

Role of In-Scanner Conscious Experience in Resting-State

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National Institute
of Mental Health

Resting-state fMRI: 30s Primer



“Try not to move, remain awake and let your mind wander freely”



Amenable to all populations
Easy to acquire and share
Explore several systems

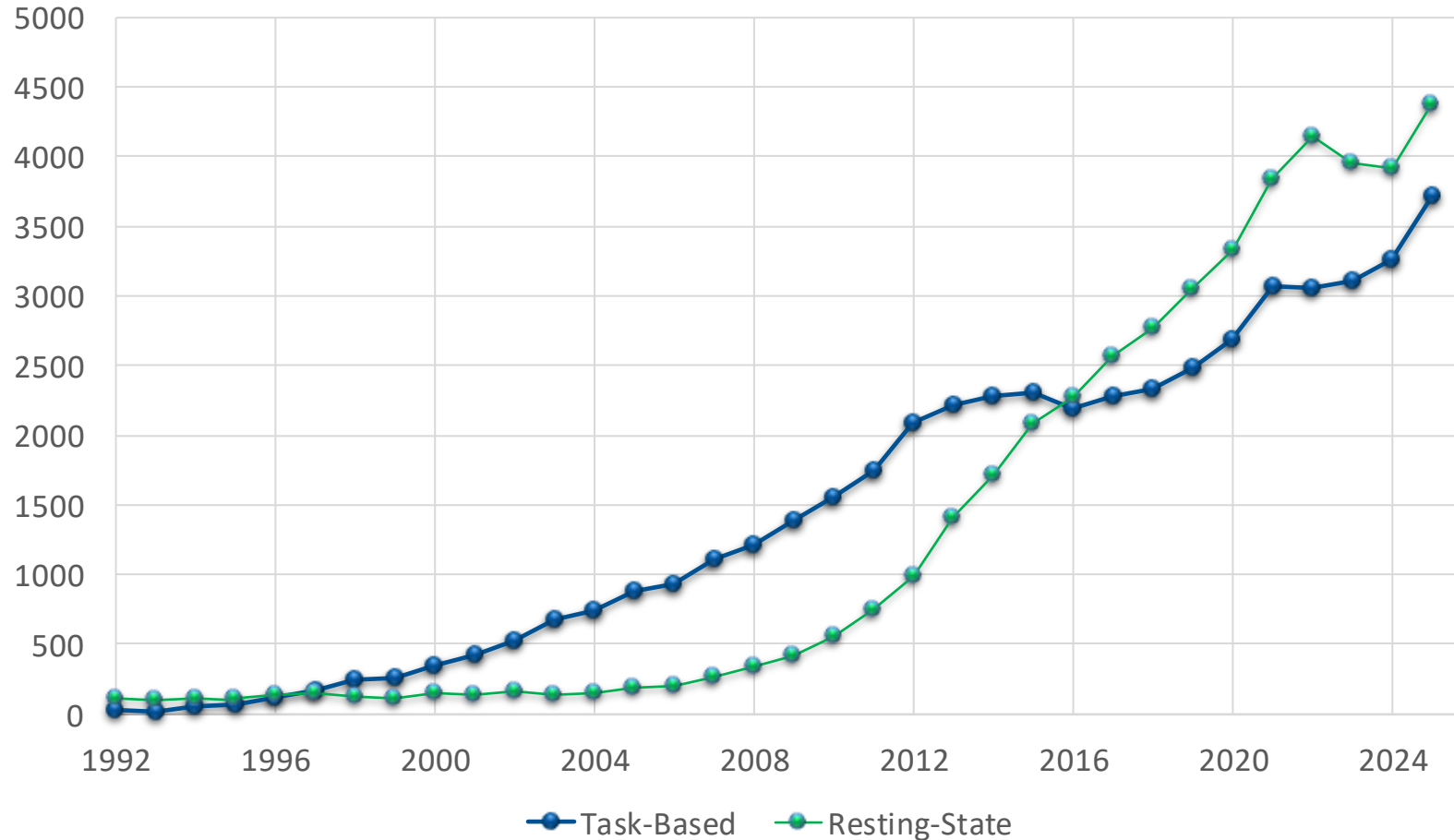


Correlational / Network Analytical Tools
Hard to interpret (e.g., cognitive processes)
Baseline → Dynamics → “Not all rest is made equal”

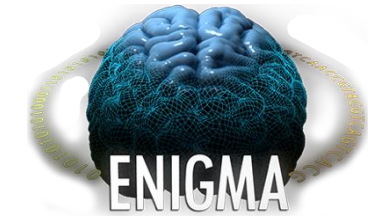
Resting-state fMRI: Relevance | Adoption



Publications Per Year



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

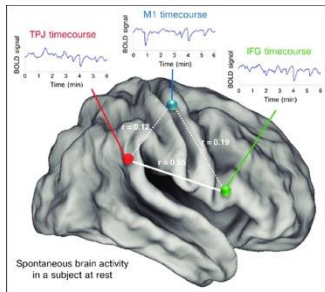


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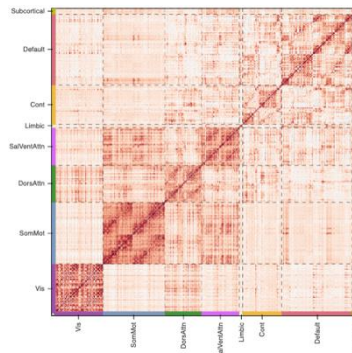
Resting-state fMRI: Common Analytical Frameworks



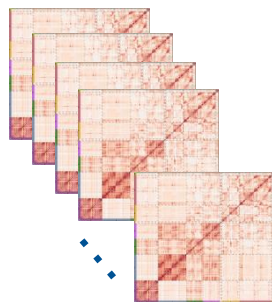
Population Differences



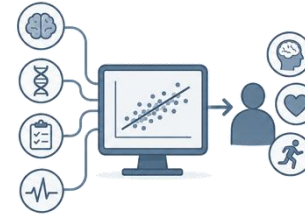
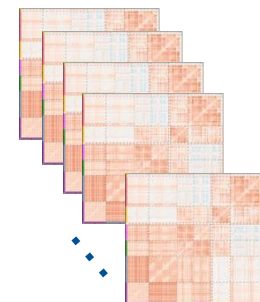
Gleibert & Mantini (2012)



Population A



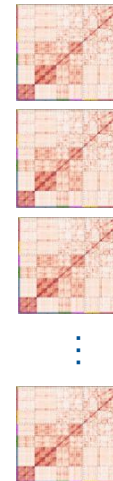
Population B



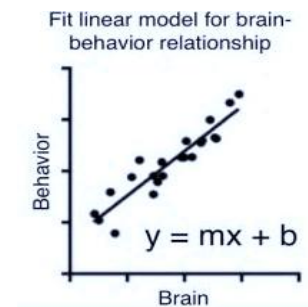
Phenotype Prediction

Phenotype/
Behavior/
Symptom

FC



10
12
15
⋮
9



Cognitive Abilities | Clinical labels | Personality Traits

Resting-state: What is it? What processes drive these observations?



Unconscious Processes

Memory Consolidation

Lewis et al. (2009) PNAS, Laumann & Snyder (2021) Cur Op Bio Sci

Homeostatic Processes

Marder & Goaillard (2006) Nat Rev. Neuroscience

Interoceptive Monitoring

Choe et al. (2021) PLoS One

Internal Model Optimization

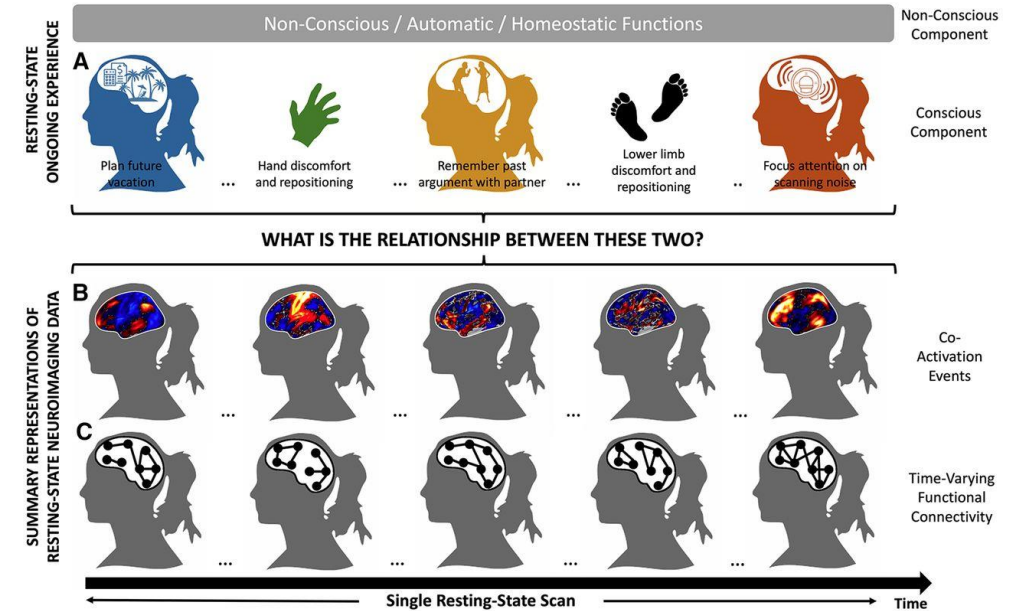
Pezzulo et al. (2021) Trends Cog Science

Fluctuations in Vigilance

Liu X et al. (2018) Nat. Comms., Laumann & Snyder (2021), Gonzalez-Castillo et al. (2021) NeuroImage

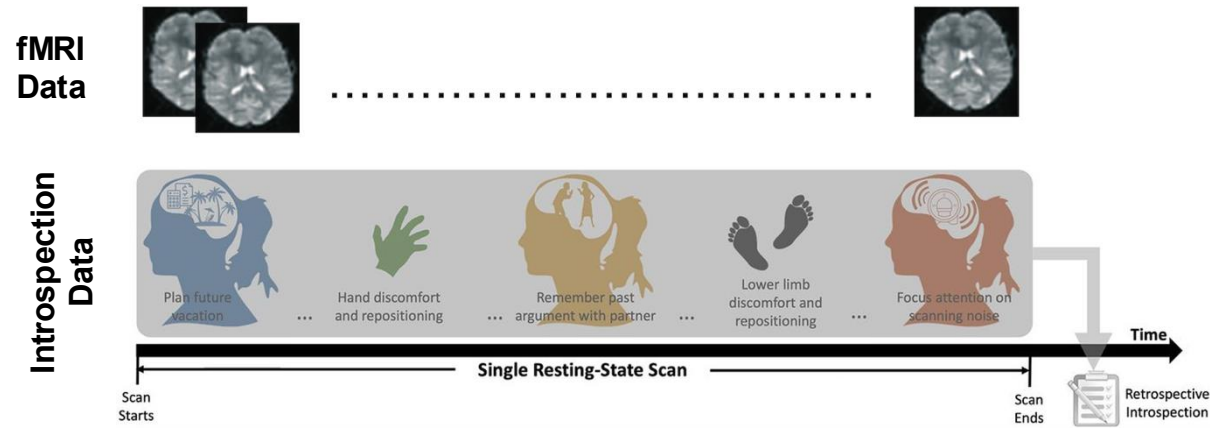


Conscious Experience / Processes

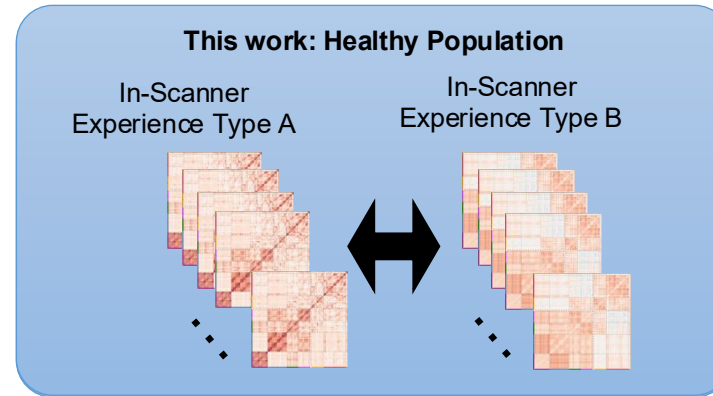


Gonzalez-Castillo et al, J of Neuroscience (2021)

Should we consider experience when interpreting resting-state?



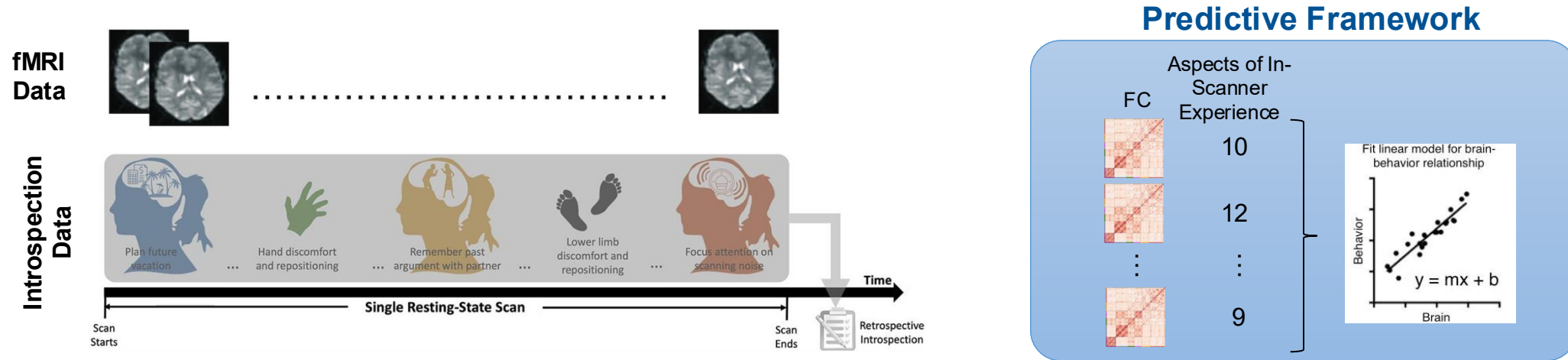
Population Differences Framework



Q1 | Do subjects tend to be in the same mental state when asked to rest?

Q2 | Can we detect differences in FC if we group scans according to thought pattern?

Should we consider experience when interpreting resting-state?



- Q1** | Do subjects tend to be in the same mental state when asked to rest?
- Q2** | Can we detect differences in FC if we group scans according to thought pattern?
- Q3** | Can we predict characteristics of ongoing thought based on FC measures?
- Q4** | Are these observations driven by other underlying phenotypes?

Max Plack Institut – Mind-Brain-Body Dataset



Neuroimaging Data

175 Subjects
 1 – 4 rs-fMRI scans (Eyes Open)
 15 min rs-fMRI
 TR = 1.4s | 2.3mm³ | 3T



471 Scans from 133 subjects passed QA



Basic Demographics Data

Age Range (5 year intervals) & Gender



Phenotype Data

- Personality / Habitation Behaviors (21)
- Mind Wandering / Mindfulness (4)
- Synesthesia (1)
- Cognitive Controls / Sustained Att. (1)
- Creativity (4)



Multi-Dimension Experience Sampling Reports

FORM

My thoughts were intrusive	0 ... 100
My thoughts were more specific than vague	0 ... 100
My thoughts were in the form of words	0 ... 100
My thoughts were in the form of images	0 ... 100

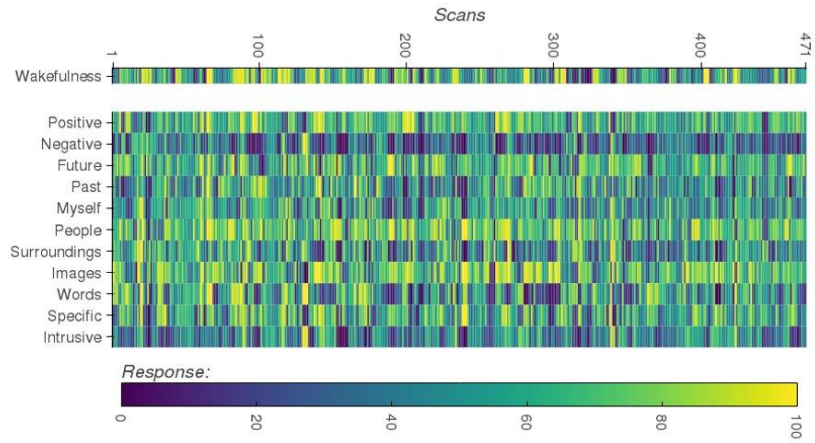
CONTENT

I thought about my environment / surrounding	0 ... 100
I thought about other people	0 ... 100
I thought about myself	0 ... 100
I thought about past events	0 ... 100
I thought about future events	0 ... 100
I thought about something negative	0 ... 100
I thought about something positive	0 ... 100

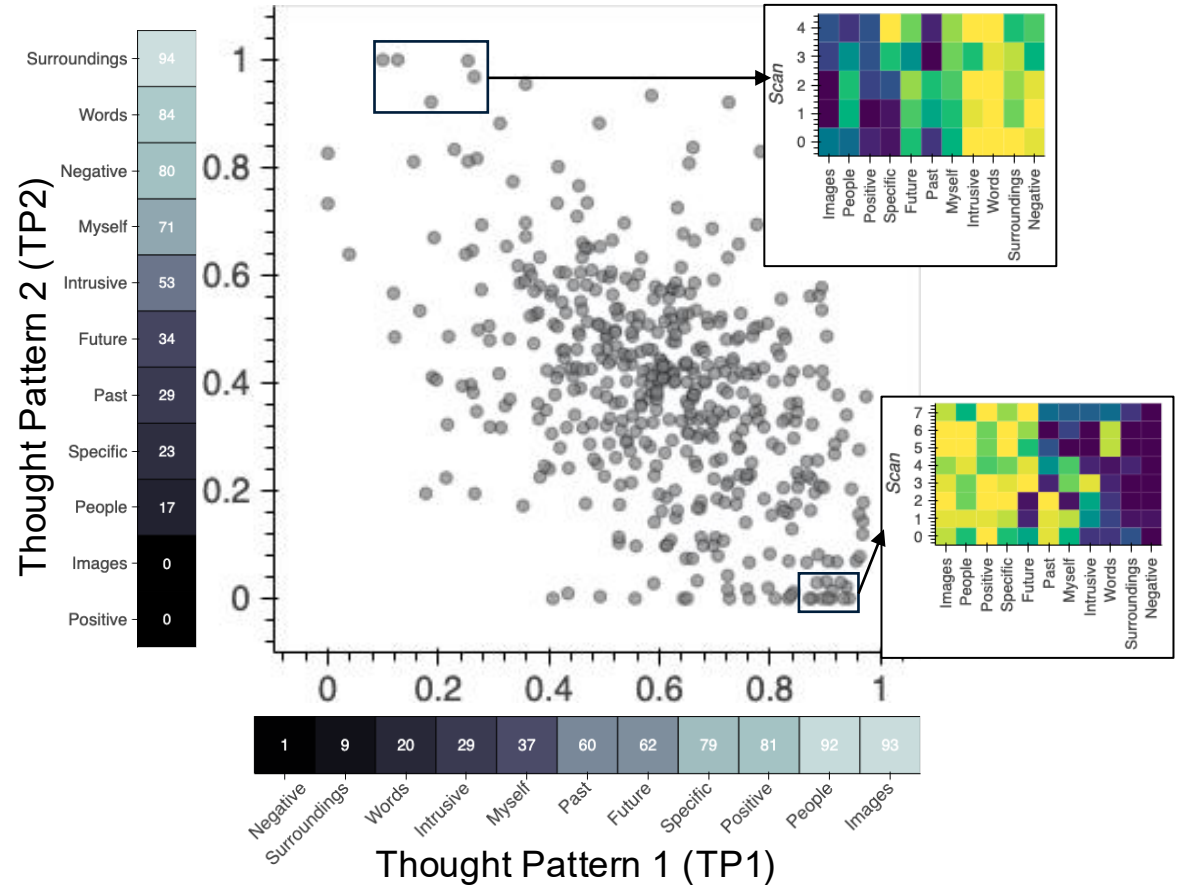
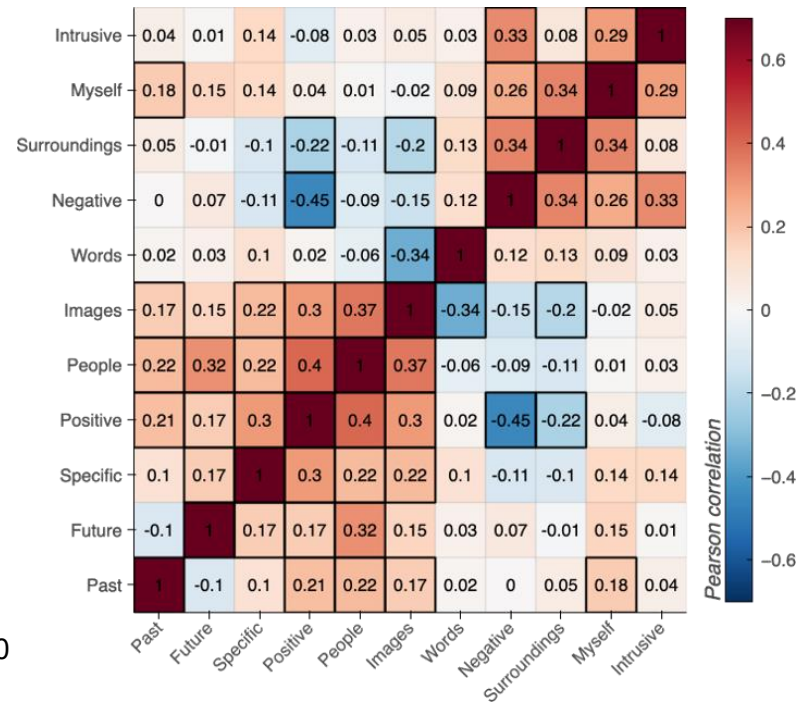
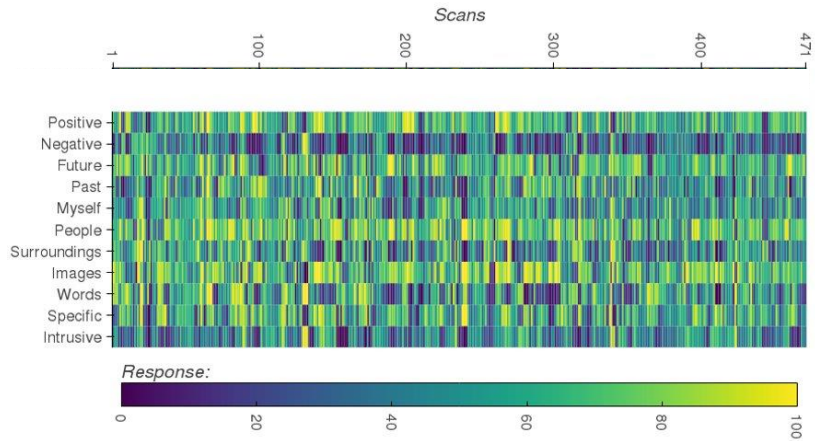
VIGILANCE

I was completely awake	0 ... 100
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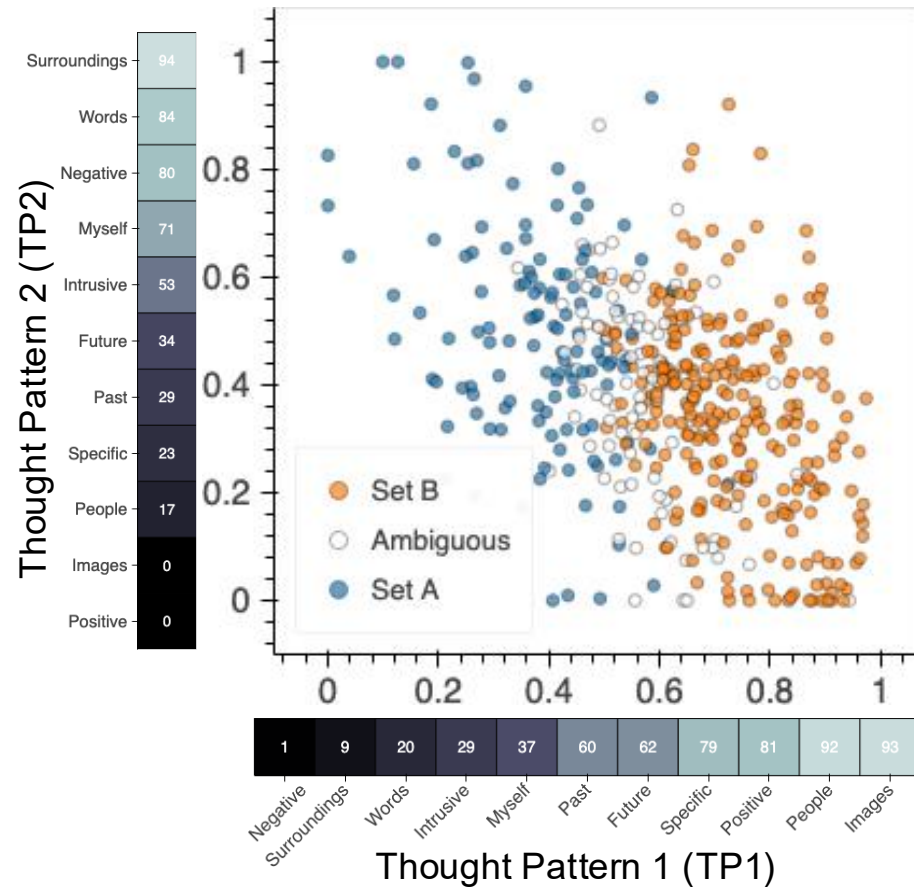
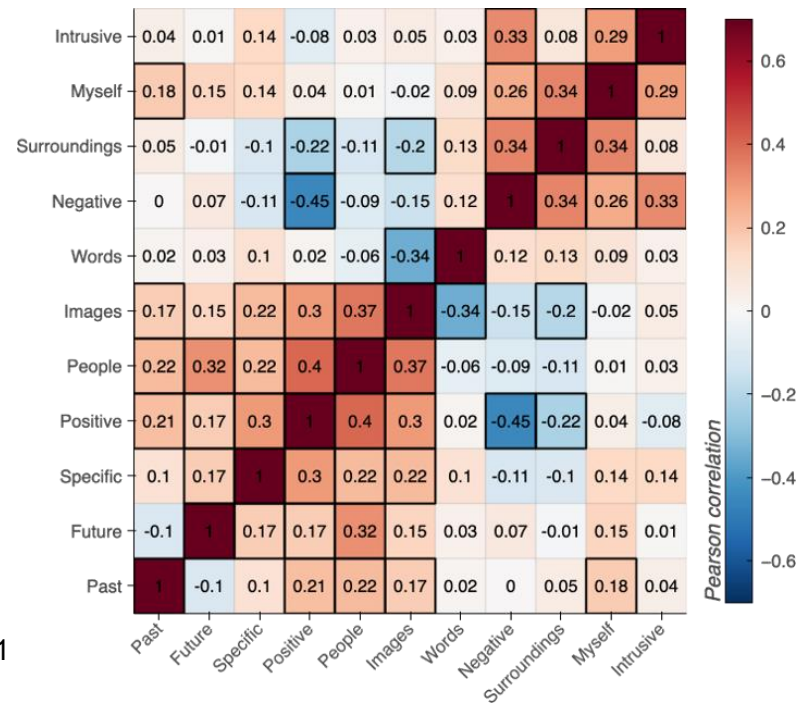
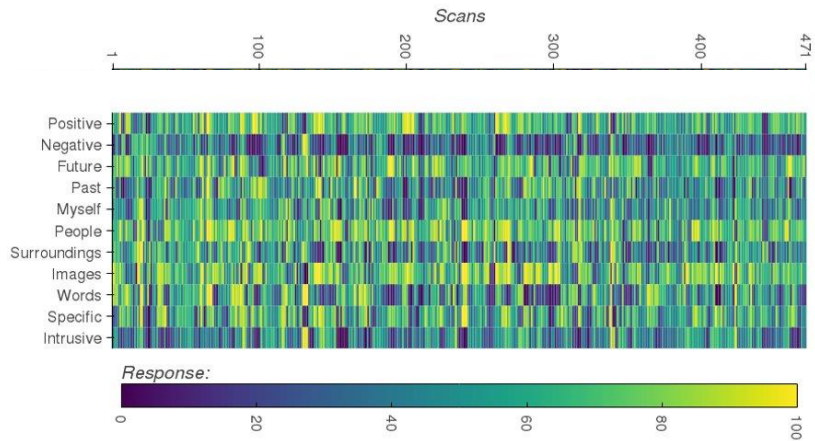
Experiential Data



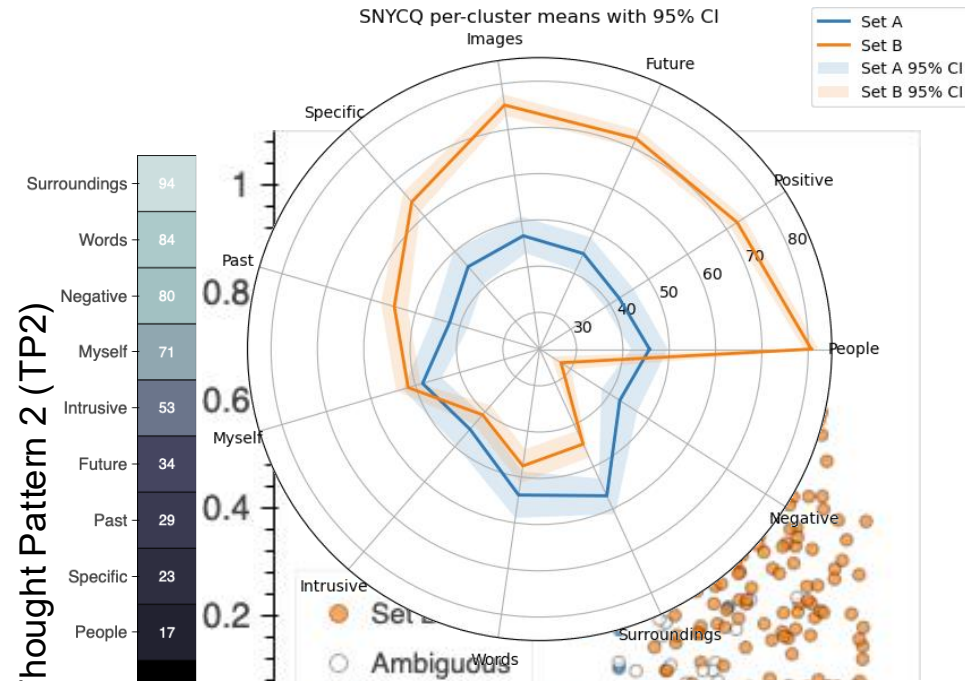
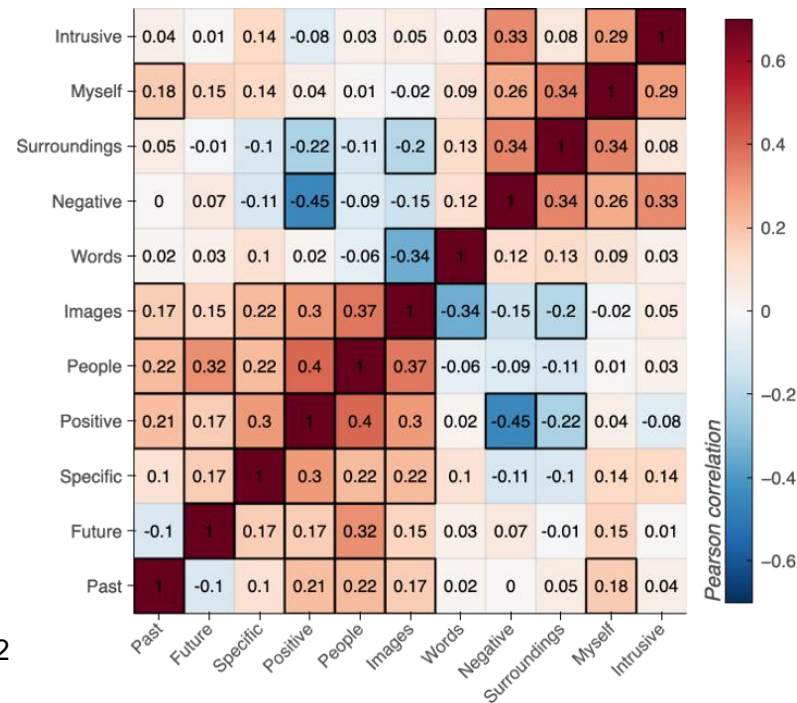
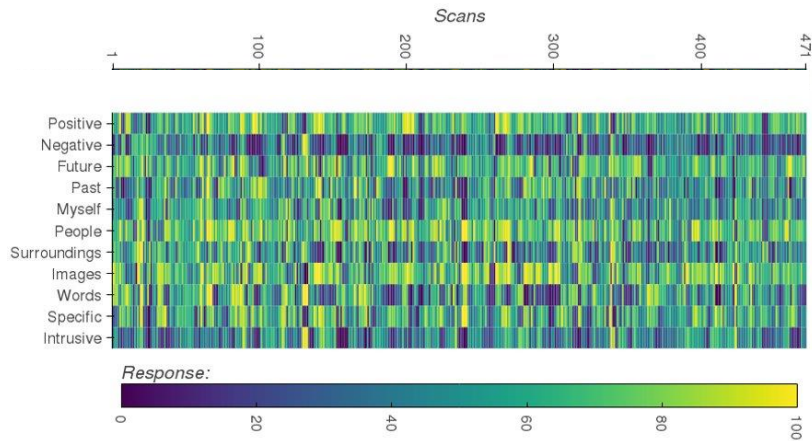
MDES Data



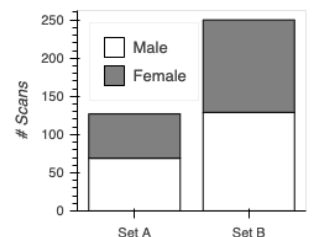
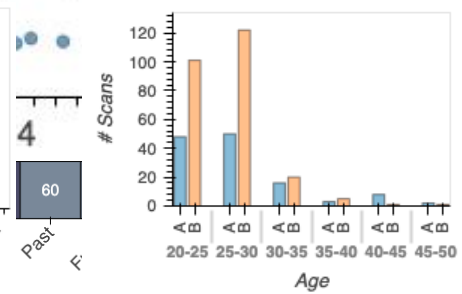
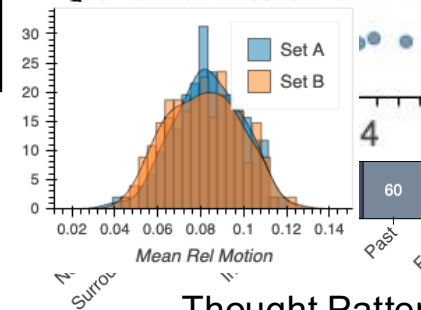
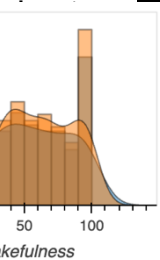
MDES Data



MDES Data



Thought Pattern 2 (TP2)



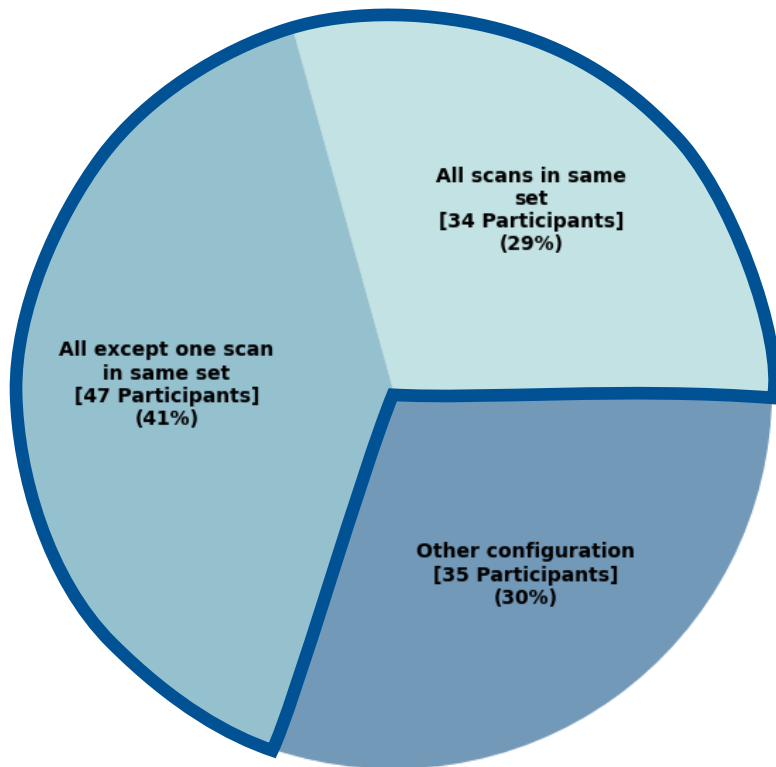
Thought Pattern 1 (TP1)

Q1

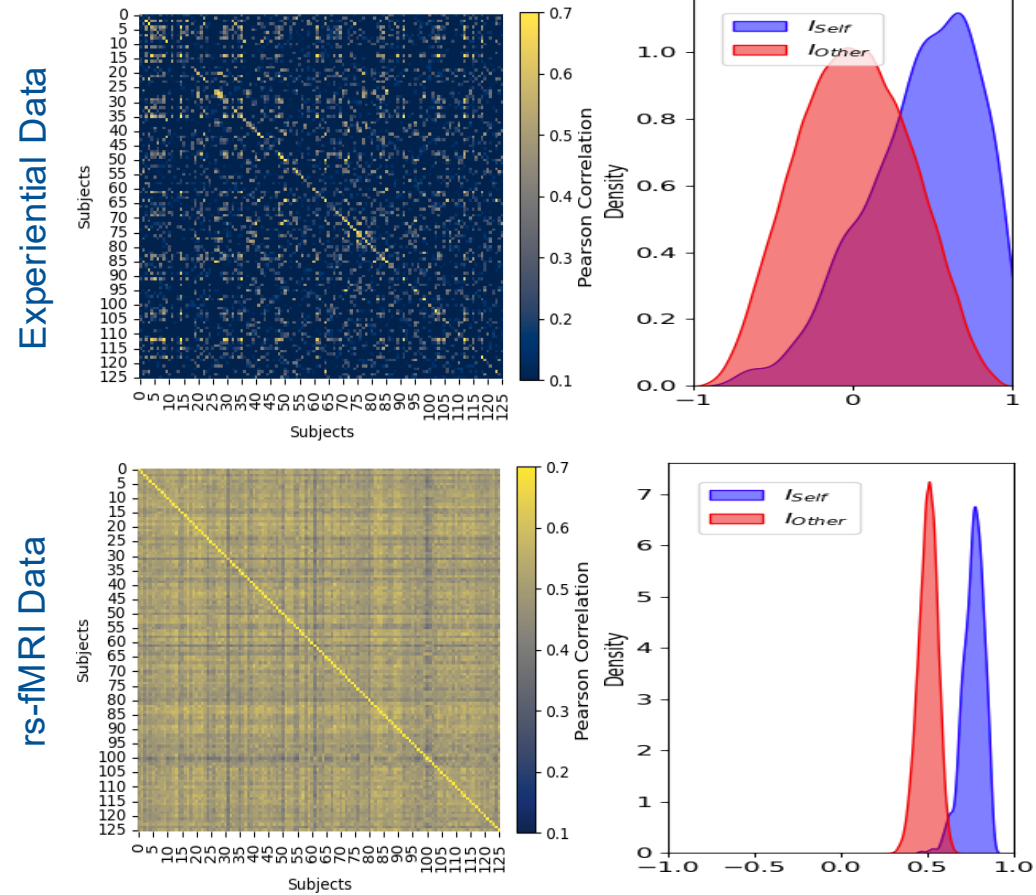
Do subjects tend to be in the same mental state when asked to rest?



Repeated Set Membership

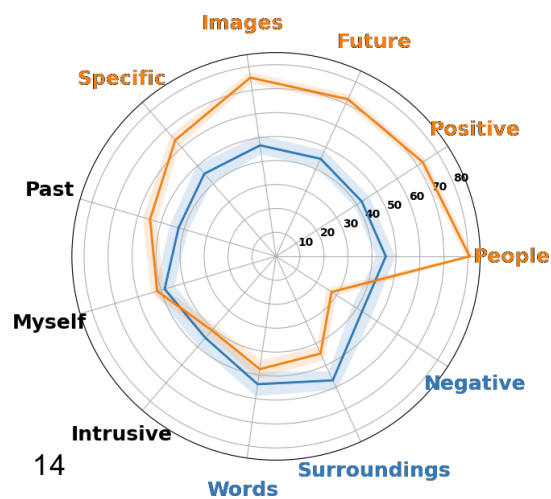
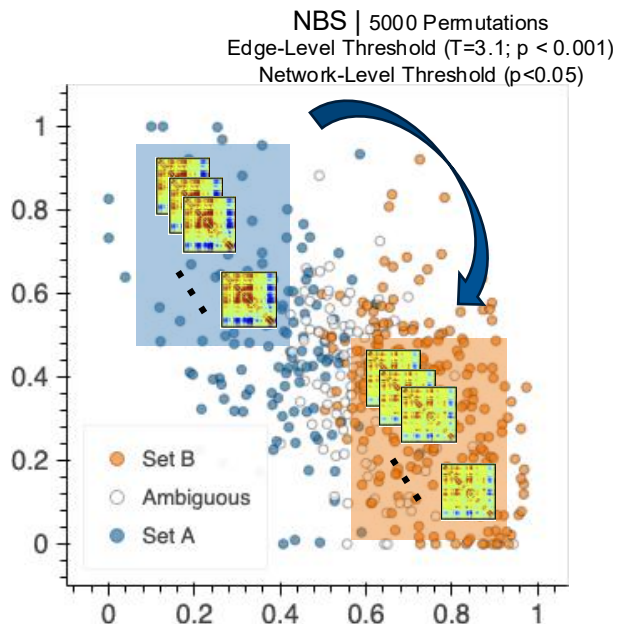


Identifiability Matrix

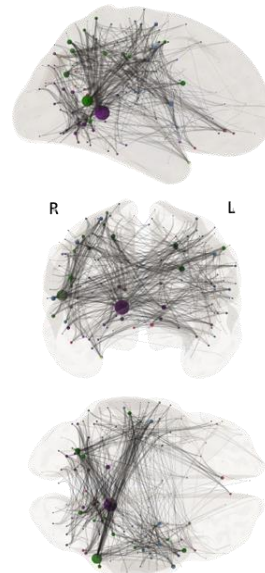
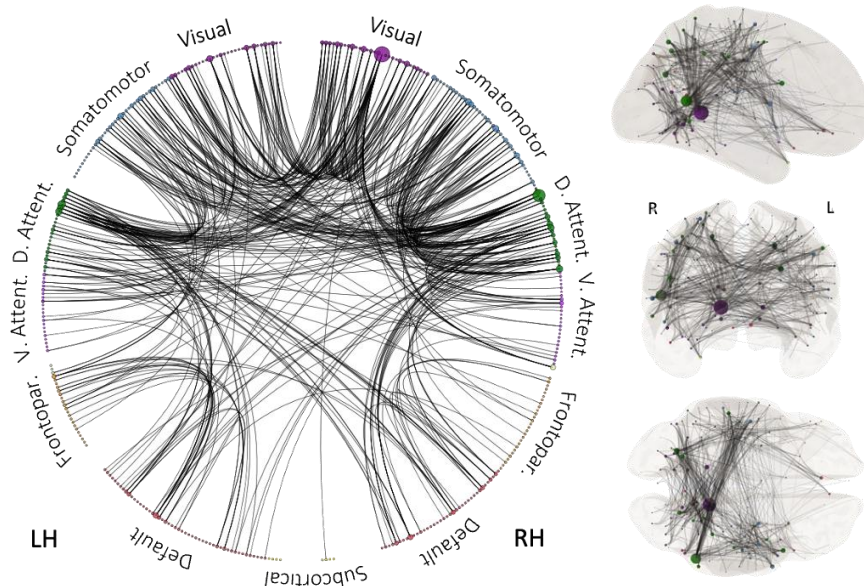


Q2

Can we detect differences in FC if we group scans according to thought pattern?

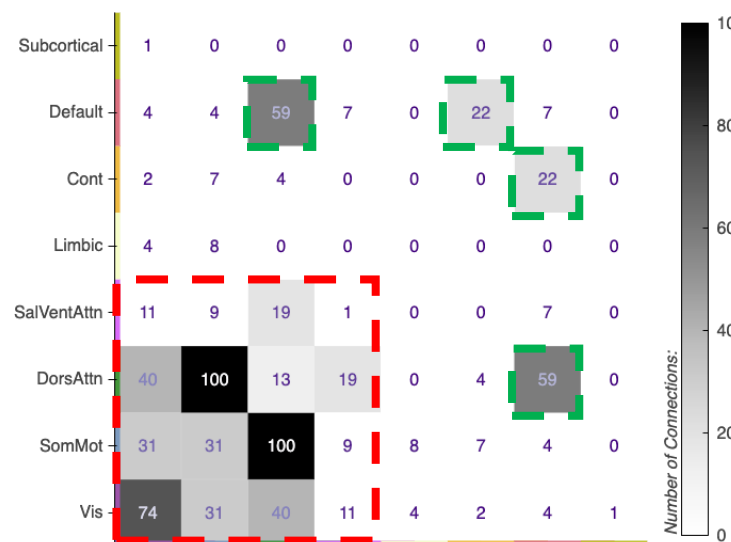
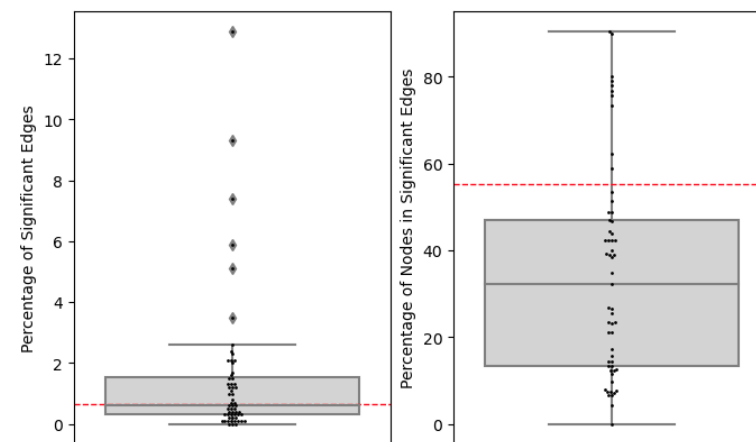


Set A > Set B



Laterality Index = -0.32 (right)
Number of Nodes = 210 (out of 380) → 55%
Number of Connections = 458 → 0.7%

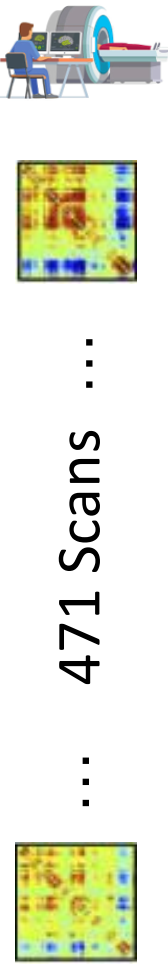
Comparison to Prior Literature




Q3

Can we predict characteristics of ongoing thought based on FC measures?

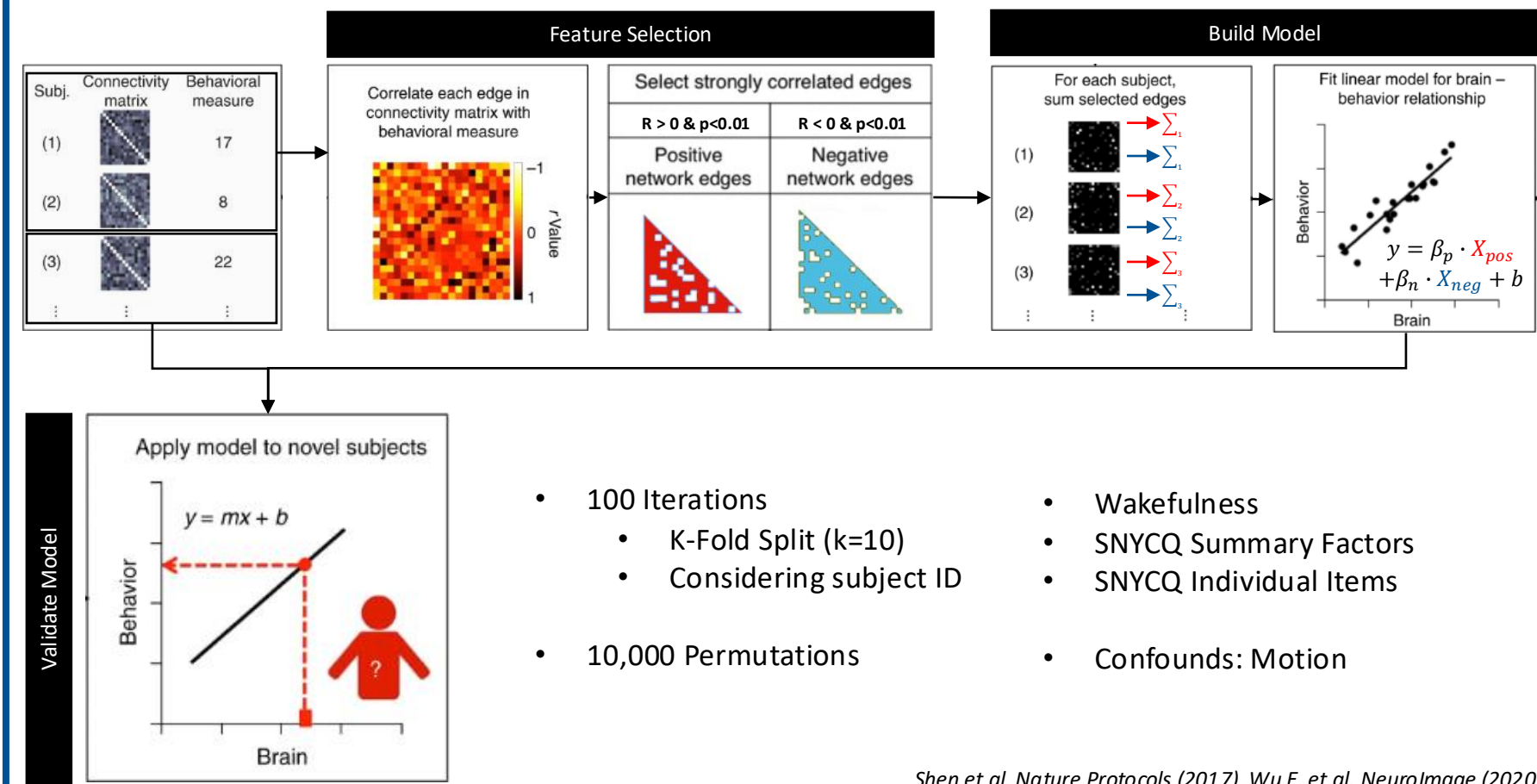
... 471 Scans ...



... 471 SNYCQ ...



Connectome Predictive Modeling (CPM)

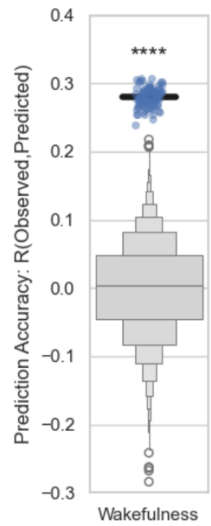


- 100 Iterations
 - K-Fold Split (k=10)
 - Considering subject ID
- 10,000 Permutations
- Wakefulness
- SNYCQ Summary Factors
- SNYCQ Individual Items
- Confounds: Motion

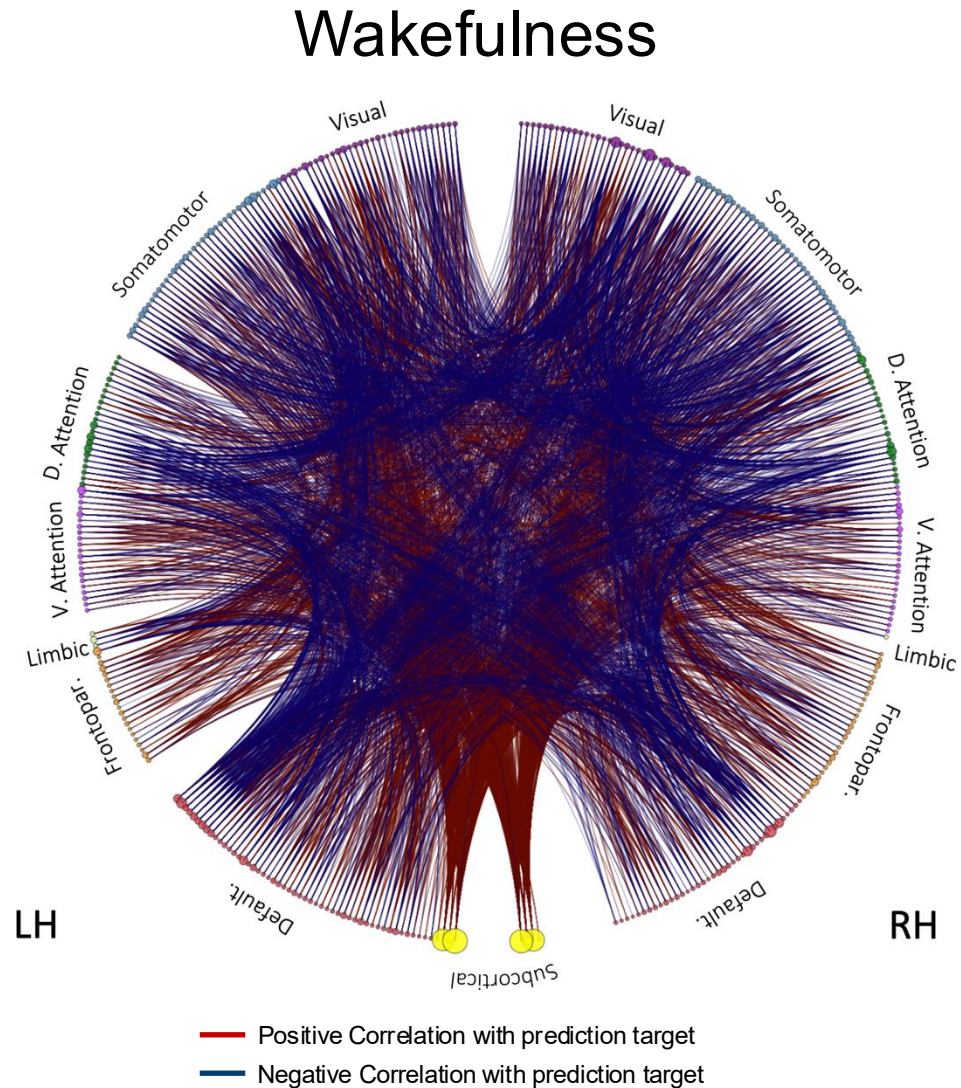
Shen et al. Nature Protocols (2017), Wu E. et al. NeuroImage (2020)

Q3

Can we predict characteristics of ongoing thought based on FC measures?

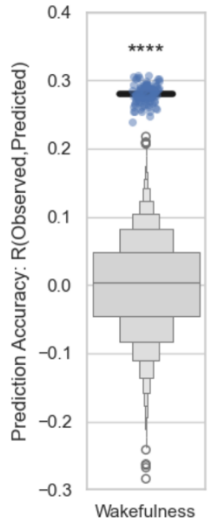


* p<0.05 | ** p<0.01 | *** p< 1e-3 | **** p < 1e-4



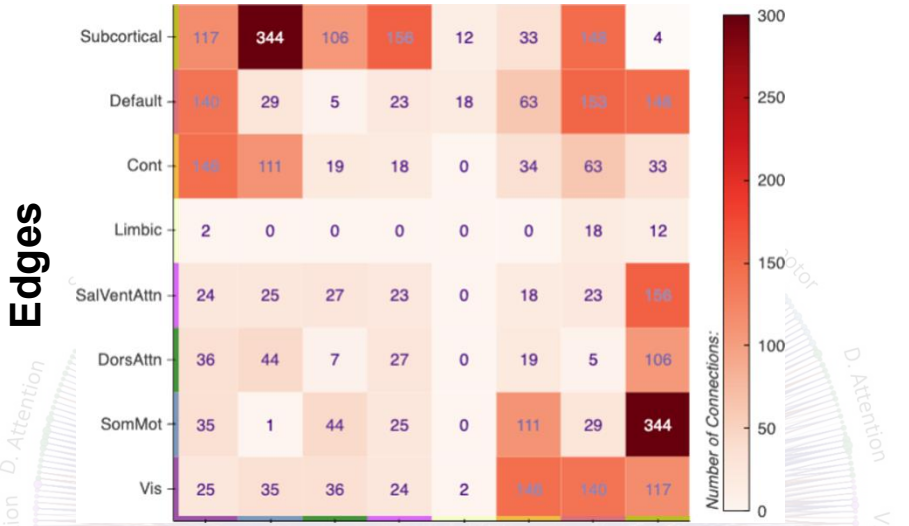
Q3

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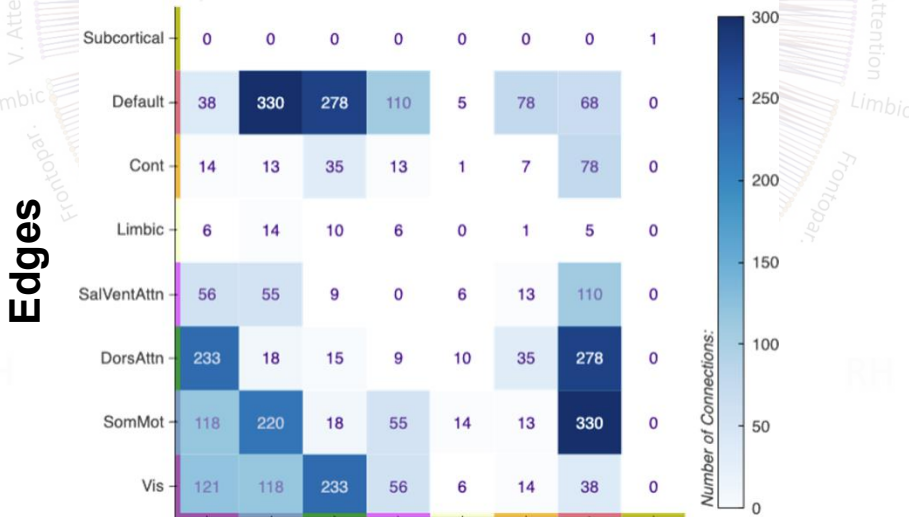


* p<0.05 | ** p<0.01 | *** p< 1e-3 | **** p < 1e-4

Positively Correlated Edges



Negatively Correlated Edges



S0 > S1

S1 > S0

Spoormaker et al. J. of Neuroscience (2010)

C

Wakefulness

AASM (EEG)

SVM (fMRI)

SVM (fMRI)

N1 sleep

AASM (EEG)

SVM (fMRI)

SVM (fMRI)

Tagliazucchi et al. NeuroImage (2012)

Wake vs. N1 sleep

Wake < N1 sleep
Wake > N1 sleep

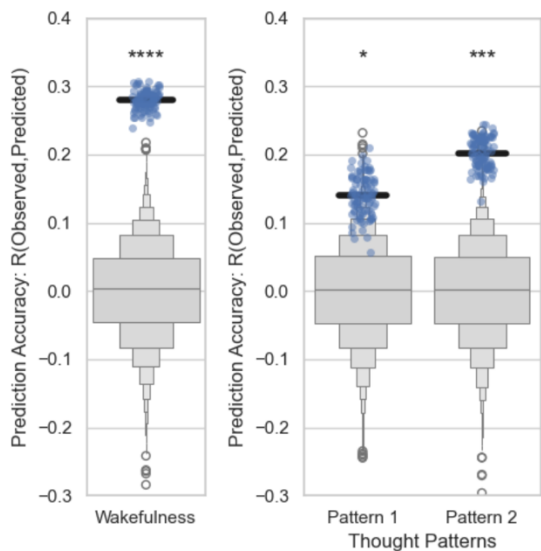
Tagliazucchi & Laufs, Neuron (2014)

As wakefulness decreases into light sleep:

- Thalamocortical connectivity sharply reduced
- Cortico-cortico connectivity increases

Q3

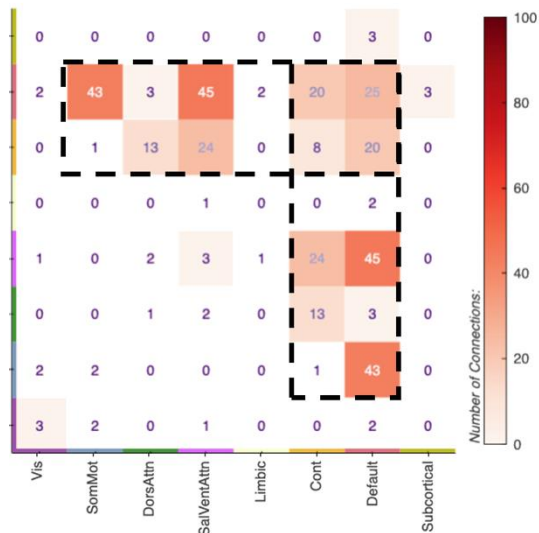
Can we predict characteristics of ongoing thought based on FC measures?



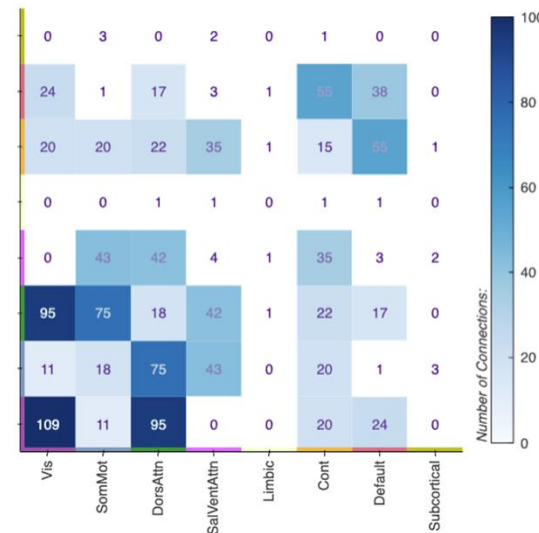
* p<0.05 | ** p<0.01 | *** p< 1e-3 | **** p< 1e-4

TP1: Images, People, Positive...

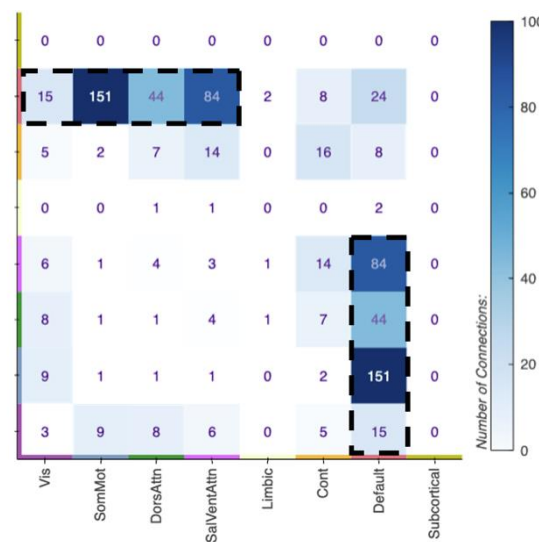
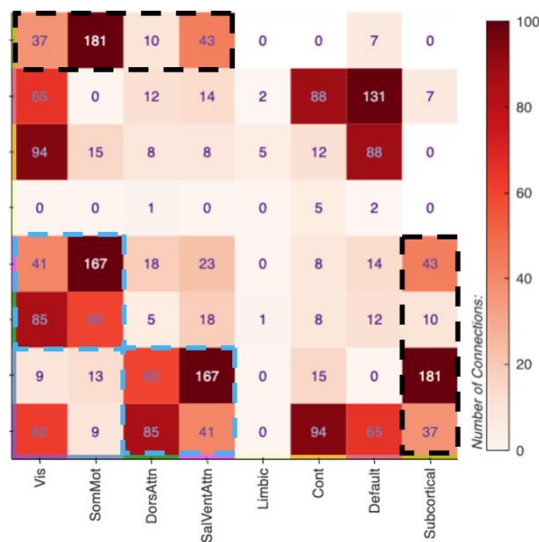
Positively Correlated Edges



Negatively Correlated Edges

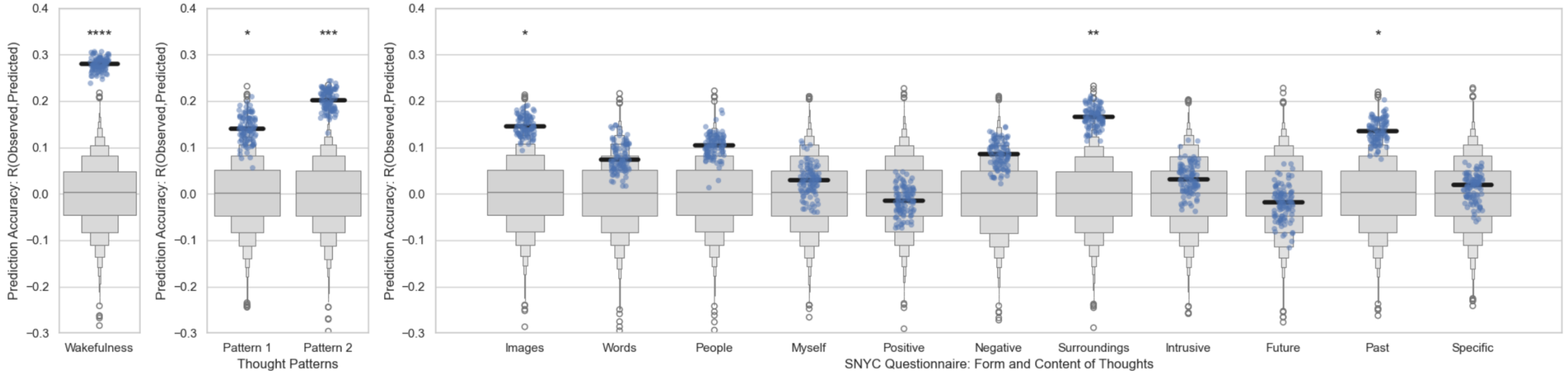


TP2: Surroundings, words, negative...



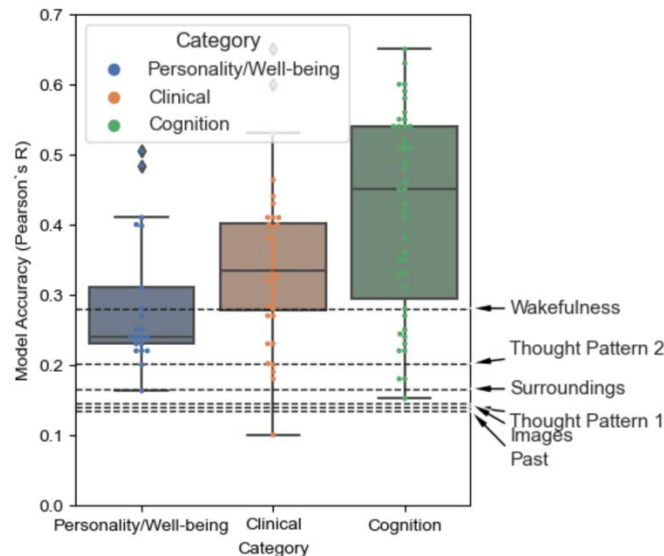
Q3

Can we predict characteristics of ongoing thought based on FC measures?



* $p < 0.05$ | ** $p < 0.01$ | *** $p < 1e^{-3}$ | **** $p < 1e^{-4}$

Comparison to Prior Literature



Dataset: additional behavioral data

SCIENTIFIC DATA

OPEN Data Descriptor: A functional connectome phenotyping dataset including cognitive state and personality measures

Received: 27 October 2017
 Accepted: 5 November 2018
 Published: 12 February 2019

Natacha Mendes¹, Sabine Olligschlager^{1,2,3}, Mark E. Lauckner¹, Johannes Golcher¹, Julia M. Huntenburg^{1,3}, Marcel Falkiewicz¹, Melissa Ellami¹, Sarah Krause¹, Blazej M. Baczkowski^{1,2,3}, Roberto Cozart¹, Anastasia Osolanu^{1,4}, Deniz Kumral^{1,8}, Jared Pool¹, Laura Goltz^{1,9}, Maria Dreyer¹, Philipp Hauels^{1,8}, Rebecca Jost¹, Yelyzaveta Kramarenko¹, Haakon Engen^{1,10}, Katharina Ohnberger^{1,8}, Krzysztof J. Gorgolewski¹⁰, Nicolas Farrugia¹⁰, Anahit Babayan¹⁰, Andrea Reiter^{1,11}, H. Lina Schaare^{1,7}, Janis Reinelt¹, Josefín Röbbig¹, Marie Uhlig^{1,7}, Miray Erbey¹, Michael Gaebler^{1,4}, Jonathan Smallwood¹, Arno Villringer^{1,8} & Daniel S. Margulies¹



Neuroimaging Data



Demographic Data



Introspective Data

Abbreviation	Behavioral Measure	N
Personality and Habitual Behaviors		
AMAS	Abbreviated Math Anxiety Scale ⁹	145
ASR	Adult Self Report adapted from ¹³	213
BDI	Beck Depression Inventar-II ¹⁴⁻¹⁶	210
BIS/BAS	Behavioral Inhibition and Approach System ¹⁷⁻²⁰	288
BCQ	Body Consciousness Questionnaire ²¹	79
BP	Boredom Proneness Scale ²²	209
SCS	Brief Self-Control Scale ^{23,24}	214
ESS	Epworth Sleepiness Scale ^{25,26}	210
FBI	Facebook Intensity Scale ²⁷	---
Gold-MSI	Goldsmiths Musical Sophistication Index	---
HADS	Hospital Anxiety and Depression Scale	---
IAT	Internet Addiction Test	---
IMIS	Involuntary Musical Imagery Scale	---
MPU	Mobile Phone Usage	---
MGIQ	Multi-Gender Identity Questionnaire	---
MMI	Multimedia Multitasking Index	---
NEO PI-R	NEO Personality Inventory (Revised)	---
PSSI	Personality Style and Disorder Inventory	---
SE	Self-Esteem Scale ³⁸	---
SD3	Short Dark Triad ³⁹	---
SDS	Social Desirability Scale	---
TPS	Tuckman Procrastination Scale	---
UPPS-P	UPPS-P Impulsive Behavior Scale	---

31 Behavioral Surveys

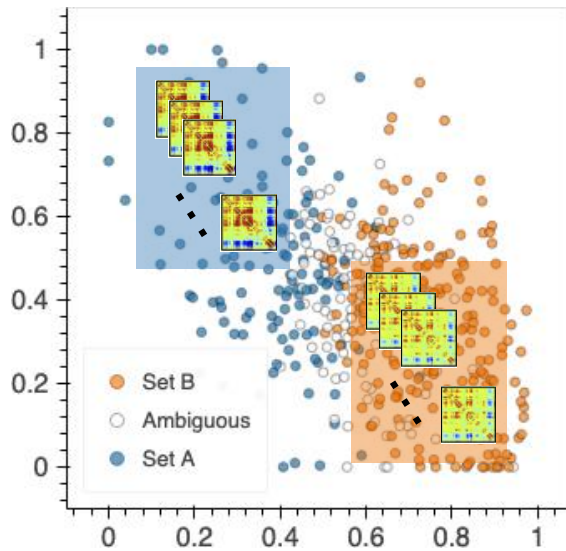
- Personality / Habitation Behaviors (21)
- Mind Wandering / Mindfulness (4)
- Synesthesia (1)
- Cognitive Controls / Sustained Att. (1)
- Creativity (4)

51 Behavioral Metrics

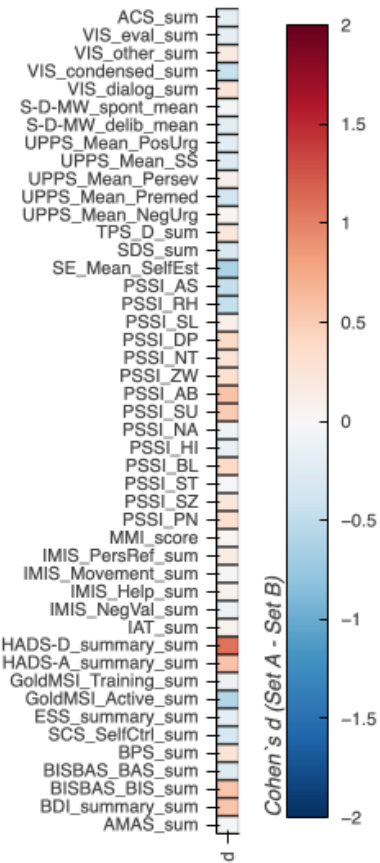
- Available in at least 70%

CATEGORY	SURVEY	# METRICS	SURVEY NAME
PERSONALITY / HABITUATION BEHAVIORS	AMAS	1	Abbreviated Math Anxiety Scale
	BDI	1	Beck Depression Inventory II
	BISBAS	2	Behavioral Inhibition and Approach System
	BPS	1	Boredom Proneness Scale
	SCS	1	Brief Self-Control Scale
	ESS	1	Epworth Sleepiness Scale
	GoldMSI	2	Goldsmiths Musical Sophistication Index
	HADS	2	Hospital Anxiety and Depression Scale
	IAT	1	Internet Addition Test
	IMIS	4	Involuntary Musical Imagery Scale
	MPU	19	Mobile Phone Usage
	MNI	1	Multimedia Multitasking Index
	NEO	5	NEO Personality Inventory (Revised)
	PSSI	14	Personality Style and Disorder Inventory
	SE	1	Self-Esteem Scale
	SDS	1	Social Desirability Scale
	TPS	1	Tuckman Procrastination Scale
	UPPS	5	Impulsive Behavior Scale
	MINDFULNESS	SDMW	5
VISQ		4	Varieties of Inner Speech Questionnaire
COGNITIVE CONTROL	ACS	1	Attention Control Scale

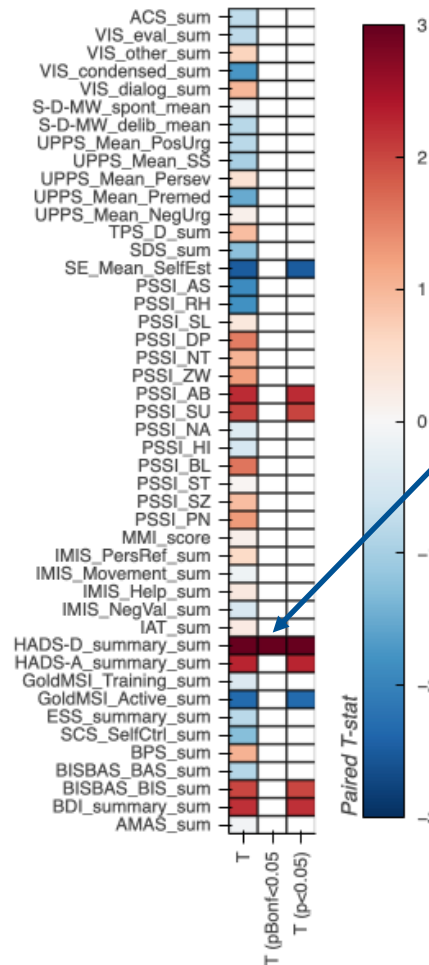
Influence of trait-level phenotypes in group differences



Cohen's d (A - B)

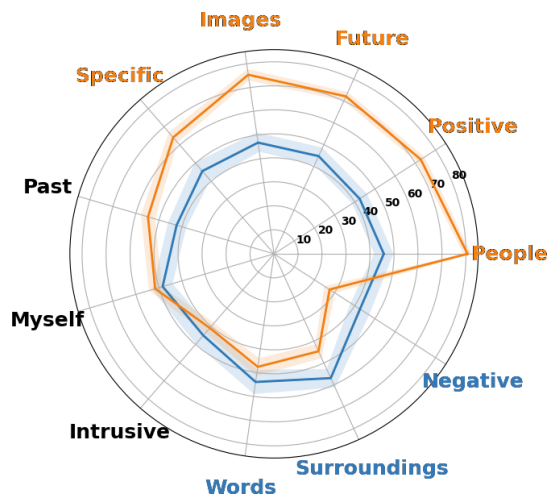


T-test

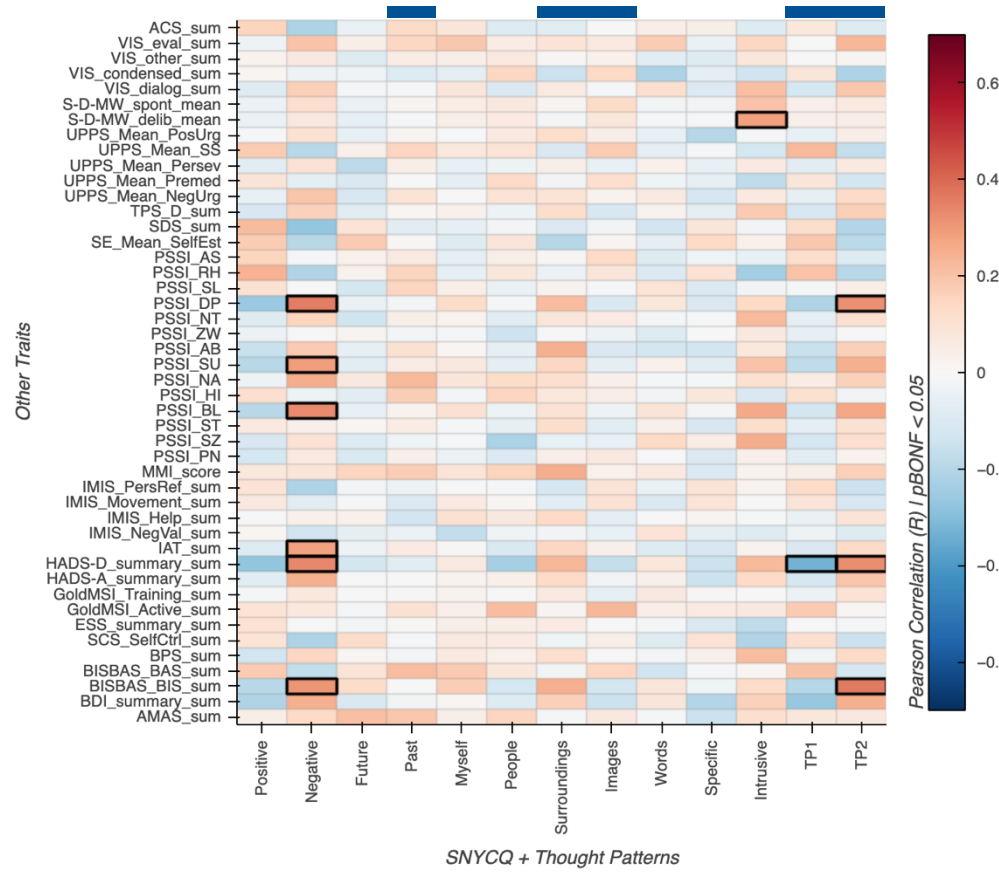
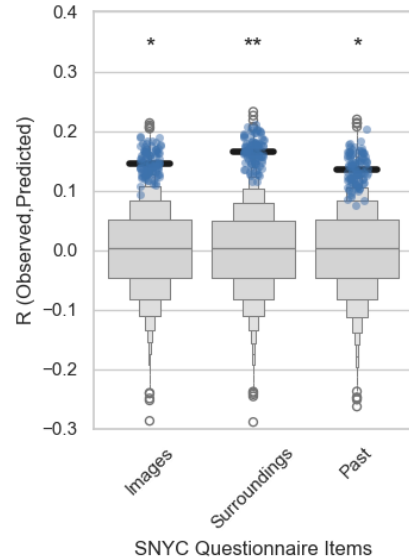
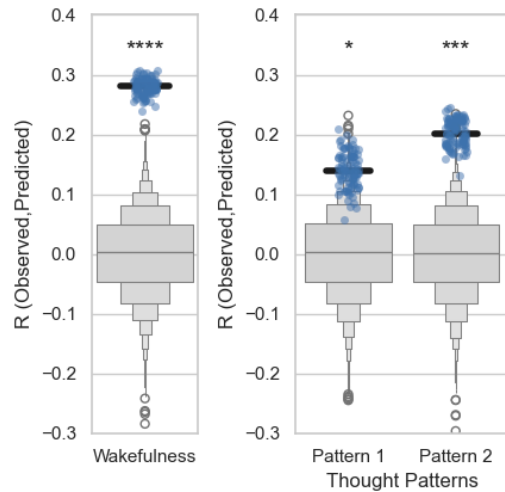


Hospital Anxiety and Depression Scale (HADS)

"measures the severity of depression (D) and anxiety (A) related symptoms for the week prior to completion and can be used to assess subclinical tendencies of depression and anxiety."



Influence of trait-level phenotypes in predictive modeling



PSSI: Personality Style and Disorder Inventory

IAT: Internet Addiction Test

BIS: Behavioral Inhibition System

SD-MW Delib: Deliberate Spontaneous Mind Wandering

Conclusions

In-scanner subjective experience meaningfully shapes resting-state functional connectivity

- **Systematic differences in experience produced widespread FC differences**, even when healthy groups were similar in motion, wakefulness, age, and gender.
- **FC could significantly predict several experiential measures** beyond wakefulness, including both latent thought-pattern dimensions, and specific items such as images and surroundings.
- **Observations could not be explained by correlations to other trait-level phenotypes.**

Practical implication: rs-fMRI studies should collect, at least, brief post-scan experiential reports

- Characterizing the in-scanner experience may explain some currently unexplained variance in rs-fMRI and improve biomarker interpretation.
- Adds minimal cost relative to that of an *rs-fMRI* scan.
- Enhances the research value of rs-fMRI scans by enabling investigations of other aspects of spontaneous thought.

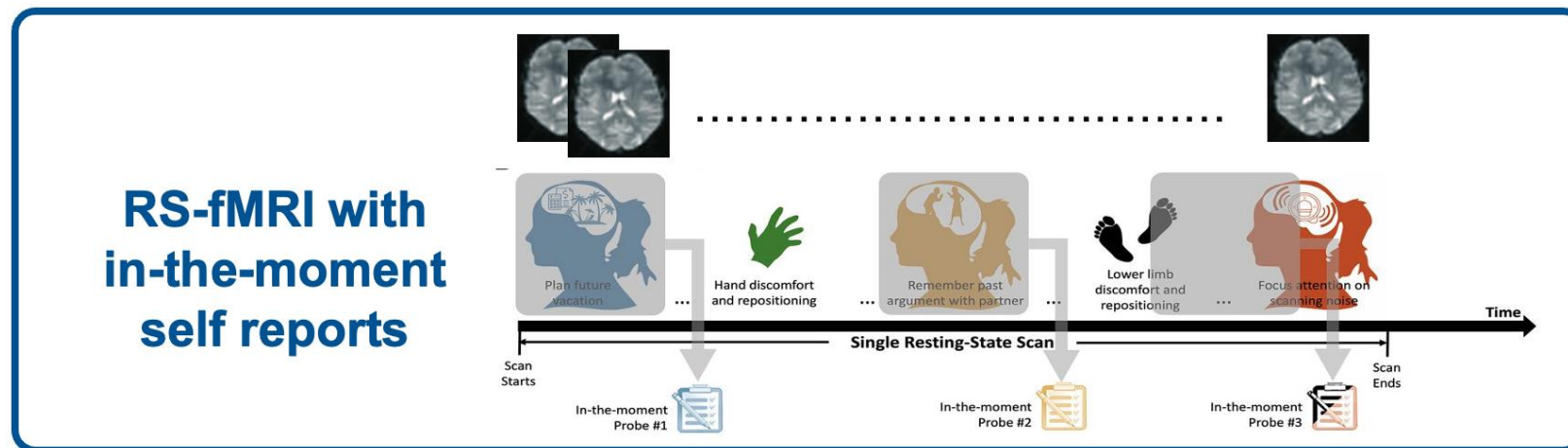
Future work / Open Questions

Brain – Mind relationships as a function of spatiotemporal scales

Activity vs. Connectivity

Dynamic vs. Static

In the moment vs. Retrospective



Future work / Open Questions

Brain – Mind relationships as a function of spatiotemporal scales

Activity vs. Connectivity

Dynamic vs. Static

In the moment vs. Retrospective

Reliability, Precision, etc. of 1st Person Data

MDES vs. Open Ended
Training

What aspects
matter most

Covert Measures

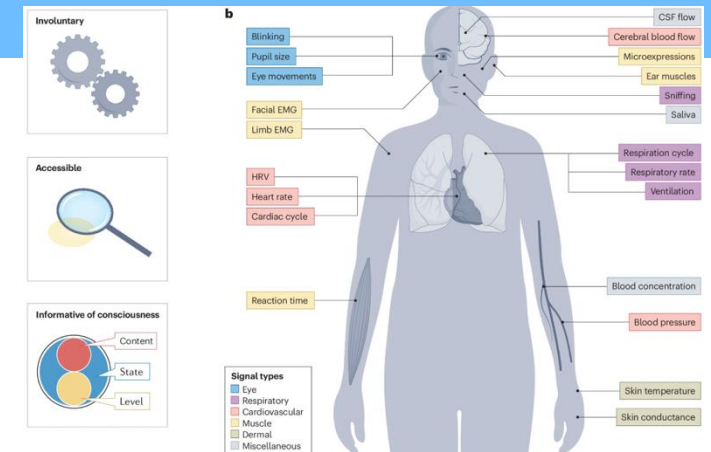


Resting-State Q	Amsterdam Resting-State Q	NYC-Q
62 Items	50 Items	31 Items
5 Mental Activities + Content	Thoughts + Feelings	Content and Form of Thoughts

Delamillieure et al. (2009)
Brain Research Bulletin

Diaz et al. (2013) Frontiers
in Human Neuroscience

Gorgolewski et al. PLoS ONE
(2014)



Kronemer, Bandettini & Gonzalez-Castillo, 2025 Nat Rev Neuroscience

Future work / Open Questions

Brain – Mind relationships as a function of spatiotemporal scales

Activity vs. Connectivity

Dynamic vs. Static

In the moment vs. Retrospective

Reliability, Precision, etc. of Introspective Data

MDES vs. Open Ended

What aspects
matter most

Covert Measures

Training

Reciprocal Causation Problem



Thank you...

NIMH

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