

Inner-Experience during rest: implications for fMRI research

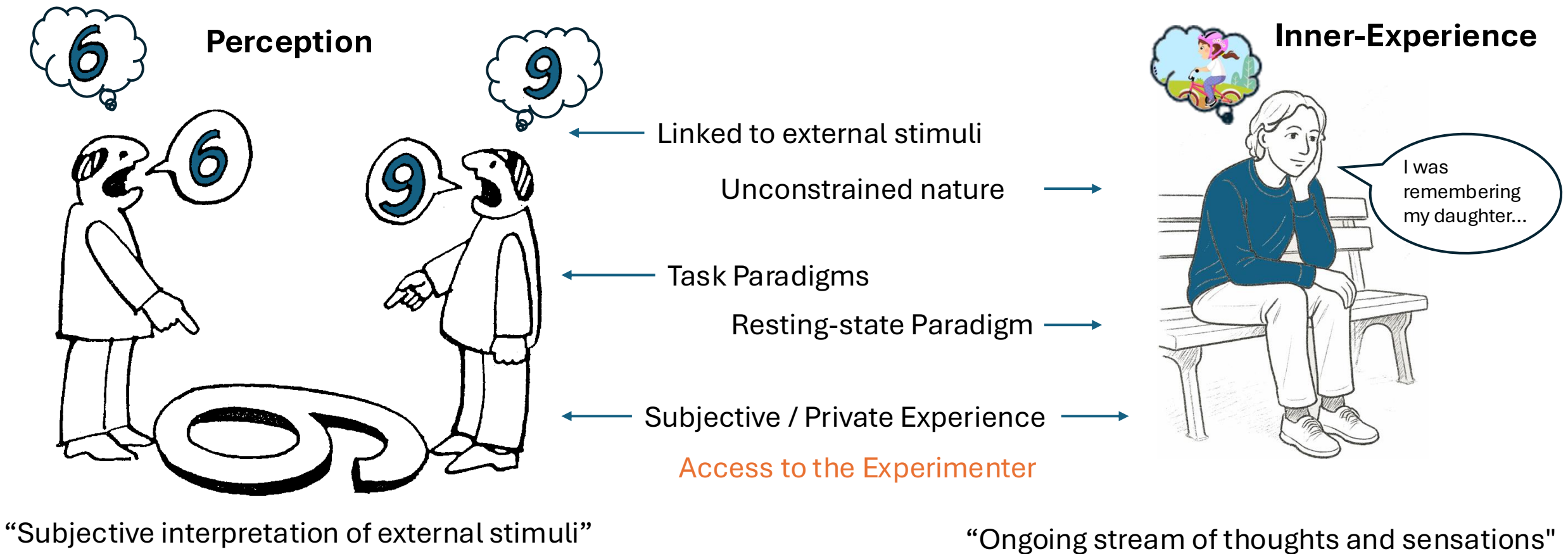
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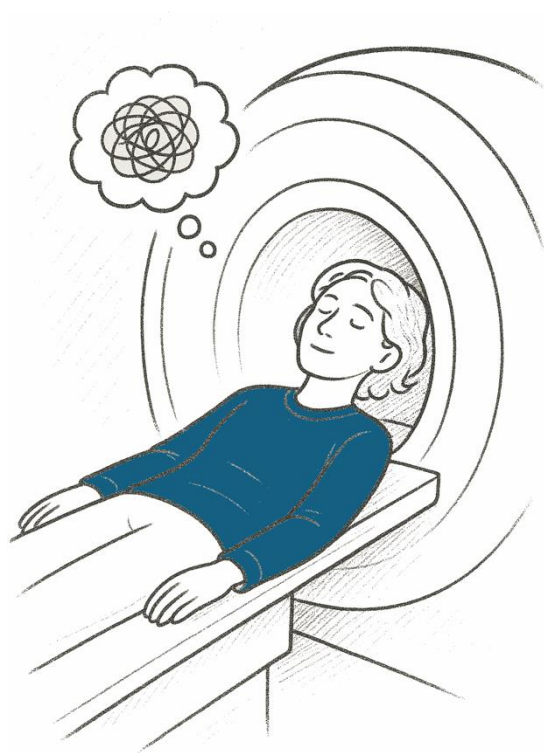
Agenda

Title: Perception in the Primate Brain

Workshop Description: This workshop explores research on perception in both the healthy and impaired primate brain. Presentations will focus on the neural mechanisms that underlie how primates perceive and interpret the world around them. By examining both normal perceptual function and disruptions caused by injury or disease, the workshop aims to deepen our understanding for the biological sources of perception. Insights gained from this research may inform future strategies for diagnosing, managing, and treating perceptual disorders in humans.



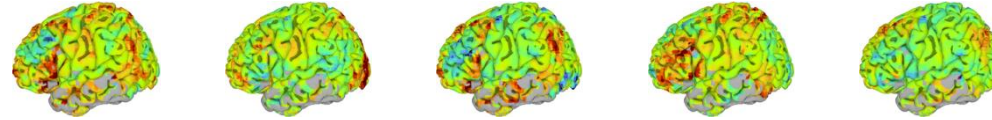
Resting-state fMRI



Lay still and let your mind wander freely

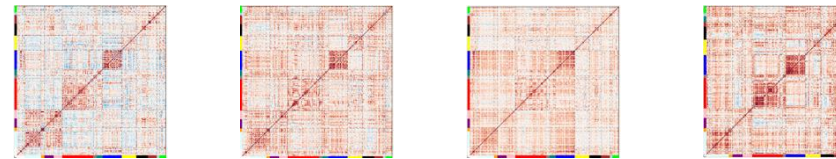
fMRI Recordings

Instantaneous
Brain Activity



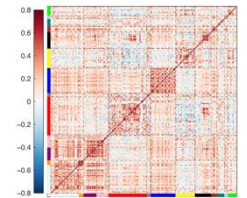
Time [~10 mins]

Functional
Connectivity



Time-varying FC

Static FC



To what degree?

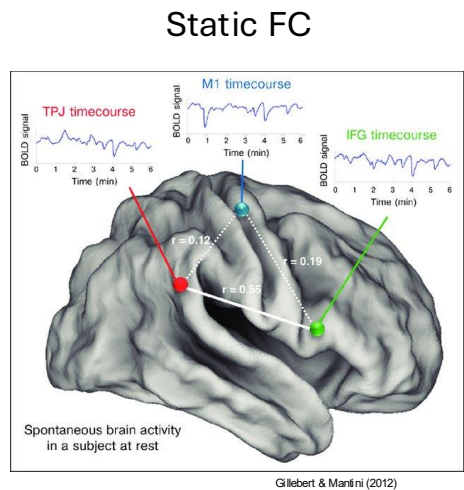
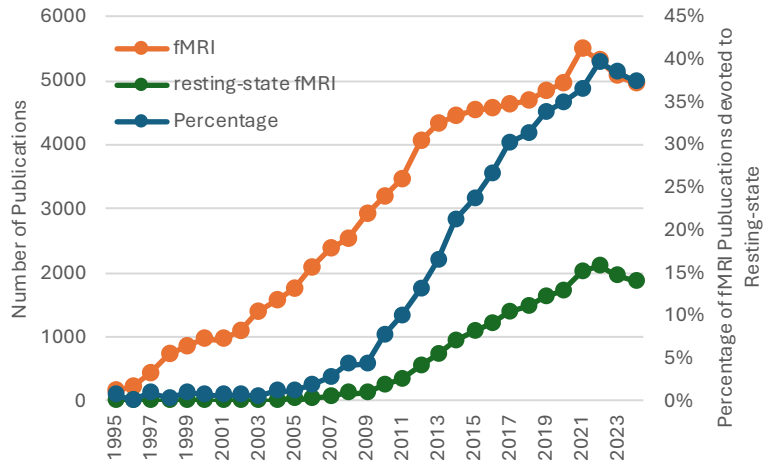
At what spatiotemporal scale?

What aspects of the inner experience?

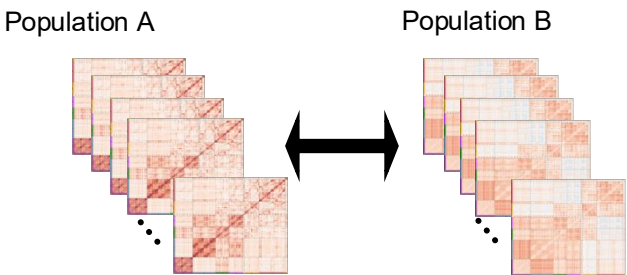
Inner Experience



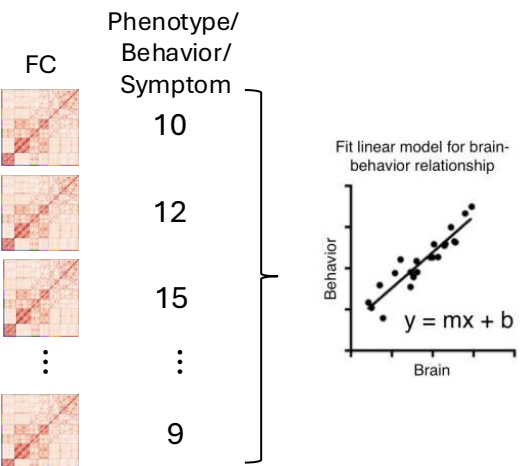
Resting-state fMRI (II)



Application 1: Uncover FC differences across (clinical) populations



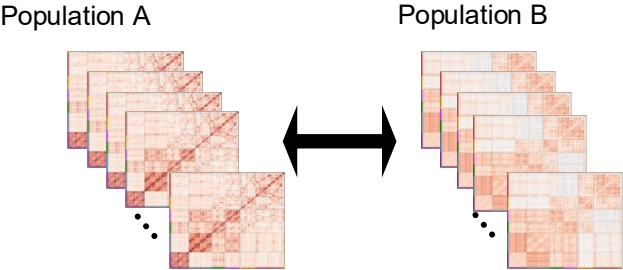
Application 2: Brain-wide Associations



Healthy, Young Adult Datasets											
Dataset	Website	Number of Participants	Age Range	Multisite	Longitudinal	T1w	T2w	rs-fMRI	Task fMRI	Diffusion MRI	Field Strength
HCP Young Adult	https://www.humanconnectome.org/study/hcp-young-adult	1,200	22-35	Yes	No	X	X	X	X	X	3T, 7T
Amsterdam Open MRI Collection	https://atlab.uva.nl/AMIC/	928	19-26	No	No	X	No	X	X	X	3T
Brain Genomics Superstruct Project	https://dataverse.harvard.edu/dataset/GSP	1,570	18-36	No	No	X	No	X	No	No	3T
Southwest University Longitudinal Imaging Multimodal	http://fcon.1000.projects.nimh.nih.gov/retro/southwest_lqi_index.html	995	17-27	No	Yes	X	No	X	No	No	3T
Lifespan Datasets											
Dataset	Website	Number of Participants	Age Range	Multisite	Longitudinal	T1w	T2w	rs-fMRI	Task fMRI	Diffusion MRI	Field Strength
UK Biobank	https://www.ukbiobank.ac.uk	40,000+	40-69	Yes	Yes	X	X	X	X	X	3T
ABCD Study	https://abcdstudy.org	11,878	9-10	Yes	Yes	X	X	X	X	X	3T
HCP Aging	https://www.humanconnectome.org/study/hcp-lifespan-aging	1,200	36-100	Yes	Yes	X	X	X	X	X	3T
HCP in Development	https://www.humanconnectome.org/study/hcp-lifespan-development	1,350	5-21	Yes	Yes	X	X	X	X	X	3T
Baby Connectome Project	https://www.humanconnectome.org/study/baby-connectome-project	500	0-5	Yes	Yes	X	X	X	X	X	3T
Developing HCP	https://www.humanconnectome.org/study/lifespan-developing-human-connectome-project	1,500	20-44 weeks	Yes	Yes	X	X	X	No	X	3T
CamCAN	https://www.cam.ac.uk/can	~650	18-87	No	No	X	X	X	X	X	3T
OASIS-3	https://www.oasis-brains.org	1,098	42-95	No	Yes	X	X	X	No	X	1.5T, 3T
Dense Sampling and Datasets Featuring Many Tasks and Experimental Measures											
Dataset	Website	Number of Participants	Age Range	Multisite	Scan Sessions	T1w	T2w	rs-fMRI	Task fMRI	Diffusion MRI	Field Strength
MyConnectome	http://myconnectome.org	1	45	No	104 sessions	X	X	X	X	X	3T
Midnight Scan Club	https://openneuro.org/datasets/d00024/versions/1.0.3	10	24-34	No	12 sessions/pp	X	X	X	X	No	3T
StudyForest	https://www.studyforest.org	36	21-38	Yes	varies	X	X	X	X	X	3T, 7T
Natural Scenes Dataset	https://natural-scenes-dataset.org	8	19-32	No	36-40 sessions/pp	X	X	X	X	X	3T, 7T
BOLD5000	https://bald5000.github.io/	4	24-27	No	10-16 sessions/pp	X	X	No	X	X	3T
"Narrative" Collection	https://openneuro.org/datasets/d002343/versions/1.1.4	345	18-53	No	2-3 sessions/pp	X	X	No	X	No	3T
Individual Brain Charting	https://project.loria.fr/IBC/	12	26-40	No	5 sessions/pp	X	X	No	X	X	3T
Courtesy NeuroMod	https://www.neuromod.ca	6	unknown	No	weekly for 5 years	X	X	X	X	X	3T

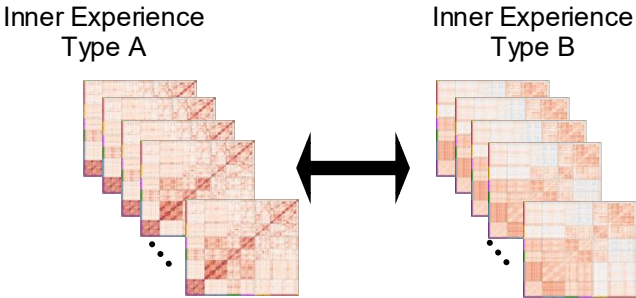
Does inner-experience play a role in observations made with resting-state fMRI?

Application 1: Uncover FC differences across (clinical) populations

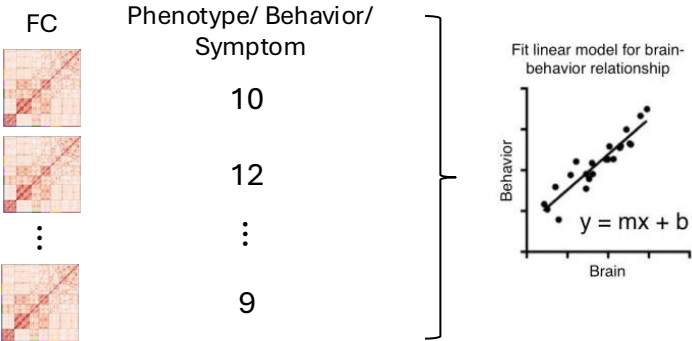


Q1 | Can we detect differences in FC if we group scans according to inner-experience?

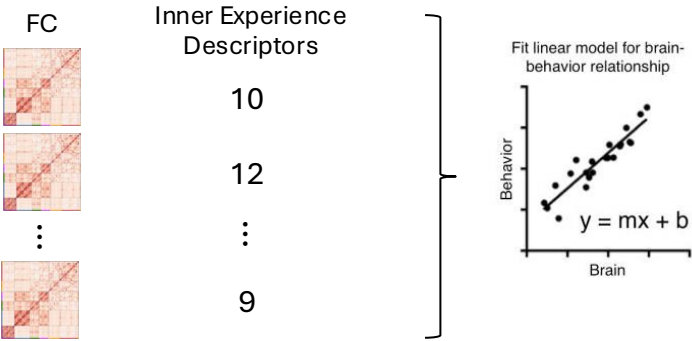
Single Healthy Population



Application 2: Brain-wide Associations



Q2 | Can we predict characteristics of inner-experience based on FC measures?



Dataset: Mind, brain, body – Max Planck Institute



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



Demographics Data

Age Range (5 year intervals) & Gender



Experience Reports

FORM

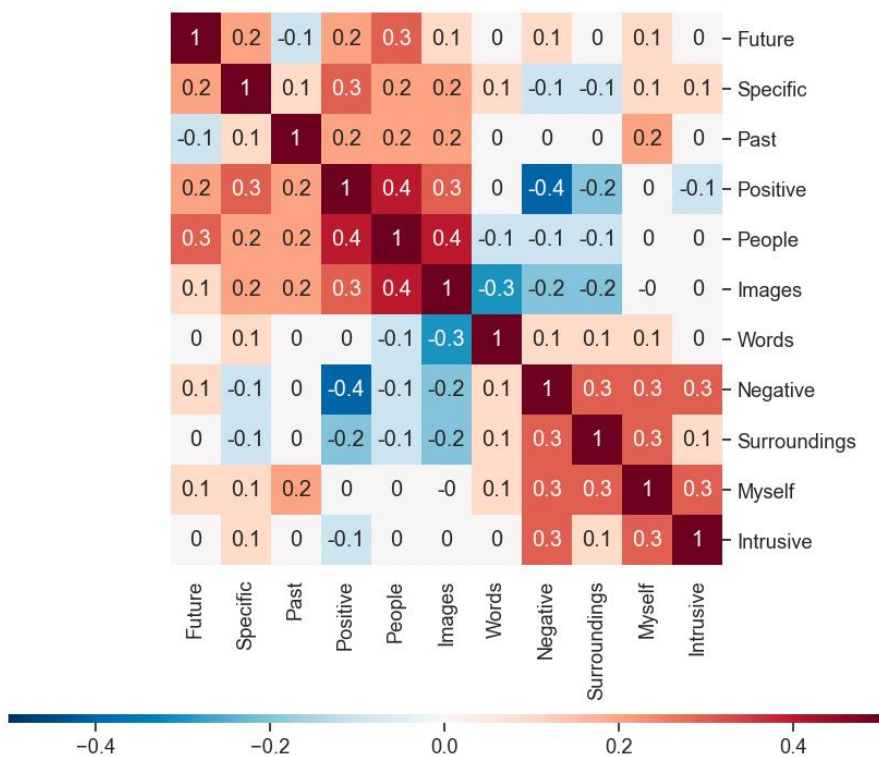
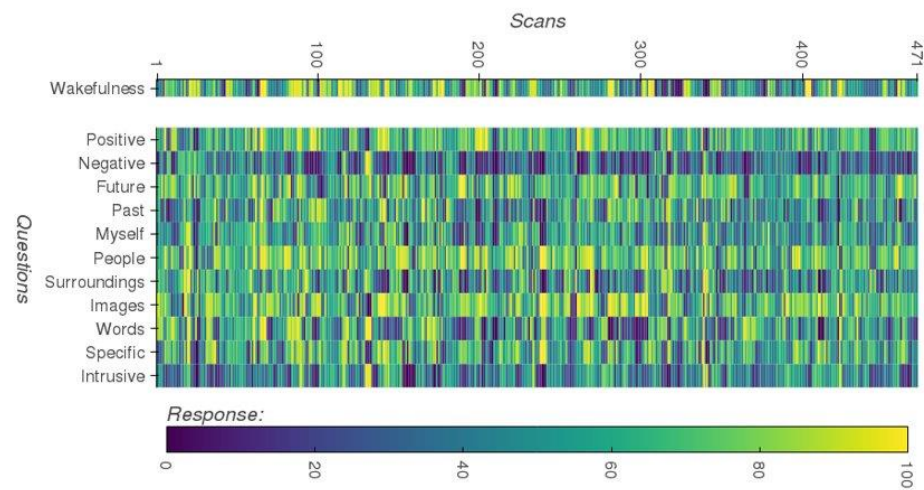
F1	My thoughts were intrusive	0 ... 100
F2	My thoughts were more specific than vague	0 ... 100
F3	My thoughts were in the form of words	0 ... 100
F4	My thoughts were in the form of images	0 ... 100

CONTENT

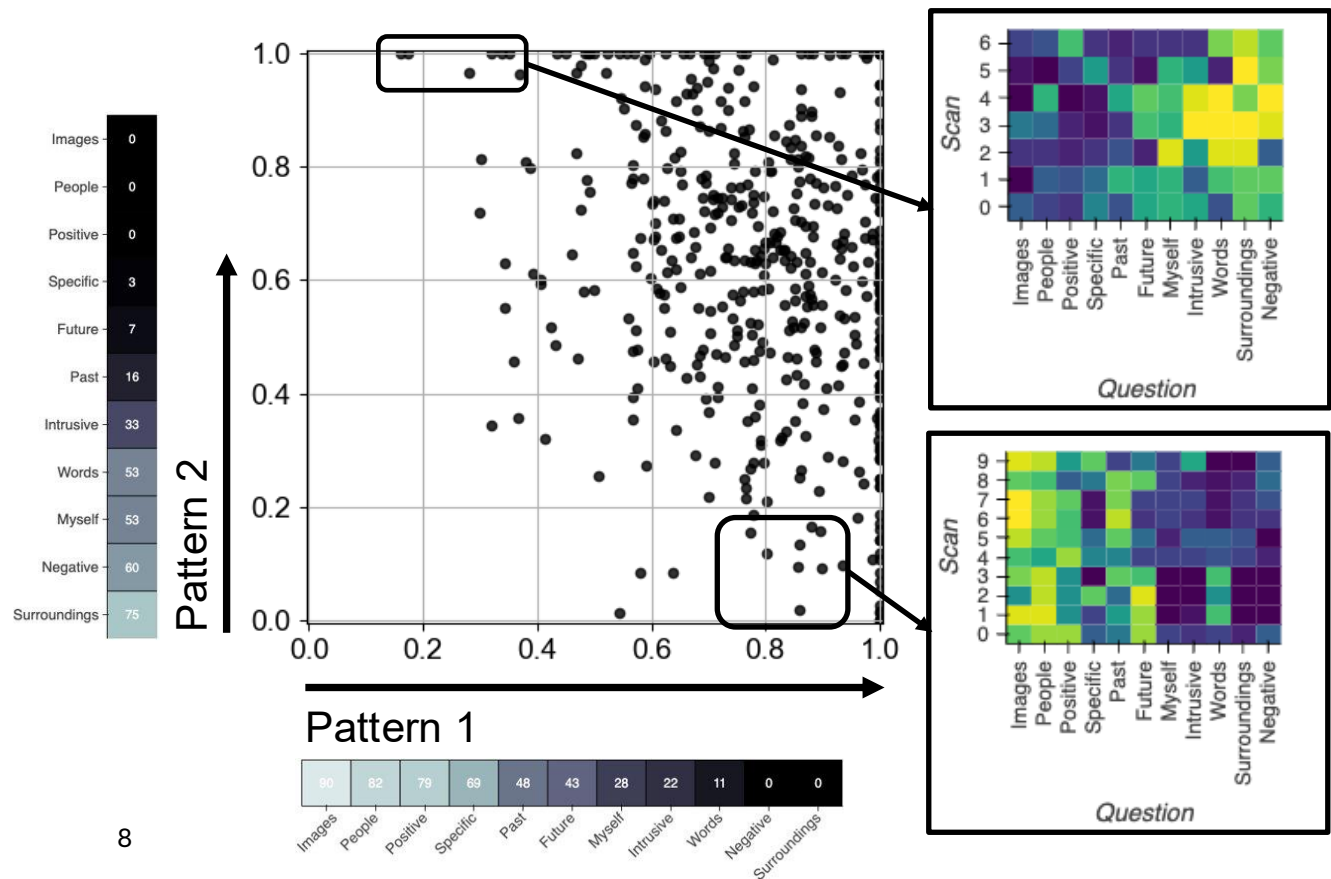
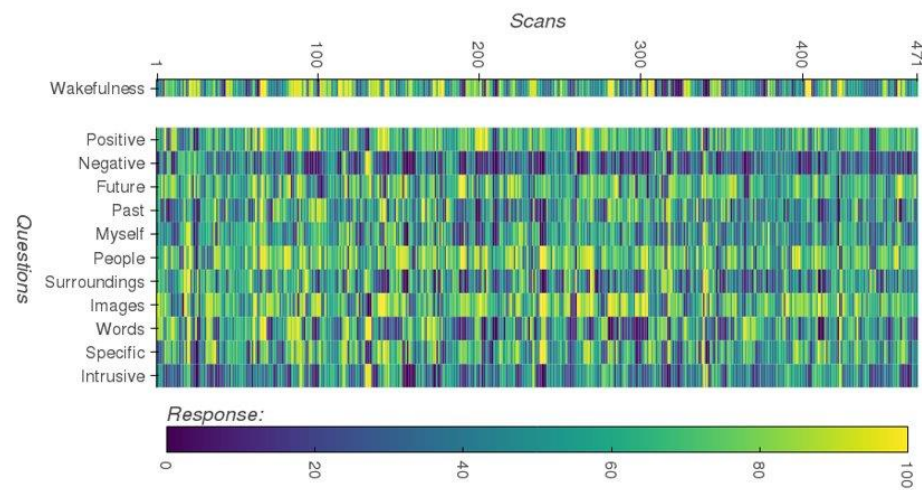
C1	I thought about my environment / surrounding	0 ... 100
C2	I thought about other people	0 ... 100
C3	I thought about myself	0 ... 100
C4	I thought about past events	0 ... 100
C5	I thought about future events	0 ... 100
C6	I thought about something negative	0 ... 100
C7	I thought about something positive	0 ... 100

W1 | I was completely awake 0 ... 100

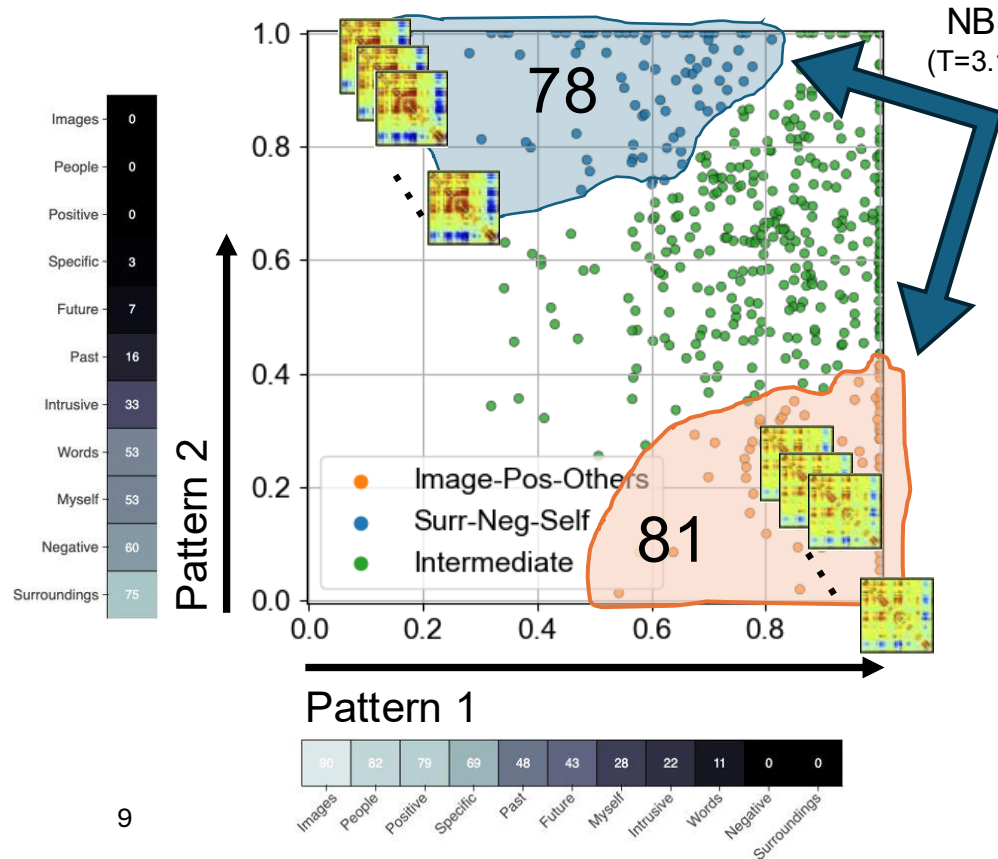
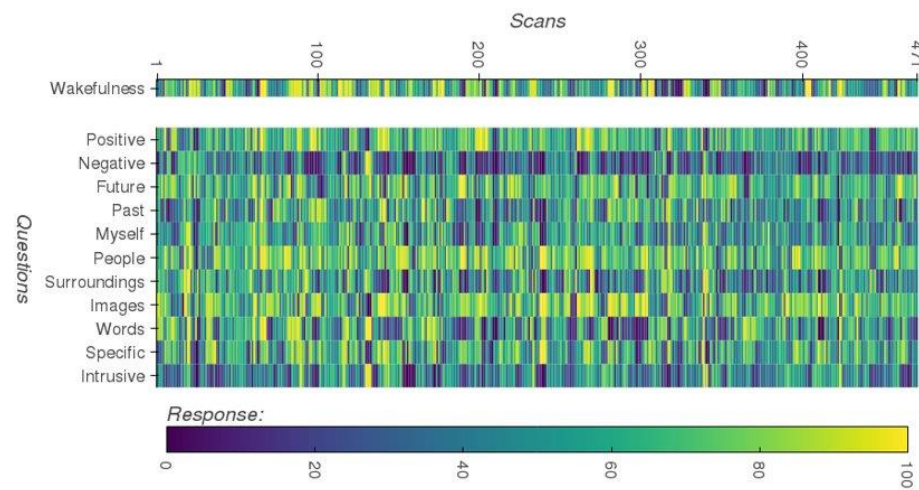
Inner-Experience Questionnaire Results



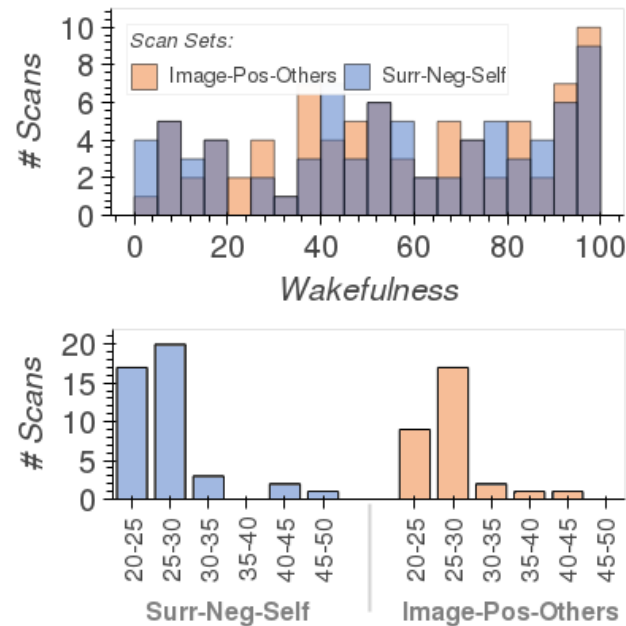
Inner-Experience Questionnaire Results



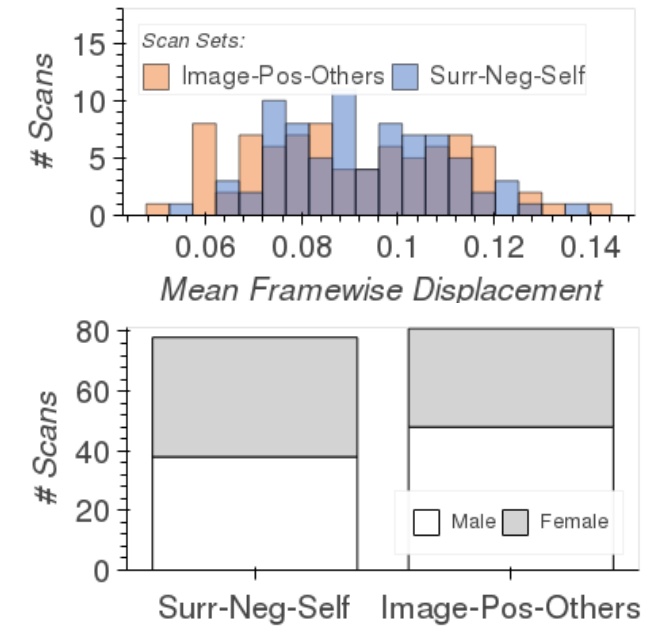
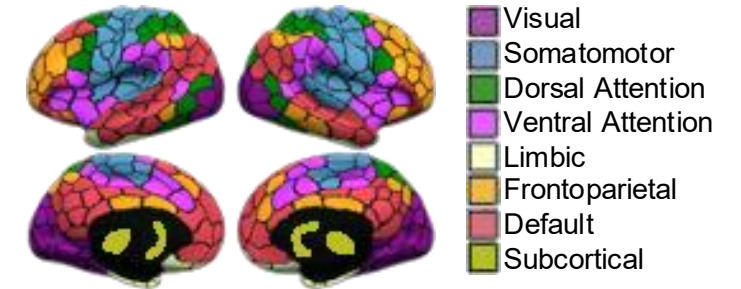
Q1 | Can we detect differences in FC if we group scans according to inner-experience?



NBS | 5000 Permutations | Edge-Level Threshold ($T=3.1$; $p < 0.001$) | Network-Level Threshold ($p < 0.05$)

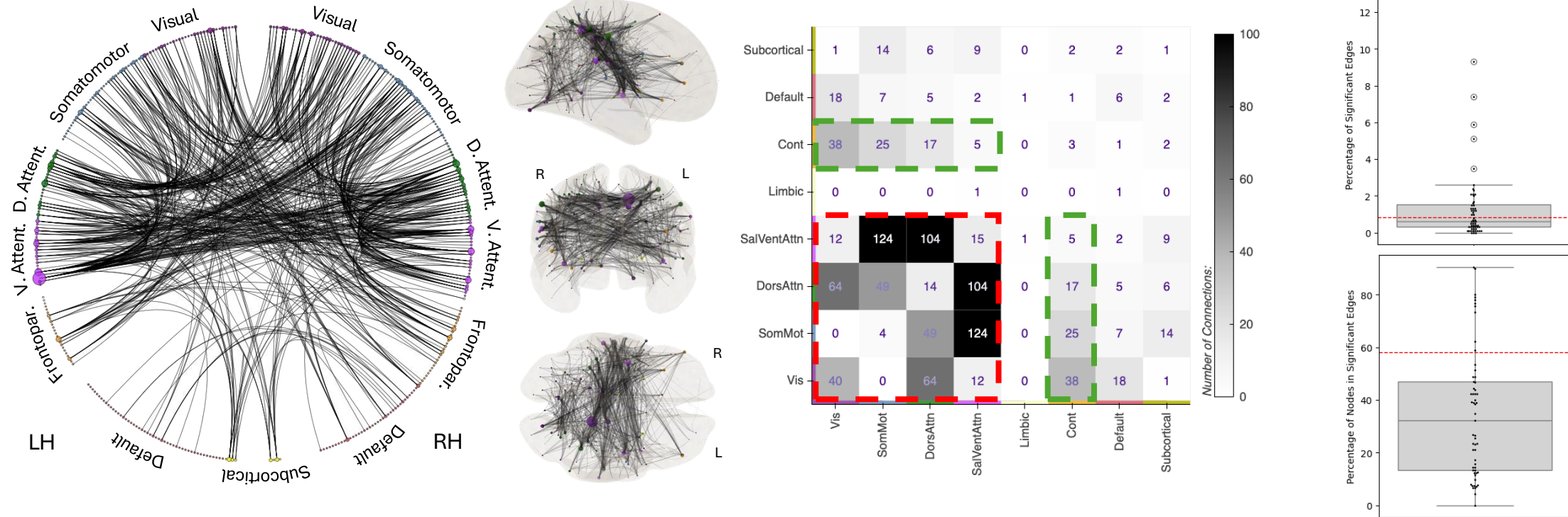


400 Schaefer Atlas + AAL Subcortical



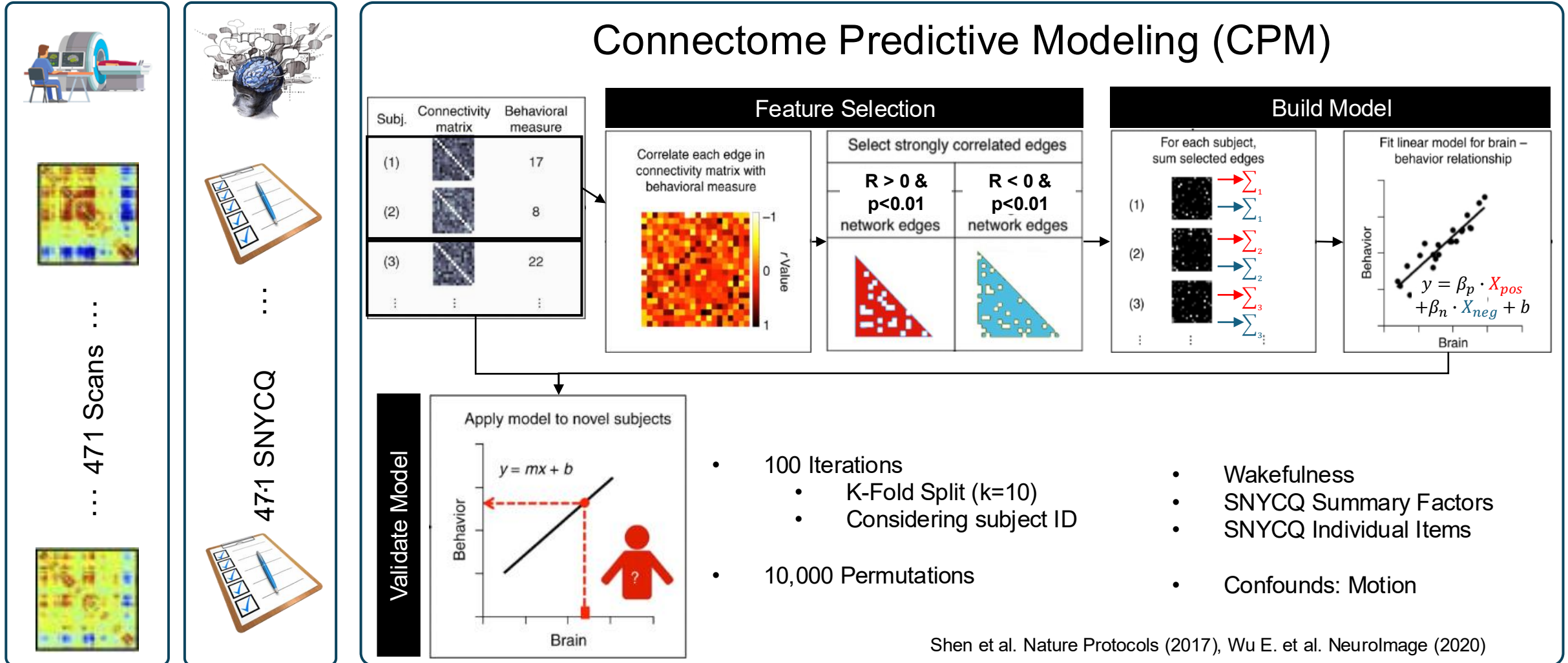
Q1 | Can we detect differences in FC if we group scans according to inner-experience?

Surr, Neg, Self > Images, Positive, Others

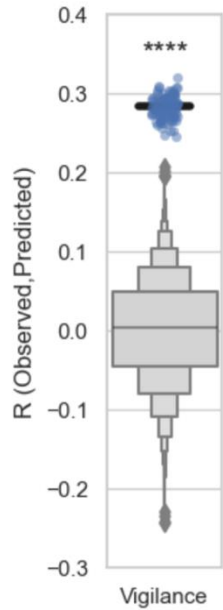


- 590 edges (0.82%) involving 221 nodes (58%) are significantly stronger for *"Surr, Neg, Self"* compared to *"Image, Pos, Others"*.
- The larger proportion of significant edges involve nodes of the Dorsal and Ventral Attention Nws and Primary Unimodal Nws.
- A second cluster of significant edges involves the Fronto-Parietal Control Nw, Primary Unimodal Nws and Attention Nws.

Q2 | Can we predict characteristics of inner-experience based on FC measures?

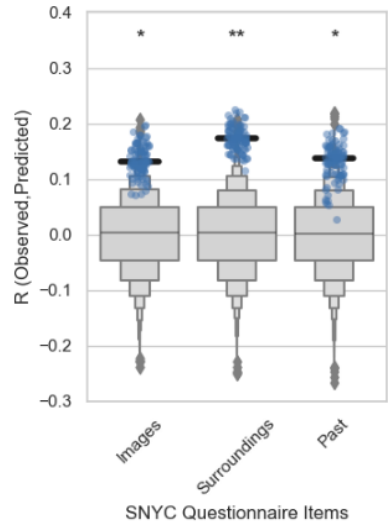
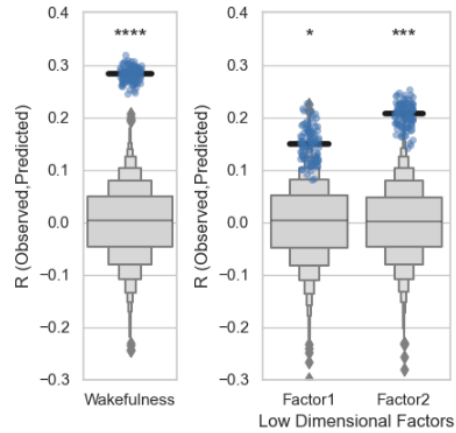


Q2 | Can we predict characteristics of inner-experience based on FC measures?



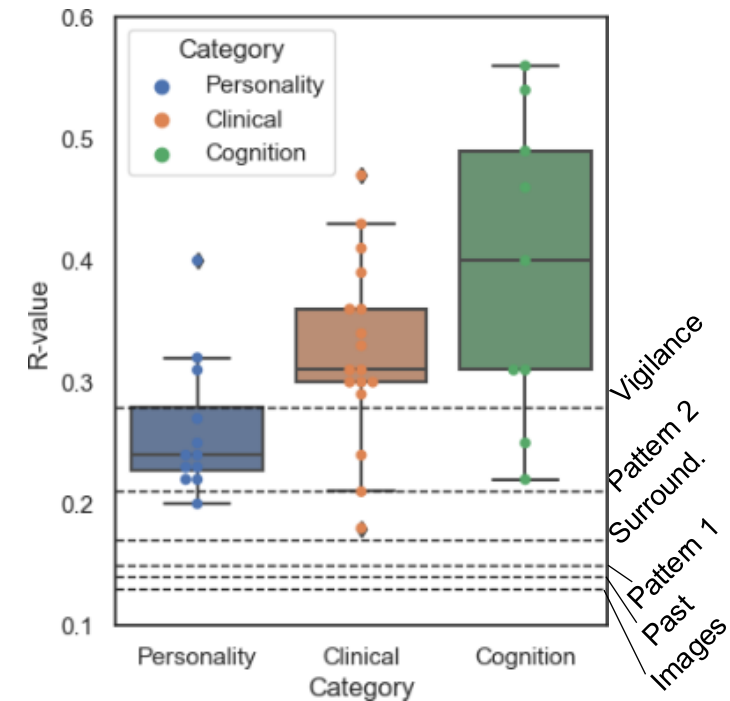
* $p < 0.05$ | ** $p < 0.01$ | *** $p < 1e^{-3}$ | **** $p < 1e^{-4}$

Q2 | Can we predict characteristics of inner-experience based on FC measures?



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

	Title of Paper	Year	# Subjects	Trait of Prediction	Category	Atlas	R-value
0	Resting-state functional connectivity predicts...	2018	114	Neuroticism	Personality	Shen 268-node	0.22
1	Resting-state functional connectivity predicts...	2018	114	Extraversion	Personality	Shen 268-node	0.22
2	Individualized Prediction of PTSD Symptom Seve...	2020	122	PTSD symptoms (CAPS-IV)	Clinical	Shen 268-node	0.30
3	Resting-State Functional Connectome Predicts I...	2022	604	Depression (SDS)	Clinical	Human Brainnetome Atlas	0.18
4	Connectome-Based Predictive Modeling of Indivi...	2021	76	Anxiety (BAI)	Clinical	Shen 268-node	0.33
5	Connectome-Based Predictive Modeling of compul...	2023	183	Compulsion (YBOCS)	Clinical	GRETNA	0.30
6	Multi-modality connectome-based predictive mod...	2022	66	Compulsion (YBOCS)	Clinical	Shen 268-node	0.36
7	Neural correlates of schizotypal traits: Findi...	2023	82	Schizotypal traits (SPQ)	Clinical	Shen 268-node	0.29
8	Brain functional connectome-based prediction o...	2020	809	Decision impulsivity	Personality	Used group-level ICA	0.25
9	Connectome-based model predicts individual psy...	2022	84	Psychopathic traits (LSRP)	Clinical	Dosenach atlas	0.30
10	Resting-State Functional Connectivity Predicts...	2018	59	Overall cognitive functioning (ADAS11)	Cognition	Shen 268-node	0.49
11	Predicting full-scale and verbal intelligence ...	2020	425	Full-scale intelligence quotient	Cognition	AAL	0.25
12	Transdiagnostic connectome signatures from res...	2022	1721	Full-scale intelligence quotient	Cognition	Schaefer 100 ROIs	0.56
13	Connectome-based models can predict early symp...	2020	108	Depression severity (HAMD)	Clinical	Shen 268-node	0.41
14	Connectome-based model predicts episodic memor...	2021	83	Auditory/verbal test-delayed recall	Cognition	AAL	0.22
15	Robust prediction of individual personality fr...	2020	810	Agreeableness	Personality	Used group-level ICA	0.23
16	Robust prediction of individual personality fr...	2020	810	Openness	Personality	Used group-level ICA	0.23
17	Robust prediction of individual personality fr...	2020	810	Conscientiousness	Personality	Used group-level ICA	0.24
18	Robust prediction of individual personality fr...	2020	810	Neuroticism	Personality	Used group-level ICA	0.20
19	Connectome-based models predict separate compo...	2018	44	Attention	Cognition	Shen 268-node	0.31
20	Connectome-based predictive modeling of trait ...	2023	100	Trait forgiveness	Personality	Shen 268-node	0.31
21	Individualized prediction of consummatory anhe...	2022	54	Anhedonia	Clinical	Shen 268-node	0.31
22	Neural mechanisms underlying empathy during al...	2022	59	Empathy	Personality	Dosenach atlas	0.40
23	Prediction of childhood maltreatment and subty...	2022	215	Childhood maltreatment	Clinical	Used NMF	0.39
24	Predicting children's math skills from task-ba...	2022	31	Math skills	Cognition	Human Brainnetome Atlas	0.54
25	Connectome-based predictive modeling predicts ...	2023	18	Paranoia	Clinical	Human Brainnetome Atlas	0.34
26	The functional and structural connectomes asso...	2021	91	Depression	Clinical	Human Brainnetome Atlas	0.36
27	The functional and structural connectomes asso...	2021	91	Anxiety	Clinical	Human Brainnetome Atlas	0.31
28	The functional connectome predicts feeling of ...	2021	673	Perceived stress	Clinical	Human Brainnetome Atlas	0.47
29	Connectome-Based Predictive Modeling of Creati...	2021	101	Creative Anxiety	Clinical	GRETNA	0.21
30	Connectome-based prediction of global cognitiv...	2021	140	Cognition	Cognition	CONN toolbox	0.46
31	Connectome-based models can predict processing...	2020	99	Processing speed	Cognition	Shen 268-node	0.40
32	Do intrinsic functional brain networks predict...	2020	468	Working memory	Cognition	Shen 268-node	0.31
33	The Functional Brain Organization of an Indivi...	2019	352	Social responsiveness	Personality	Shen 268-node	0.32
34	The Functional Brain Organization of an Indivi...	2019	79	Autism diagnosis	Clinical	Shen 268-node	0.43
35	Connectome-based model predicts individual dif...	2019	168	Trust propensity	Personality	Shen 268-node	0.27
36	Connectome-based individualized prediction of ...	2019	75	Loneliness	Clinical	Shen 268-node	0.24
37	Individualized prediction of trait narcissism ...	2018	168	Narcissism	Personality	Shen 268-node	0.24



Conclusions



Q1 | Can we detect differences in FC if we group scans according to inner-experience? ✓

Q2 | Can we predict characteristics of inner-experience based on FC measures? ✓

- Inner-experience may constitute an explanatory factor for FC in rs-fMRI.
- Across-group differences in inner experience may introduce “unmodeled” variance in rs-fMRI.
- Introspective annotations of *rs-fMRI* is needed to understand and model those effects
 - Small cost compared to that of an *rs-fMRI* scan
 - Increases the research value of *rs-fMRI* scans → study other aspects of spontaneous thought / inner experience
- What / How to gather introspective data with *rs-fMRI* remains an open challenge:
 - Lack of Standardization: What dimensions to sample? How? When? How often?
 - Robust against reliability/validity “issues” associated with first-person/introspective data.



Thank you!



Section on Functional Imaging Methods



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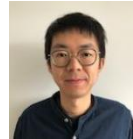
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Machine Learning Team



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Julia Kam



Scientific & Statistical Computing Core

Paul Taylor
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Rick Reynolds



Colin Hoy



BASQUE CENTER
ON COGNITION, BRAIN
AND LANGUAGE

Cesar Caballero-Gaudes



Questions