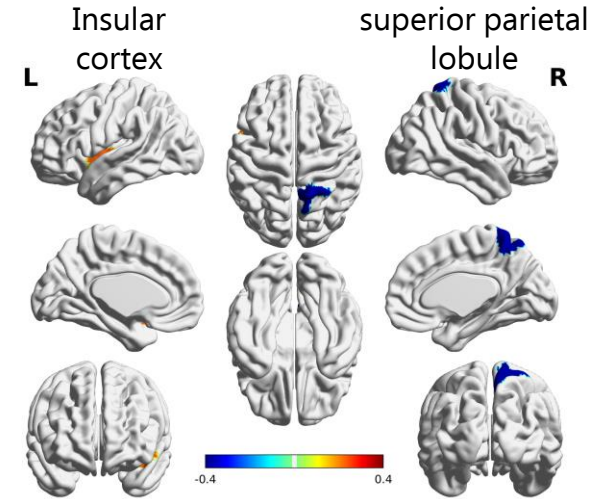


Medaglia et al., *Nature Human Behav.*, 2018

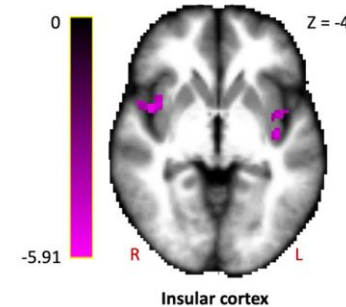


Pretti and Van De Ville, *Nature Comm.*, 2019

Structure-function decoupling and multi-sensory integration

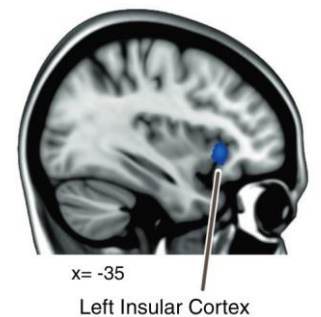


Decreased connectivity



Jillings et al., *Communications Biology*, 2023

Decreased Volume



Koppelmans et al., *npj Microgravity*, 2016

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

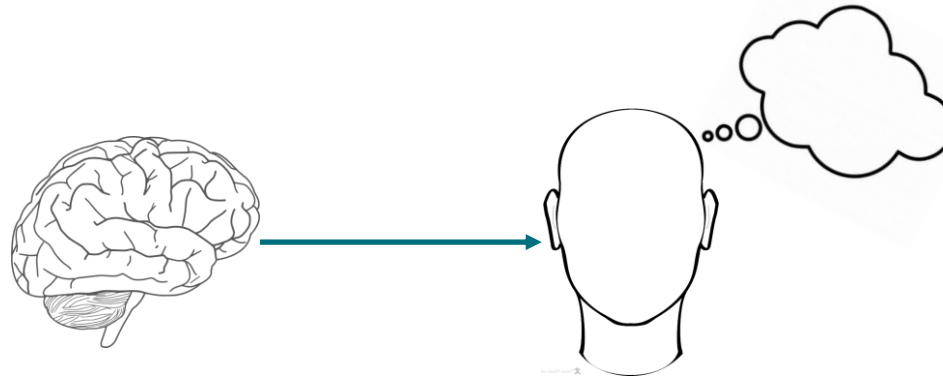
Study III:  
Spaceflight

**Study IV:  
Mental State  
Decoding**

Discussion  
and  
Perspectives

## Study IV:

*"Toward mental state decoding during rest"*



**Based on:**

**Mortaheb, S.,** Liégeois, R., Raimondo, F., Boulakis, P. A., Fort, L. D., Moallemian, S., Sharifpour R., Karapanagiotidis, T., Van De Ville, D., and Demertzi, A., **2023.** Regional functional-structural coupling and decoupling can decode ongoing mental states during task-free conditions. OSF Preregistration, <https://doi.org/10.17605/OSF.IO/TK3UW>



# Can we predict mental states during unconstrained situations?

Introduction

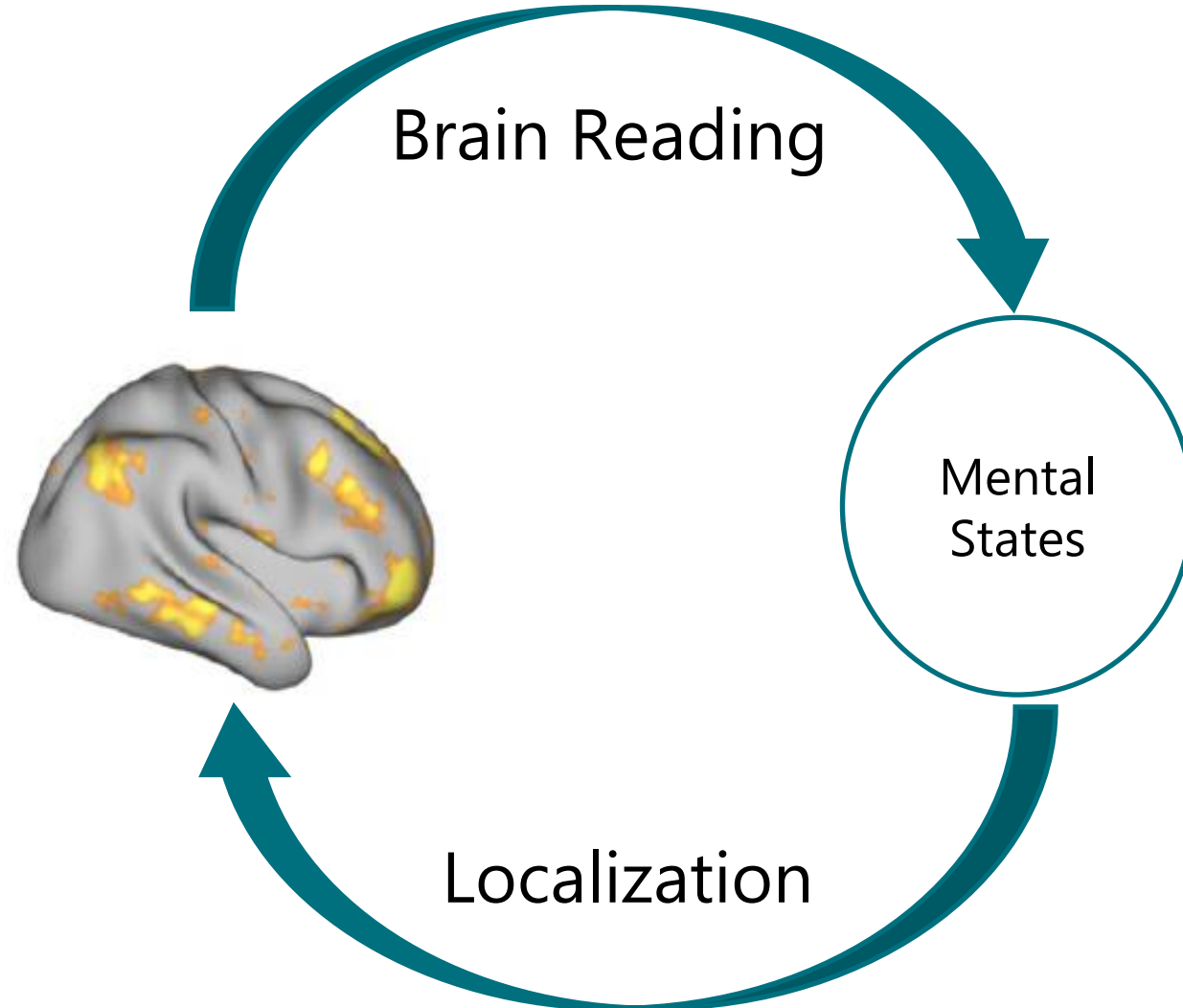
Study I:  
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Mental State  
Decoding**

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# Methods

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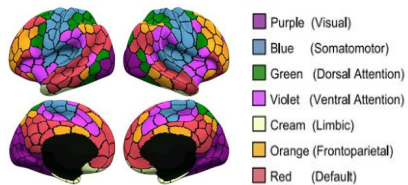
n = 8 typical  
5 Women, 3 Men  
Age:  $29.5 \pm 3.9$  y.o

## Paradigm

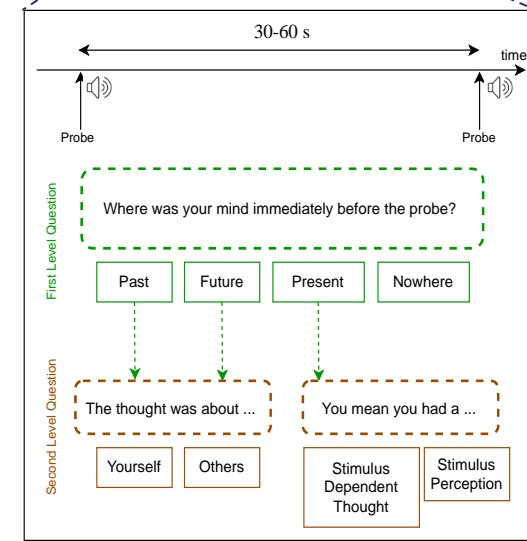
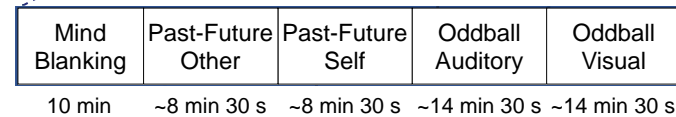
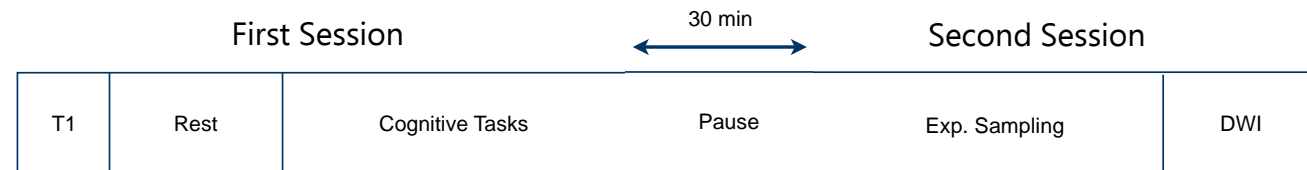
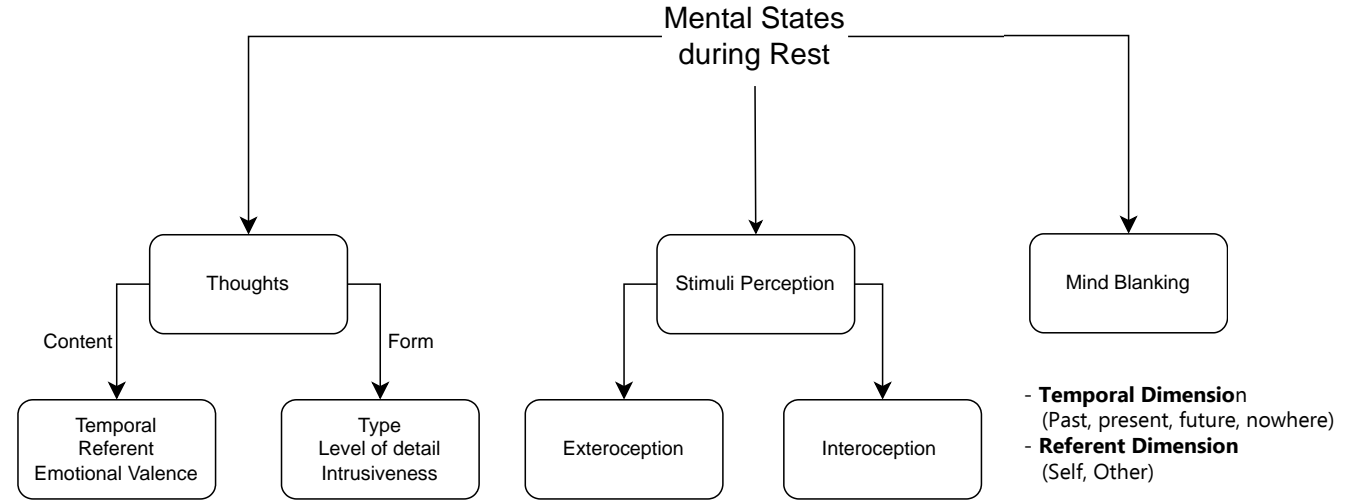
Cognitive Tasks  
Experience-Sampling  
functional MRI (3T)  
TR = 1.133 sec  
DWI

## Decoding

Schaefer Atlas (100 ROIs)



Feature extraction: GSP  
Classification: SVM  
Cross Validation: stratified 4-fold  
Performance Evaluation:  
- balanced accuracy  
- recall  
- precision





# Methods

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Study I:  
Mind Blanking

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Psychedelics

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Perspectives

## Participants

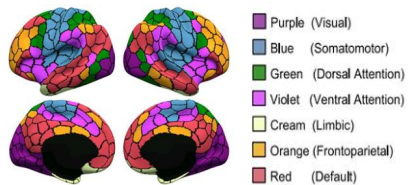
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## Paradigm

Cognitive Tasks  
Experience-Sampling  
functional MRI (3T)  
TR = 1.133 sec  
DWI

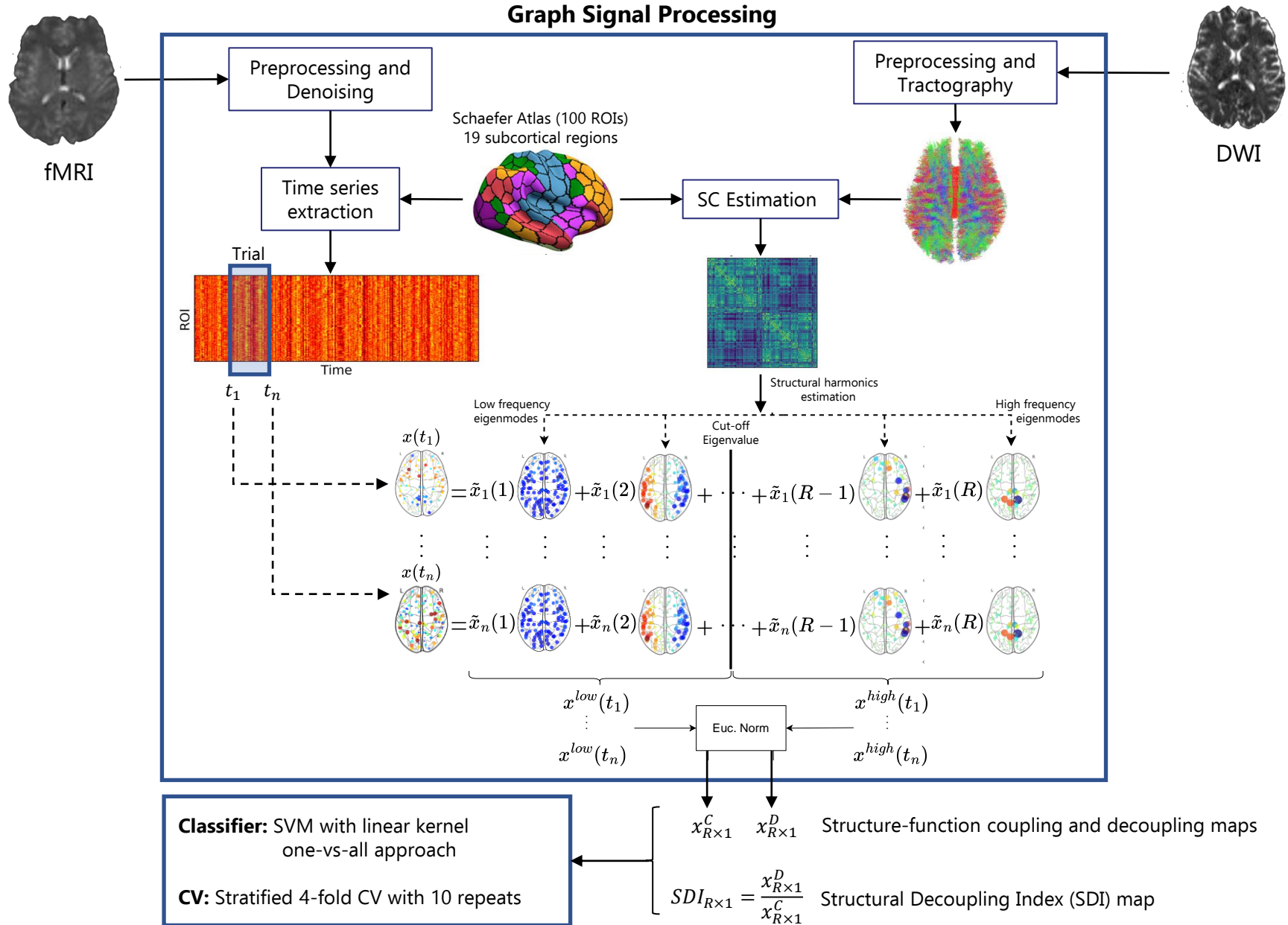
## Decoding

Schaefer Atlas (100 ROIs)



Feature extraction: GSP  
Classification: SVM  
Cross Validation: stratified 4-fold  
Performance Evaluation:  
- balanced accuracy  
- recall  
- precision

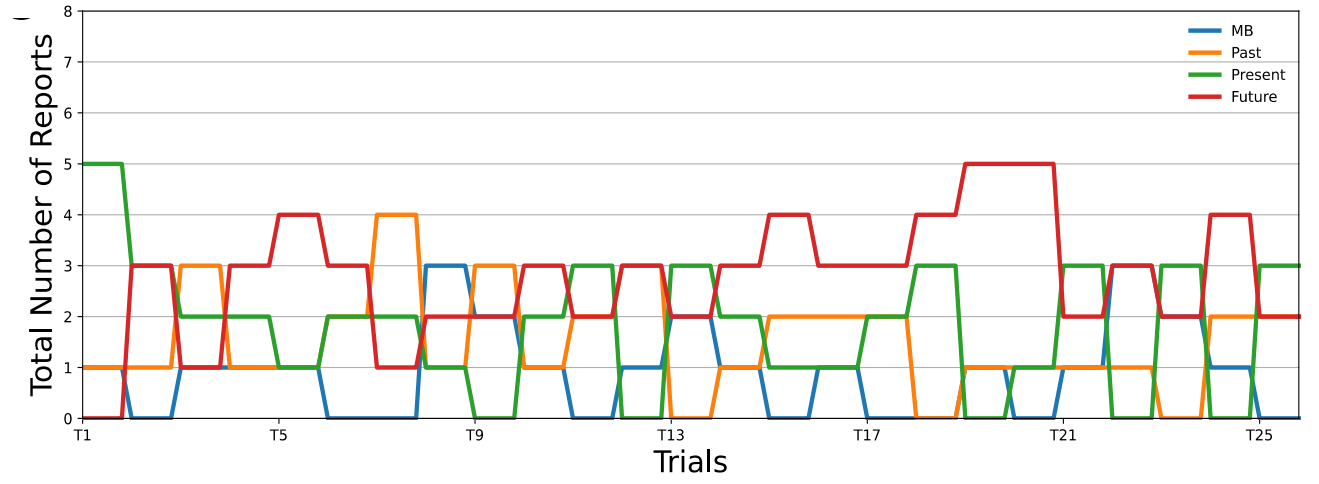
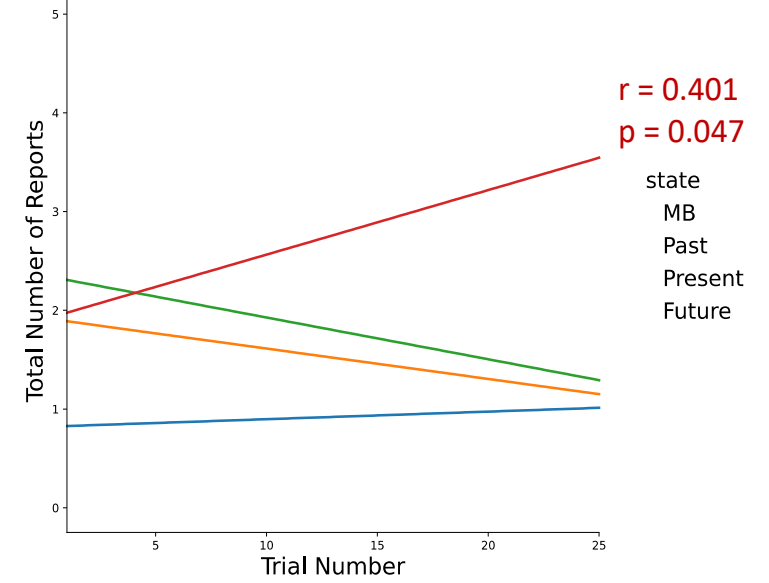
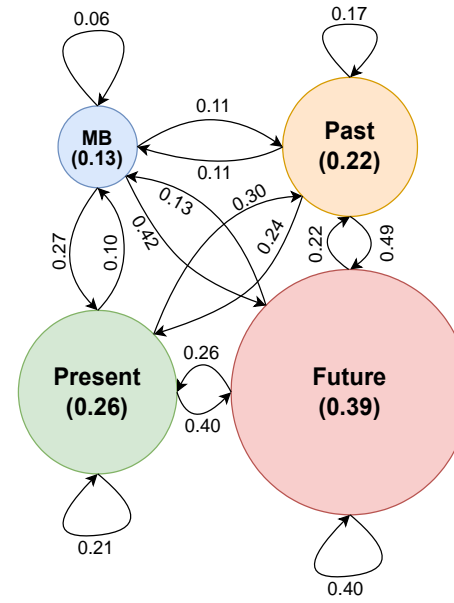
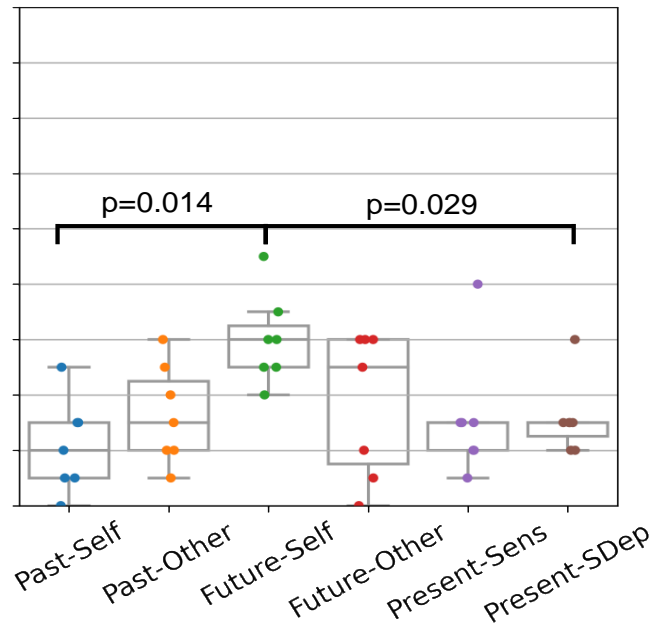
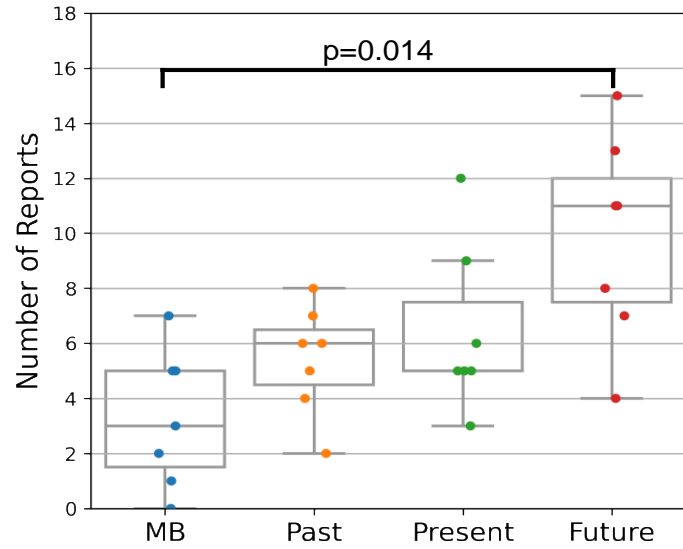
Slide: 42/48





# High number of future self-related thoughts and low number of MB

- Introduction
- Study I: Mind Blanking
- Study II: Psychedelics
- Study III: Spaceflight
- Study IV: Mental State Decoding**
- Discussion and Perspectives





# Higher than chance-level performance for temporal and referent dimension

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

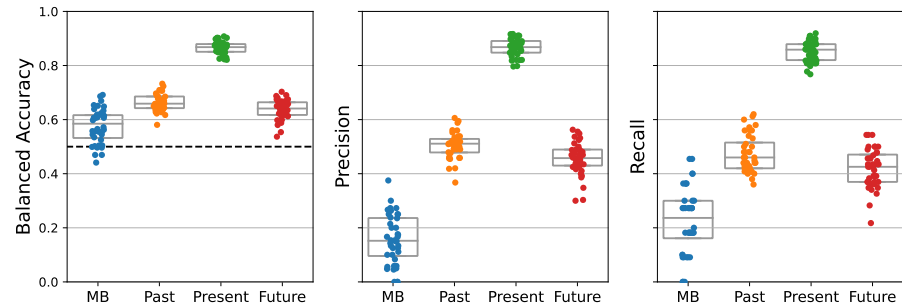
Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

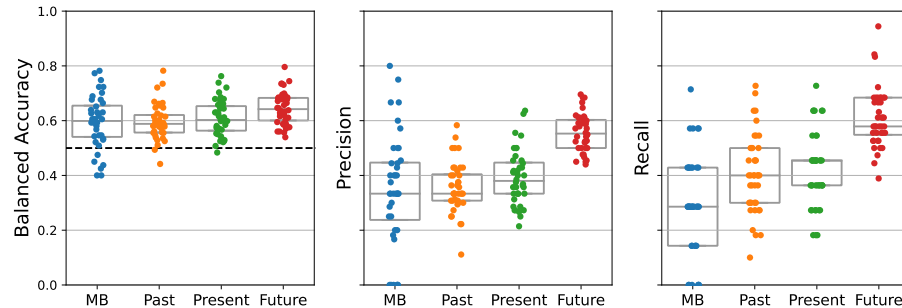
Discussion  
and  
Perspectives

Cognitive Tasks

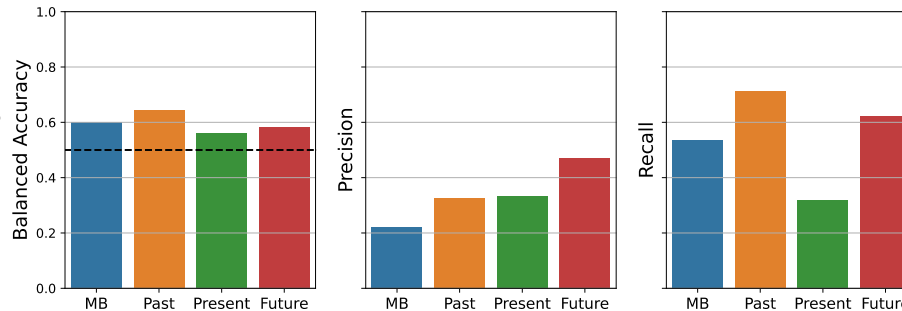
## Temporal Dimension



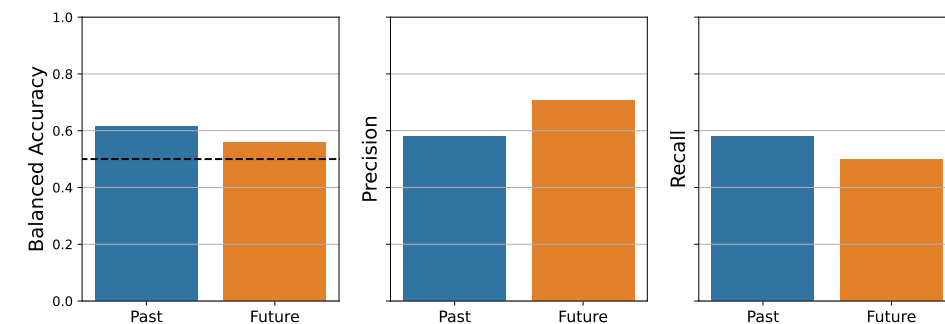
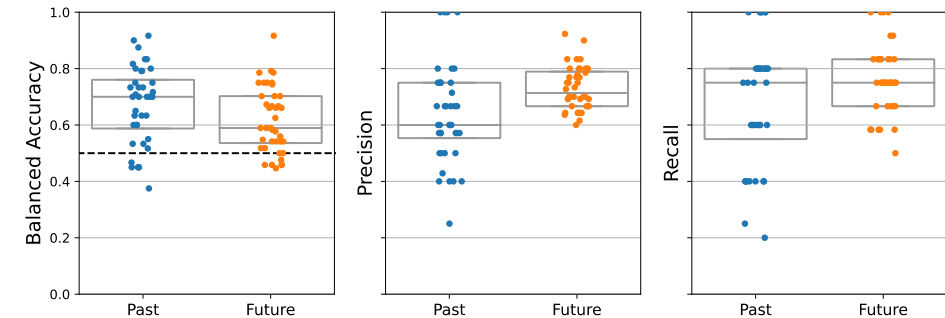
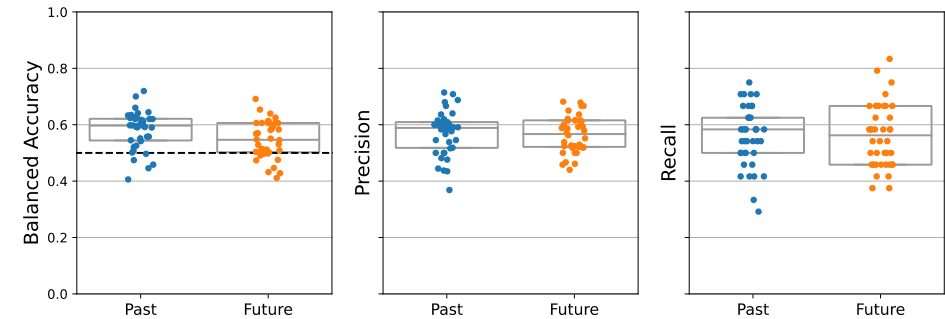
Experience Sampling



From Cognitive Tasks  
to  
Experience Sampling



## Referent Dimension





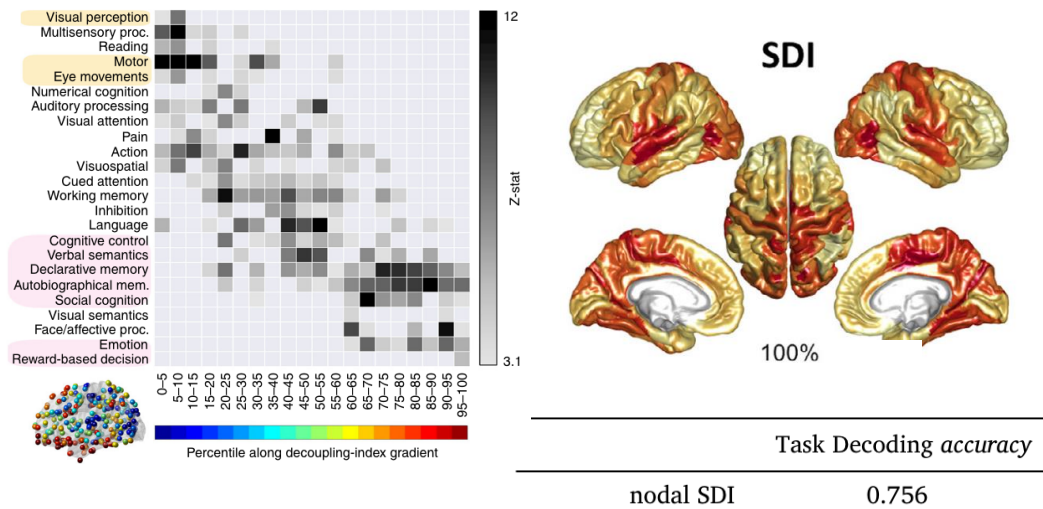
# Discussion

## Mental State Decoding at Rest

Variable duration of mental states

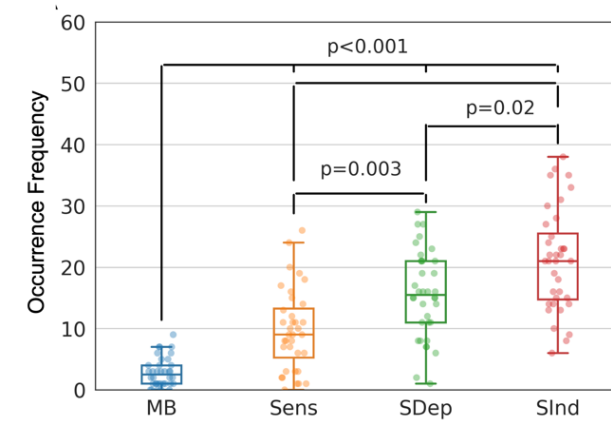
Imbalanced number of mental states

Structure-function decoupling maps as features

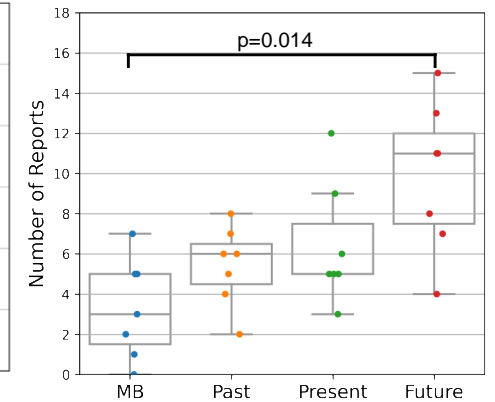


Pretti and Van De Ville, *Nature Comm.*, 2019

Griffa et al., *Neuroimage*, 2022



Mortaheb et al., *PNAS*, 2022



Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

**Discussion  
&  
Perspectives**

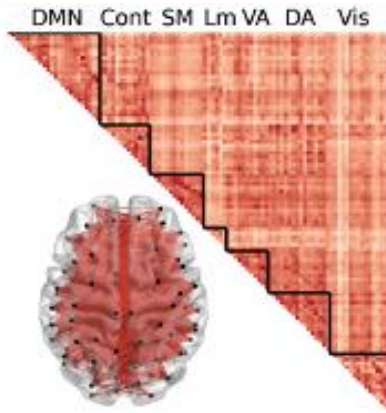
# General Discussion and Future Perspectives



# General Discussion

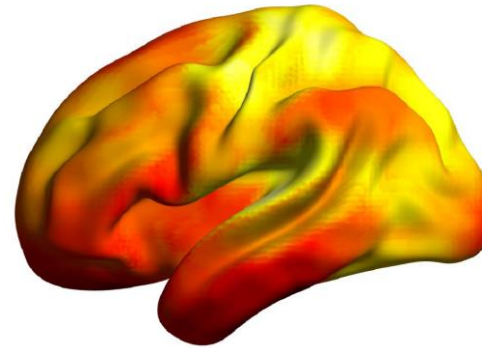
## Resting Brain and Mind

Hyper-connected functional state



Mind Blanking Ego Dissolution  
Depersonalization

Global signal as a proxy of physiological state



Arousal Vigilance  
Cognition

Structure-function (de)coupling and cognition



Mental Flexibility Fingerprint  
Mental State Decoding

Introduction

Study I:  
Mind Blanking

Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

Discussion  
&  
Perspectives



# Future Perspectives

Introduction

Study I:  
Mind Blanking

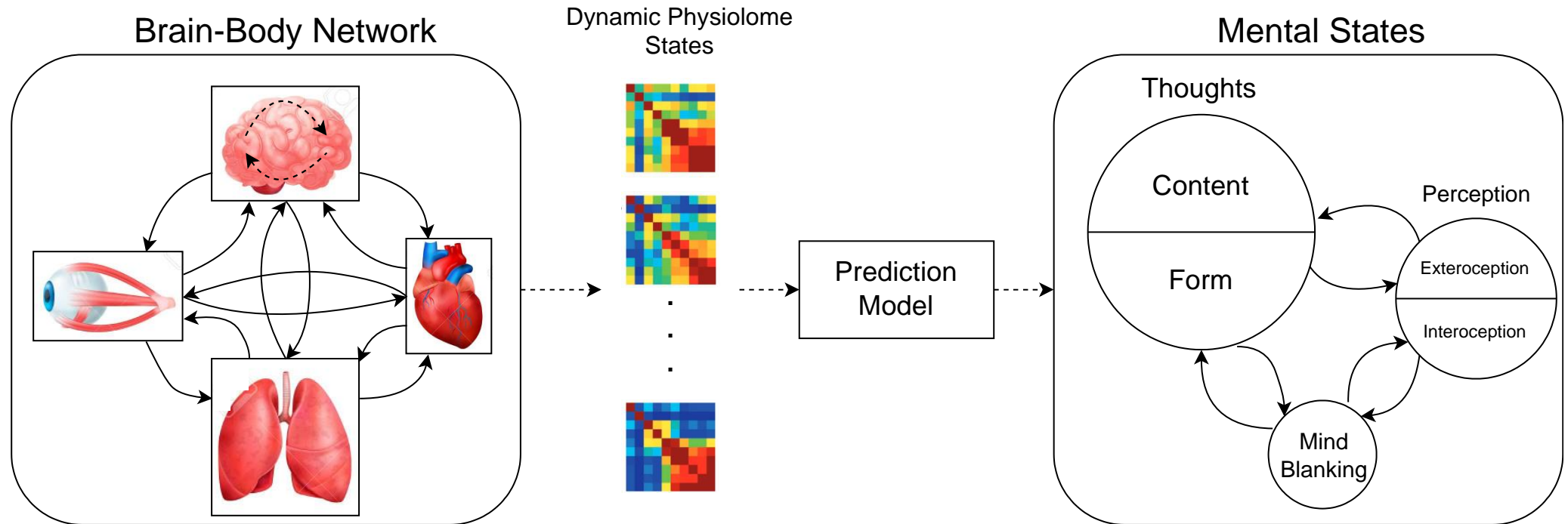
Study II:  
Psychedelics

Study III:  
Spaceflight

Study IV:  
Mental State  
Decoding

Discussion  
&  
Perspectives

- Application to individuals with neurologic disorders
- A brain-body frameworks for mental state decoding







**Contact info:**

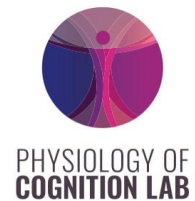


[s.mortaheb@uliege.be](mailto:s.mortaheb@uliege.be)



@Smortaheb

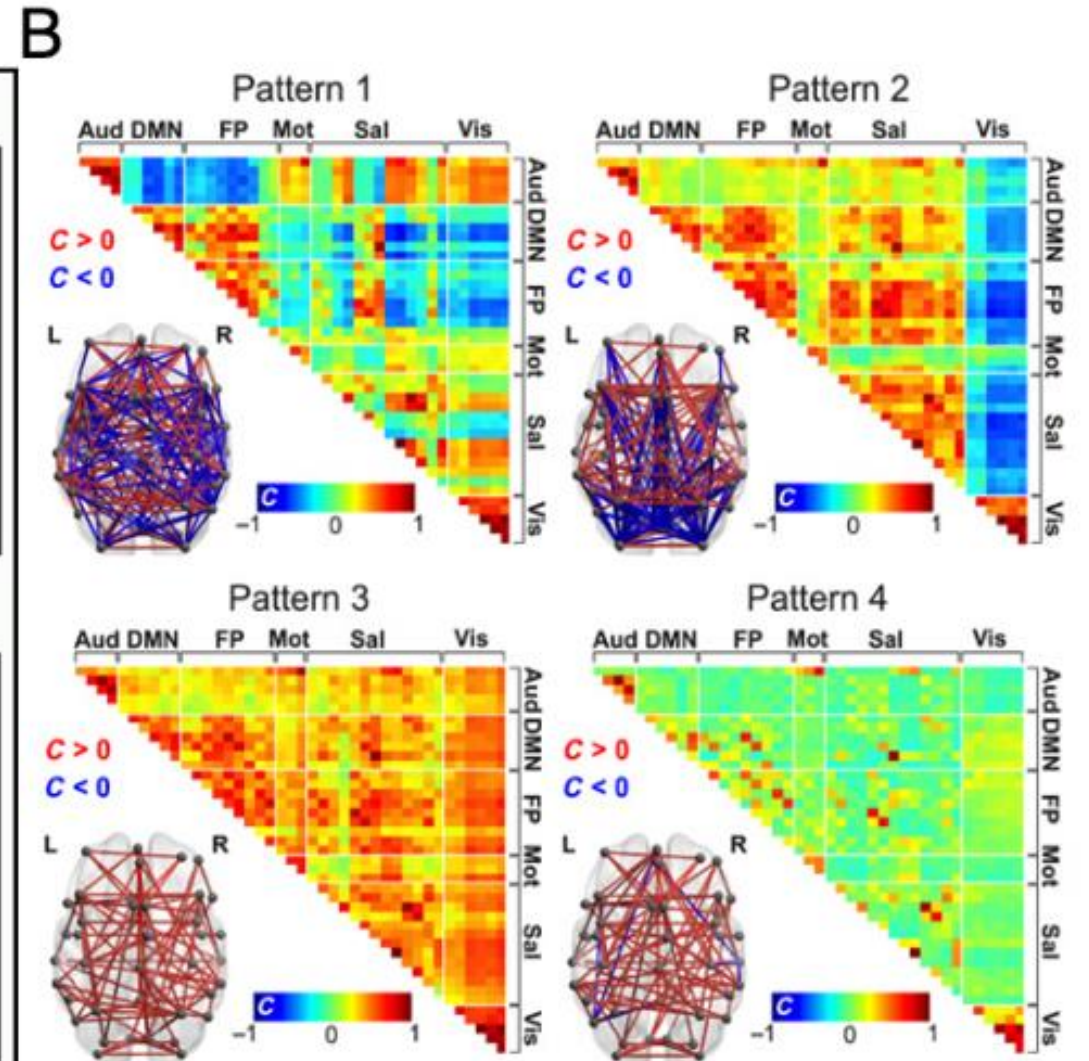
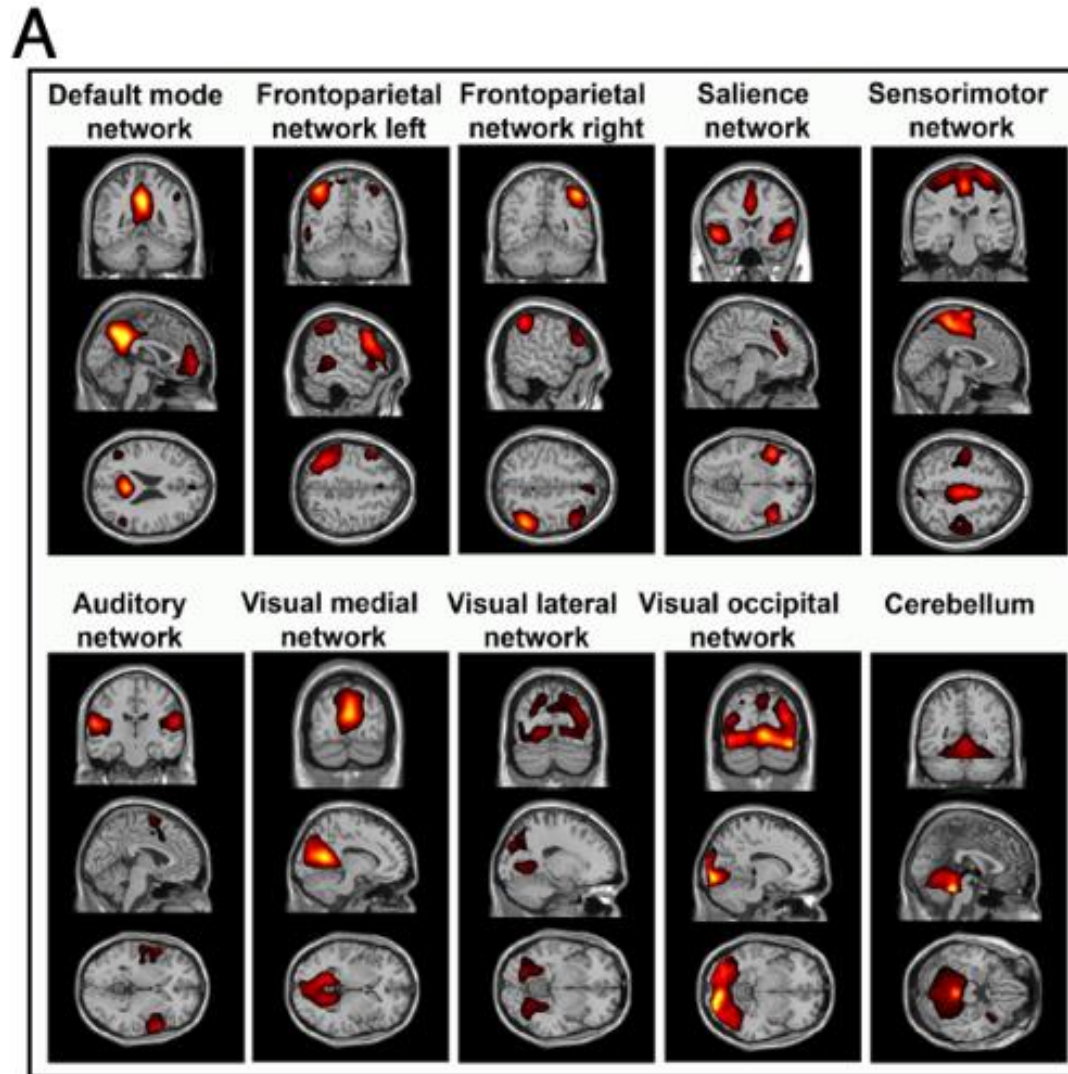
@PhysioCognGIGA



# Supplementary Information

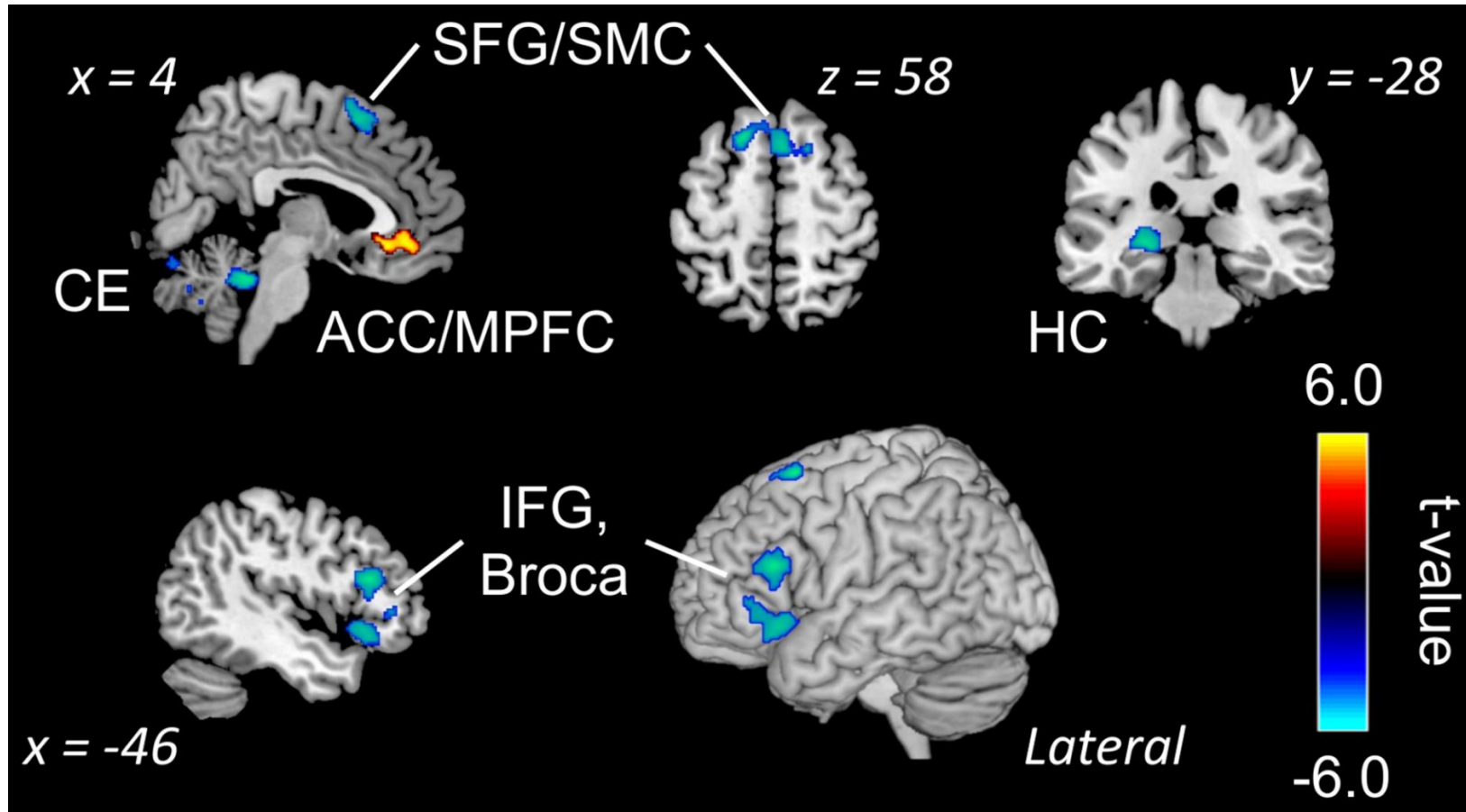
# Resting State Networks

# Resting State Networks and Dynamic Functional Patterns



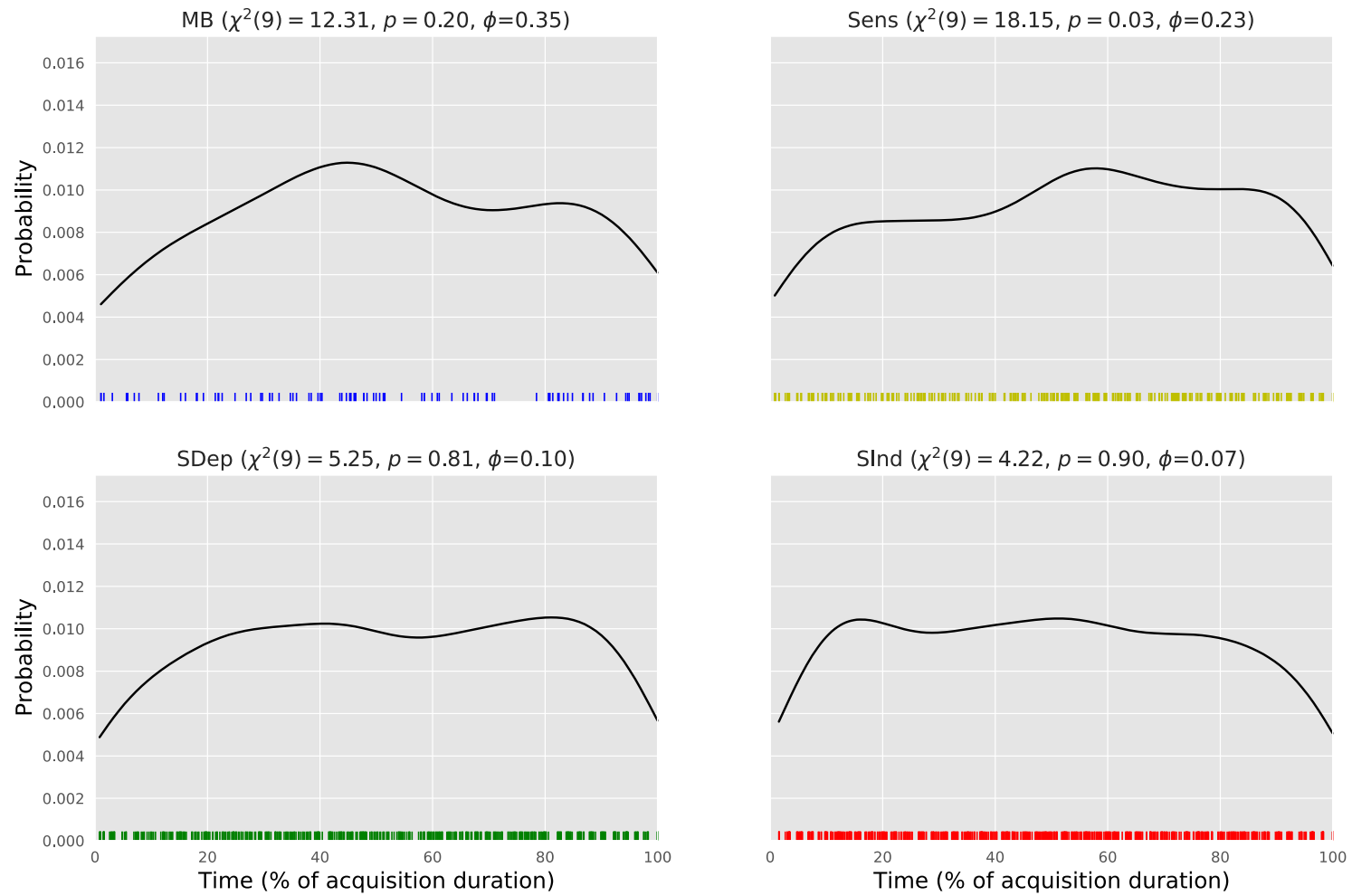
**Mind Blanking**

# Mind Blanking due to reduced inner speech?

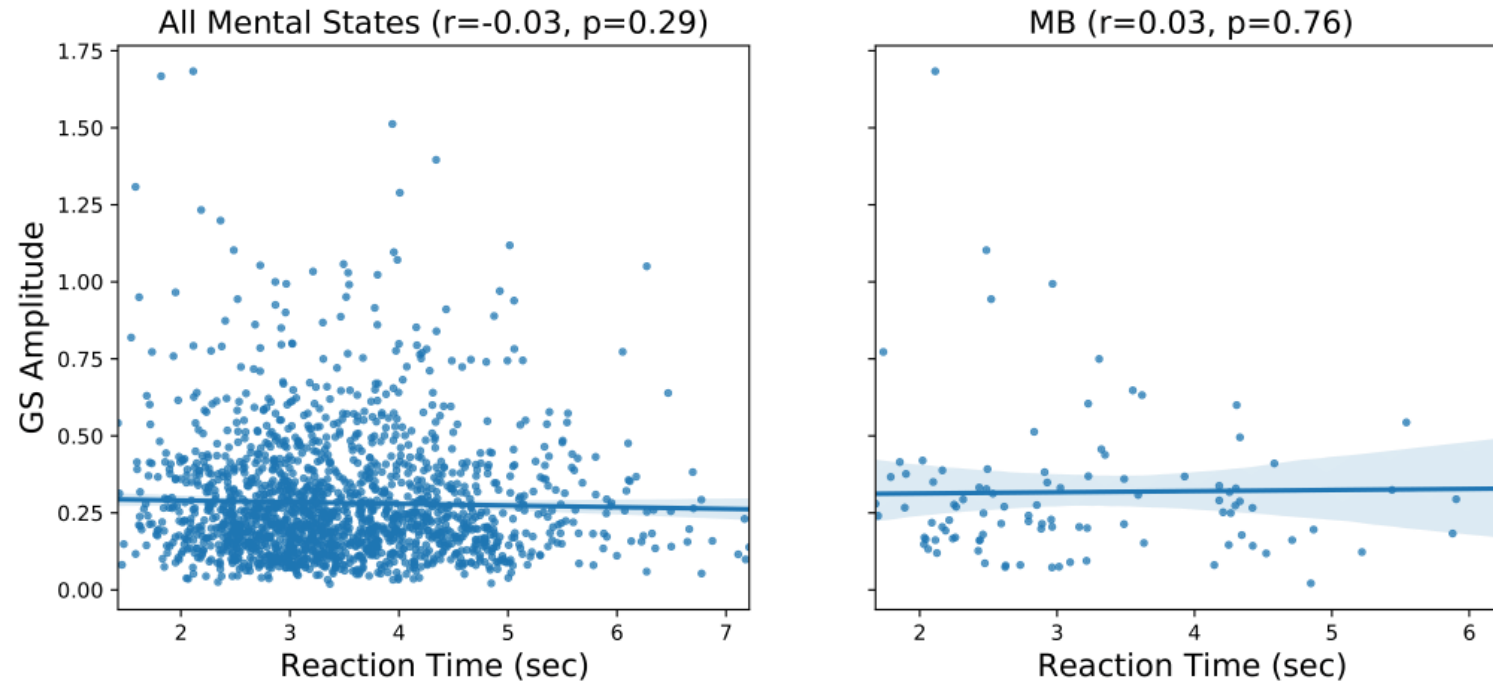


Kawagoe et al., *Human Brain Mapping*, 2019

# Mental States Reportability During Acquisition



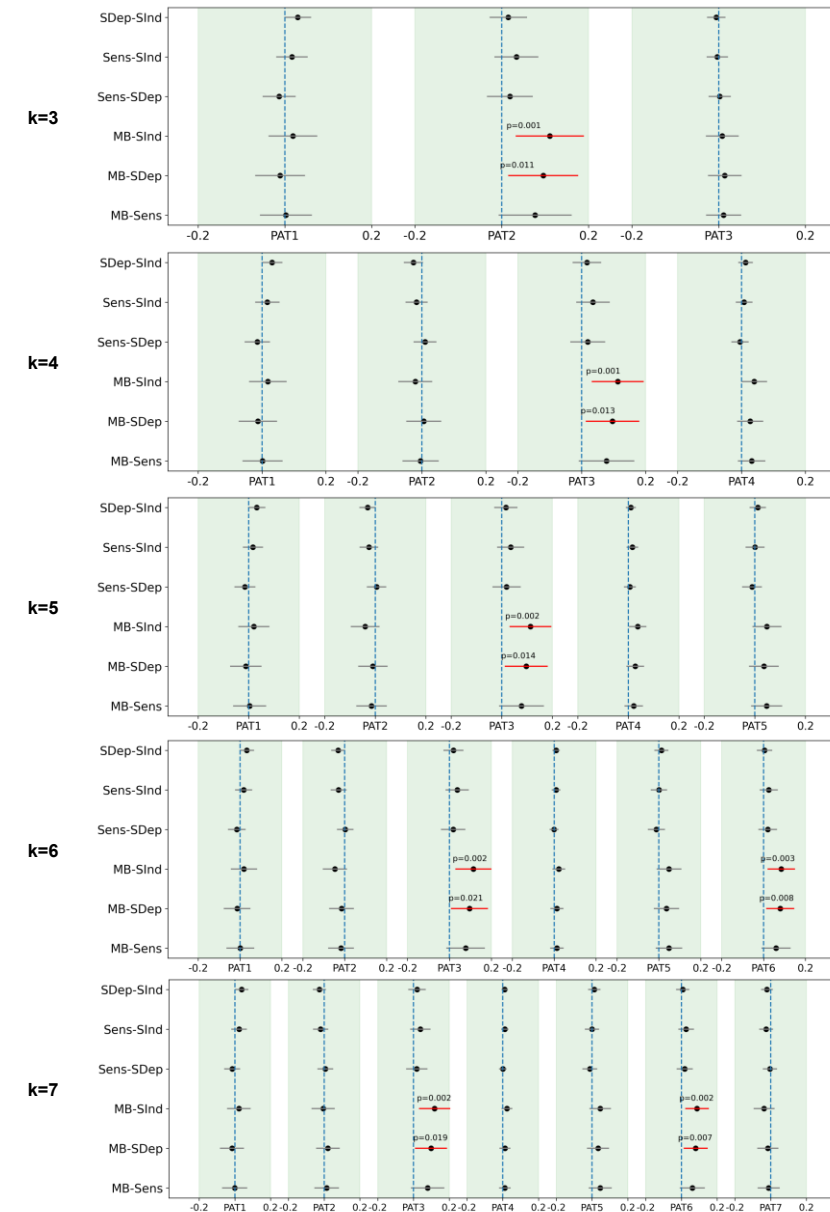
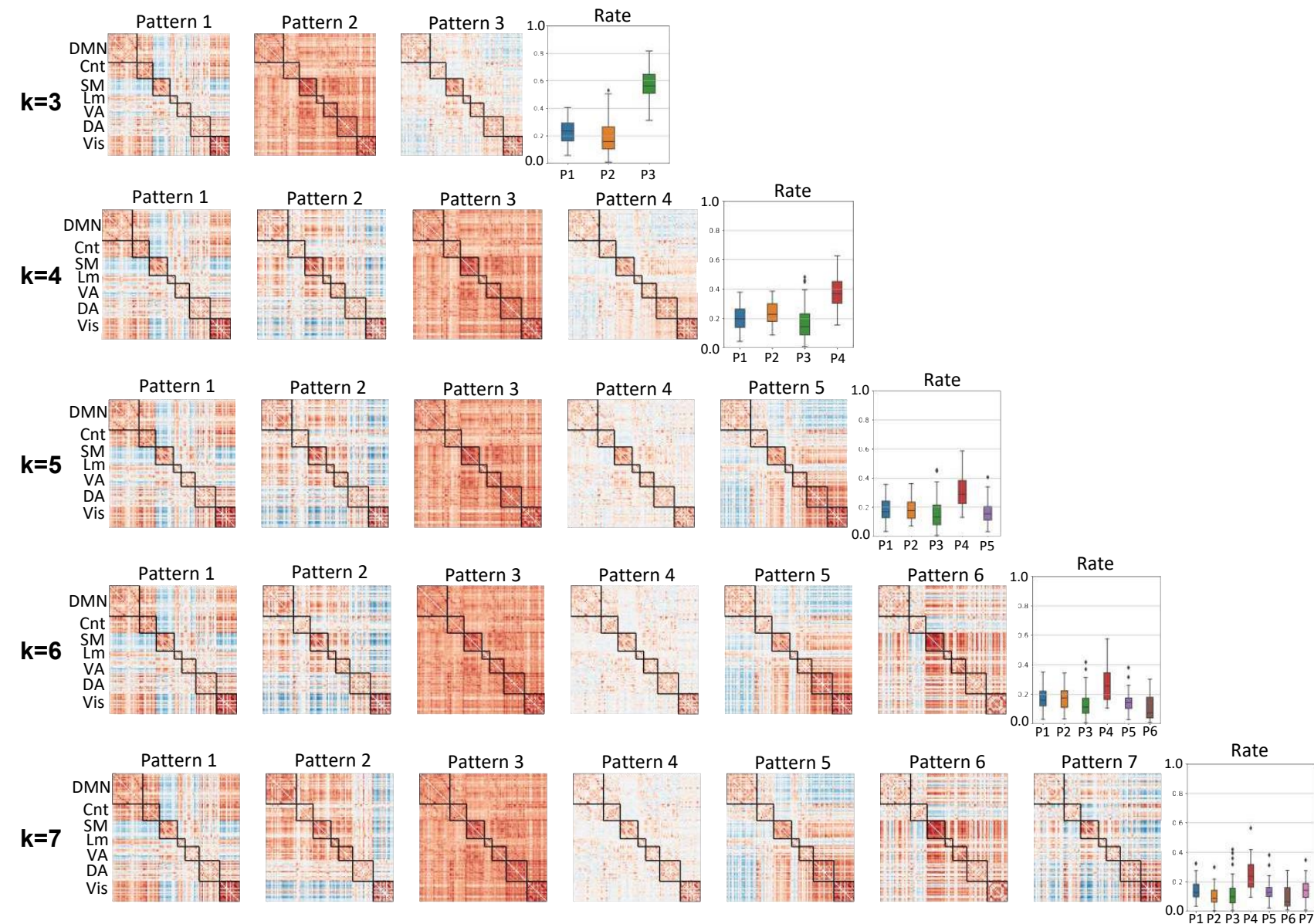
# Global Signal Amplitude and Reaction Times



Mortaheb et al., *PNAS*, 2022

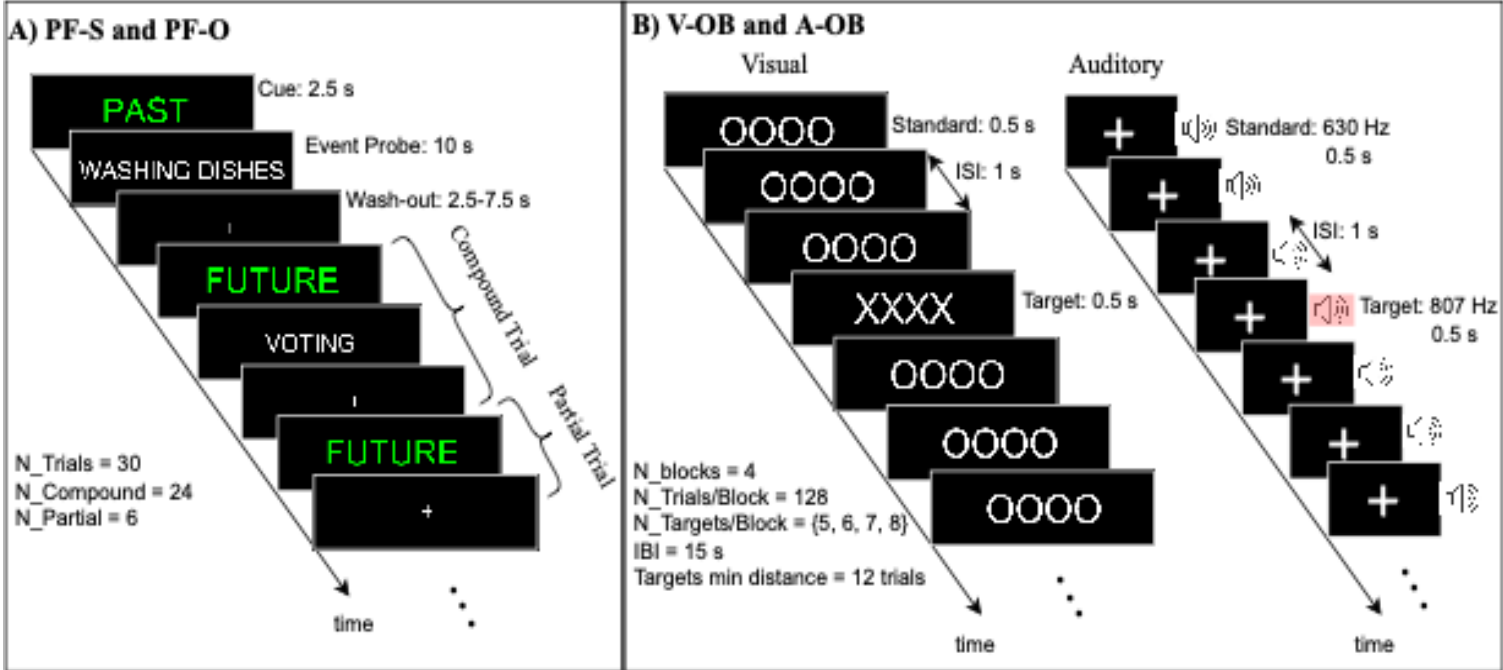


# Effects of number of clusters on dynamic connectivity patterns and MB reportability

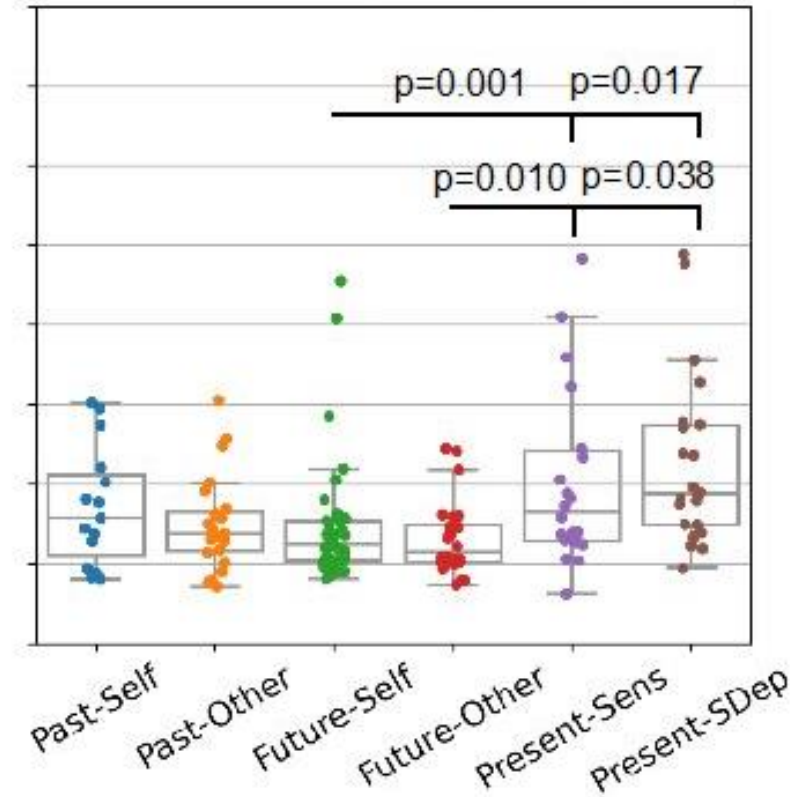
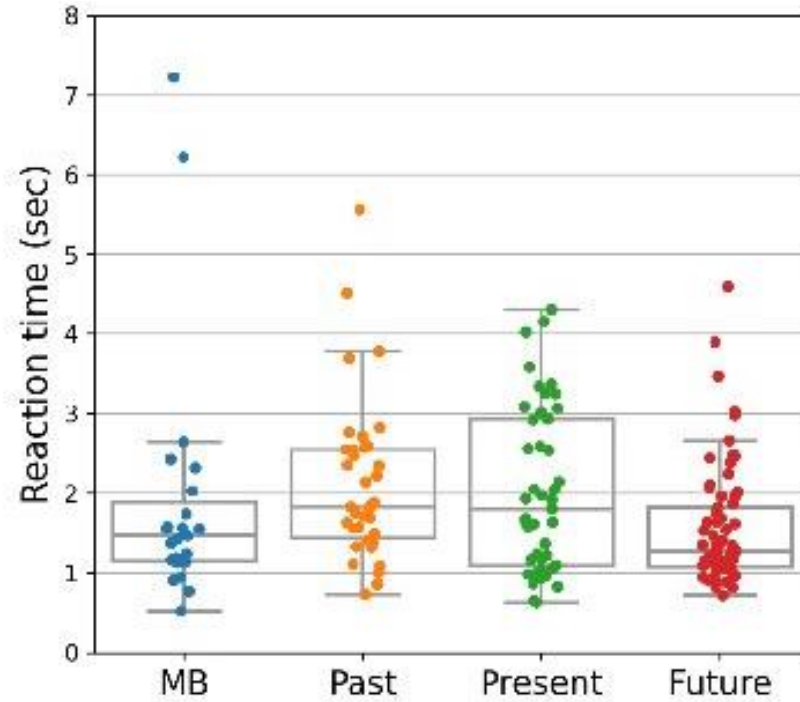


# Mental State Decoding

# Cognitive Tasks

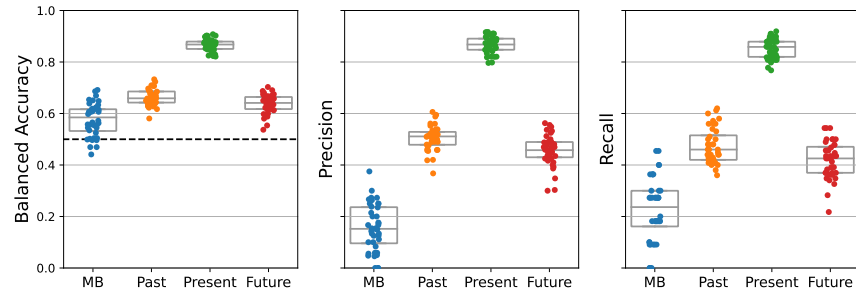


# Reaction Times in Mental States Reporting



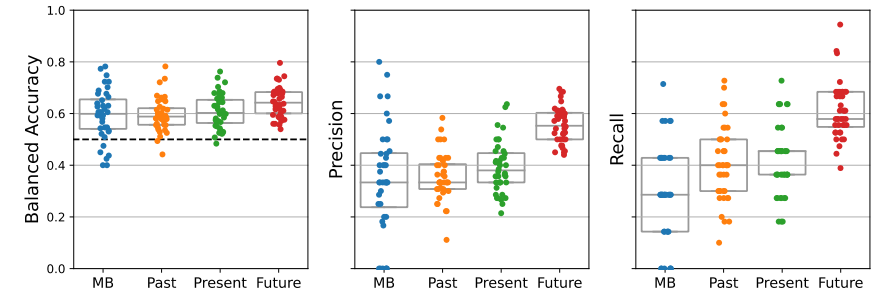
# Mental State Decoding Performance Measures (Temporal Dimension)

## Cognitive Tasks



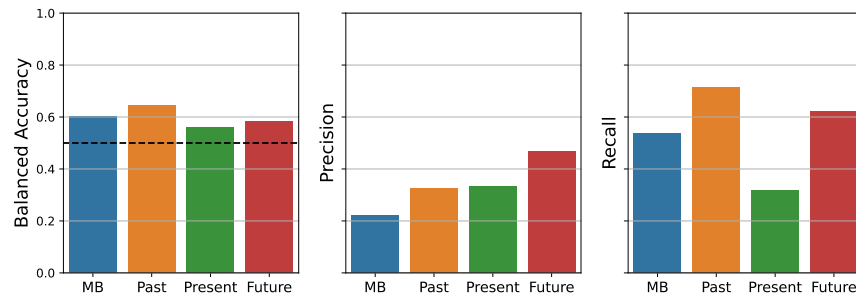
Classifier	Feature	Cut-off Eigenvalue	Balanced Accuracy	Precision	Recall
Past vs all	Decoupling map	50	0.66	0.50	0.47
Present vs all	Decoupling map	80	0.87	0.87	0.85
Future vs all	Decoupling map	70	0.64	0.46	0.42
MB vs all	Decoupling map	70	0.58	0.16	0.23

## Experience Sampling Probes



Classifier	Feature	Cut-off Eigenvalue	Balanced Accuracy	Precision	Recall
Past vs all	Decoupling map	70	0.60	0.36	0.41
Present vs all	Coupling map	40	0.61	0.39	0.42
Future vs all	SDI map	110	0.65	0.56	0.61
MB vs all	Decoupling map	40	0.60	0.35	0.29

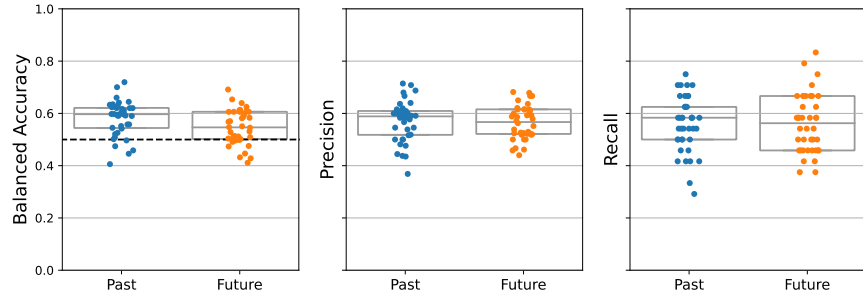
## From cognitive tasks to ES probes



Classifier	Feature	Cut-off Eigenvalue	Balanced Accuracy	Precision	Recall
Past vs all	SDI map	20	0.64	0.33	0.72
Present vs all	Coupling map	10	0.56	0.33	0.32
Future vs all	SDI map	20	0.58	0.47	0.62
MB vs all	Decoupling map	80	0.60	0.22	0.54

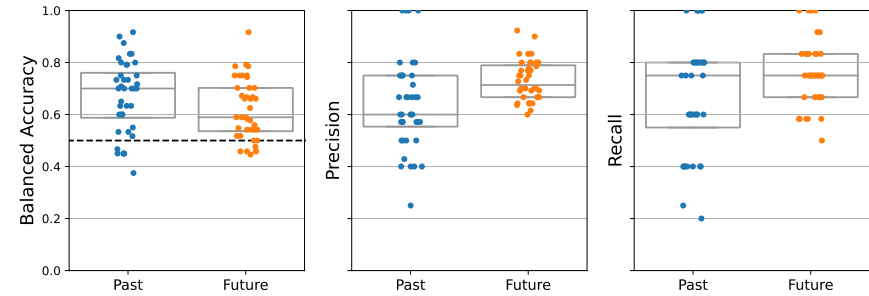
# Mental State Decoding Performance Measures (Referent Dimension)

## Cognitive Tasks



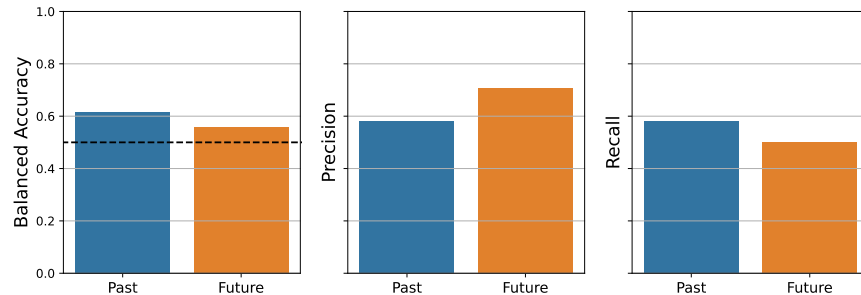
Temporal Dimension	Feature	Cut-off Eigenvalue	Balanced Accuracy	Precision	Recall
Past	Coupling map	20	0.58	0.57	0.56
Future	SDI map	80	0.55	0.56	0.56

## Experience Sampling Probes



Temporal Dimension	Feature	Cut-off Eigenvalue	Balanced Accuracy	Precision	Recall
Past	Coupling map	20	0.67	0.64	0.67
Future	SDI map	90	0.62	0.73	0.76

## From cognitive tasks to ES probes



Temporal Dimension	Feature	Cut-off Eigenvalue	Balanced Accuracy	Precision	Recall
Past	Coupling map	30	0.62	0.58	0.58
Future	Decoupling map	40	0.56	0.71	0.50

**Methods**

# Classification Performance Measures for Imbalanced Datasets

**Precision:** A parameter between 0 and 1 also defined as the ability of the classifier not to label as positive a sample that is negative.

$$Precision = \frac{TP}{TP + FP}$$

**Recall:** A parameter between 0 and 1 defined as the ability of the classifier to classify positive samples correctly.

$$Recall = \frac{TP}{TP + FN}$$

**Balanced Accuracy:** To compute balanced accuracy, each sample is weighted according to the inverse prevalence of its true class which accordingly will avoid inflated performance estimates on imbalanced datasets.

$$Balanced Accuracy = \frac{1}{2} \left( \frac{TP}{TP + FN} + \frac{TN}{TN + FP} \right)$$



## Mental State Decoding

- multiband SE-EPI sequence
- 2mm isotropic spatial resolution
- TR = 4030 ms
- TE = 69.80 ms
- 70 transverse slices
- slice thickness = 2 mm
- slice acceleration factor = 2
- in-plane resolution 2x2 mm
- FoV = 192x216 mm.
- matrix = 96x108
- acceleration factor 2
- bandwidth per pixel = 2264 Hz/Px.
- Multi-shell (b = 650, 1000 & 2000)
- 118 volumes:
  - o The first volume was discarded to avoid T1 saturation effect
  - o 105 DW images (15 b=650, 30 b=100, 60 b=2000) interleaved with 12 b=0

## Cosmonauts

- multi-shell (b = 700, 1200, & 2800 )
- 153 volumes:
  - o 145 DWI images (25 b=700, 45 b=1200, 75 b=2800) interleaved with 8 b=0
- repetition/echo time of 7800/100 ms
- voxel size of 2.4 × 2.4 × 2.4 mm<sup>3</sup>
- matrix size of 100 × 100
- 58 slices
- Imaging was accelerated by a factor of 2