HIGHLY COMPARATIVE ANALYSIS OF INTER-AREAL COUPLING FROM MEG DATA TO QUANTIFY NEURAL CORRELATES OF VISUAL EXPERIENCE

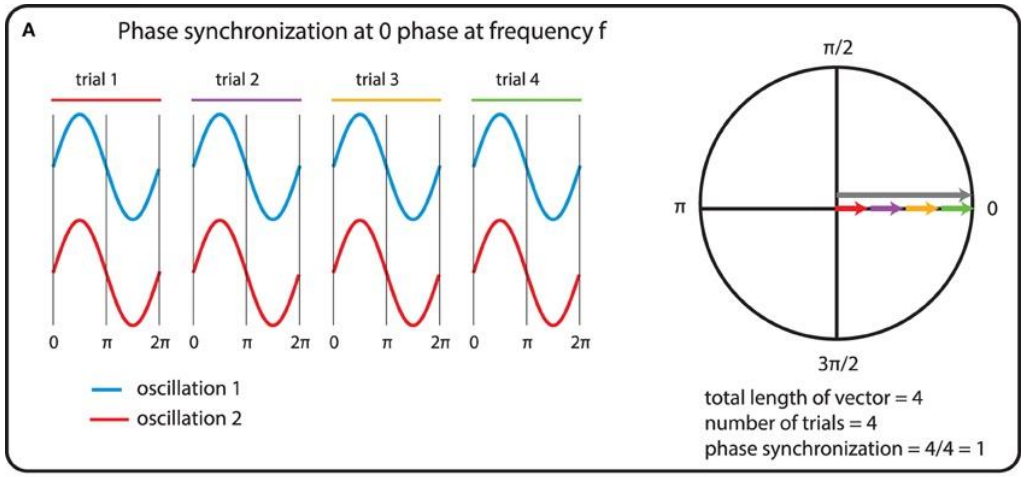
ANNIE G. BRYANT & CHRISTOPHER J. WHYTE

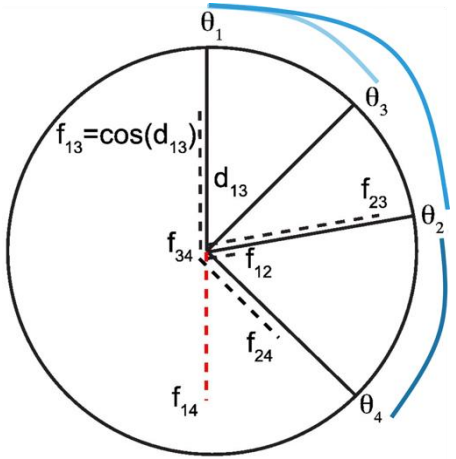
COGITATE

THE UNIVERSITY OF SYDNEY

Motivation

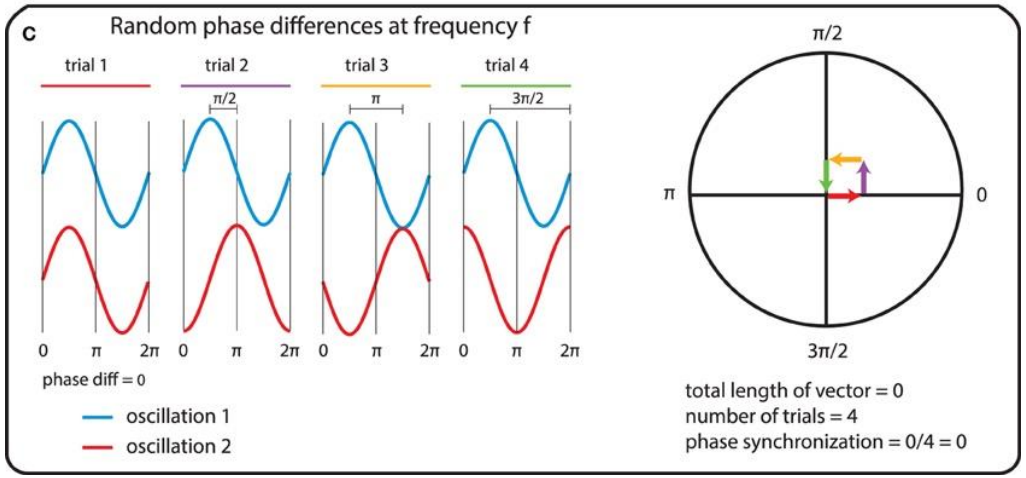
Original functional connectivity metric: **Pairwise phase consistency (PPC)**

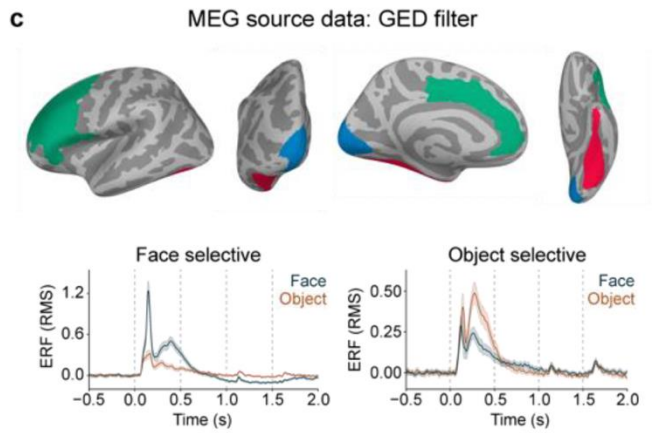


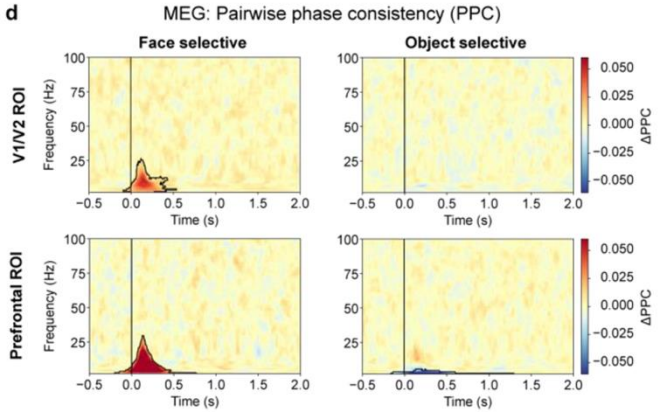


→ Average dot product across all pairs

Source: Vinck et al. *NeuroImage* 2010

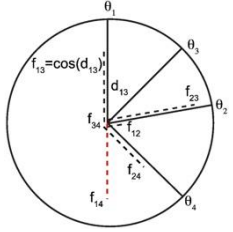






Source: Bastos & Schoffelen *Front Sys Neurosci* 2016

Motivation



M1: mean phase lag/slope indices and group delay

M2: causal models

M3: directed information and causal entropy measures

M4: transfer entropy

M5: parametric granger causality and integrated information

M6: parametric granger causality and directed spectral measures

M7: max phase lag indices

M8: phase slope indices (wavelet)

M9: mean of barycenters

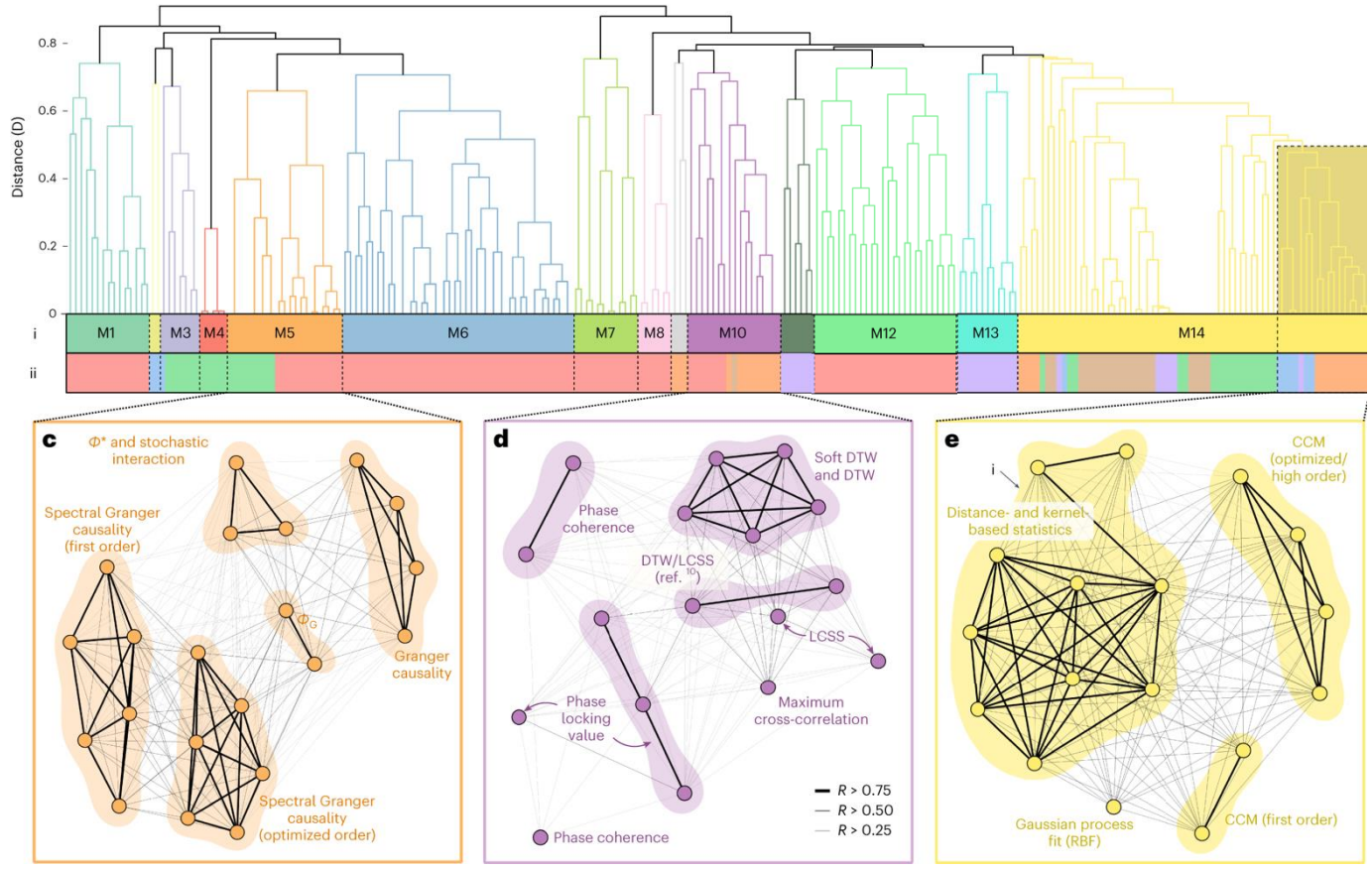
M10: dynamic time warping, phase coherence and locking values

M11: Power envelope correlation

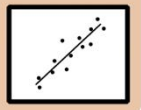
M12: undirected spectral measures

M13: co-integration

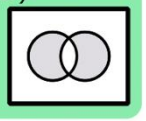
M14: a mix of contemporaneous linear-dependence statistics, information-theoretic measures, convergent cross-mapping, maximum barycenters, distance- and kernel-based statistics



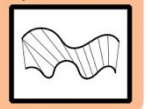
Basic (**21** SPIs)
Covariance
Kendall's tau
Cross-correlation
...



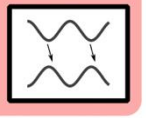
Information theory (**37** SPIs)
Mutual information
Transfer entropy
Integrated information
...



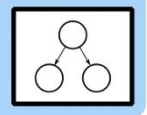
Distance similarity (**26** SPIs)
Distance correlation
Heller-Heller-Gorfine test
Dynamic time warping
...



Spectral (**126** SPIs)
Coherence magnitude
Directed coherence
Spectral Granger causality
...



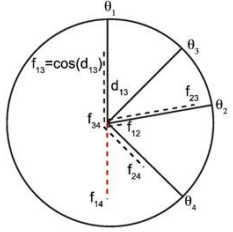
Causal indices (**10** SPIs)
Additive noise models
Convergent cross-mapping
...

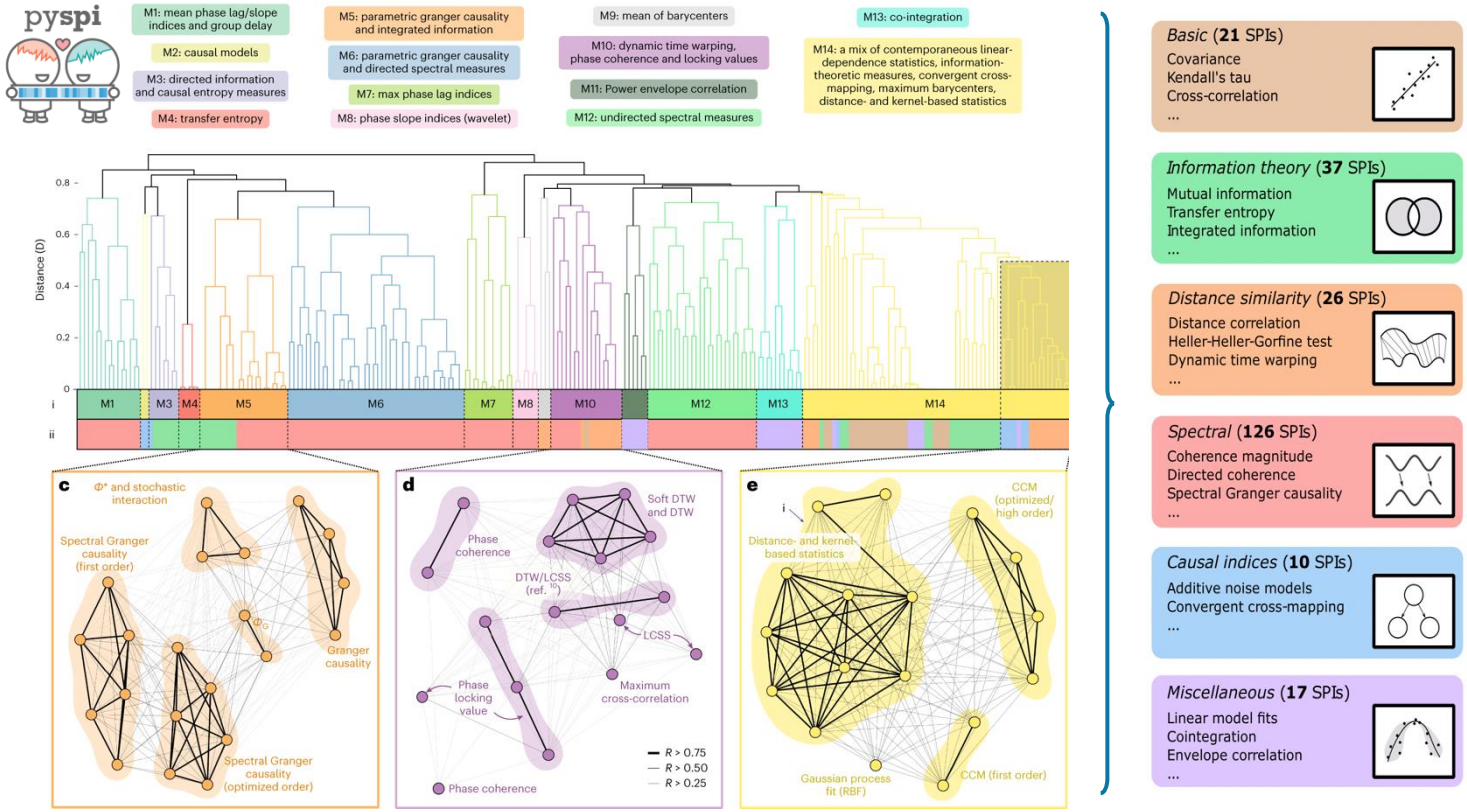


Miscellaneous (**17** SPIs)
Linear model fits
Cointegration
Envelope correlation
...

Cliff et al. *Nat Comp Sci* (2023)

Motivation





Basic (**21** SPIs)
Covariance
Kendall's tau
Cross-correlation
...

Information theory (**37** SPIs)
Mutual information
Transfer entropy
Integrated information
...

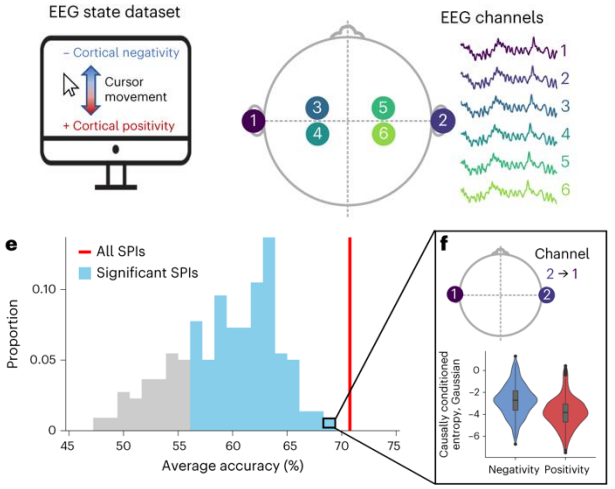
Distance similarity (**26** SPIs)
Distance correlation
Heller-Heller-Gorfine test
Dynamic time warping
...

Spectral (**126** SPIs)
Coherence magnitude
Directed coherence
Spectral Granger causality
...

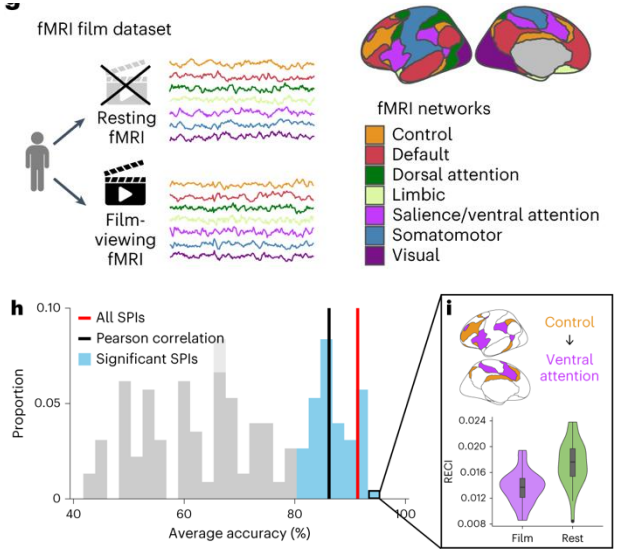
Causal indices (**10** SPIs)
Additive noise models
Convergent cross-mapping
...

Miscellaneous (**17** SPIs)
Linear model fits
Cointegration
Envelope correlation
...

Cortical state from EEG:



Film-viewing vs. resting from fMRI:



Cliff et al. *Nat Comp Sci* (2023)

Methods

Preprocessing:

An adversarial collaboration to critically evaluate theories of consciousness

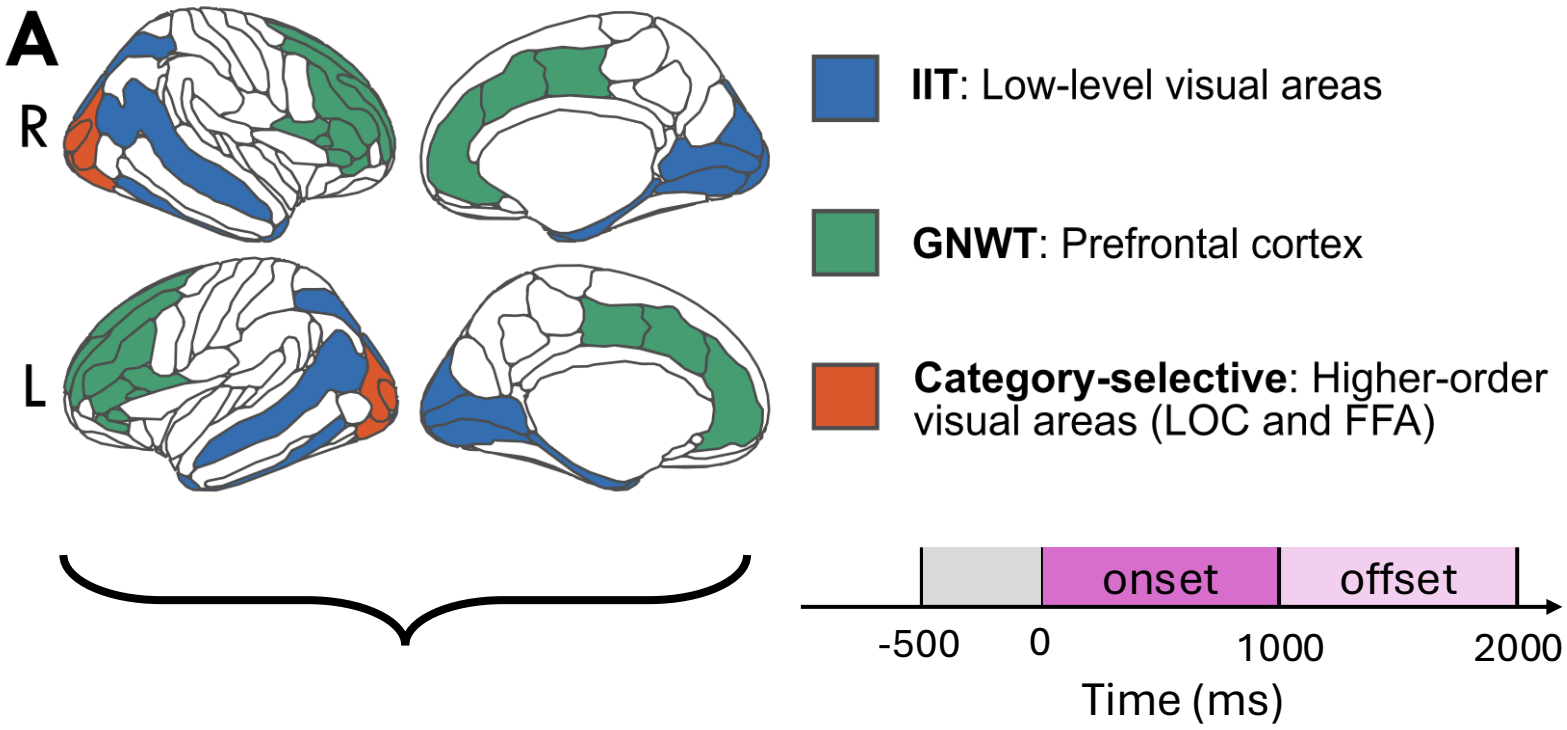
Cogitate Consortium, Oscar Ferrante, Urszula Gorska-Klimowska, Simon Henin, Rony Hirschhorn, Aya Khalaf, Alex Lepauvre, Ling Liu, David Richter, Yamil Vidal, Niccolò Bonacchi, Tanya Brown, Praveen Sripad, Marcelo Armendariz, Katarina Bendtz, Tara Ghafari, Dorottya Hetenyi, Jay Jeschke, Csaba Kozma, David R. Mazumder, Stephanie Montenegro, Alia Seedat, Abdelrahman Sharafeldin, Shujun Yang, Sylvain Baillet, David J. Chalmers, Radoslaw M. Cichy, Francis Fallon, Theofanis I. Panagiotaropoulos, Hal Blumenfeld, Floris P de Lange, Sasha Devore, Ole Jensen, Gabriel Kreiman, Huan Luo, Melanie Boly, Stanislas Dehaene, Christof Koch, Giulio Tononi, Michael Pitts, Liad Mudrik, Lucia Melloni

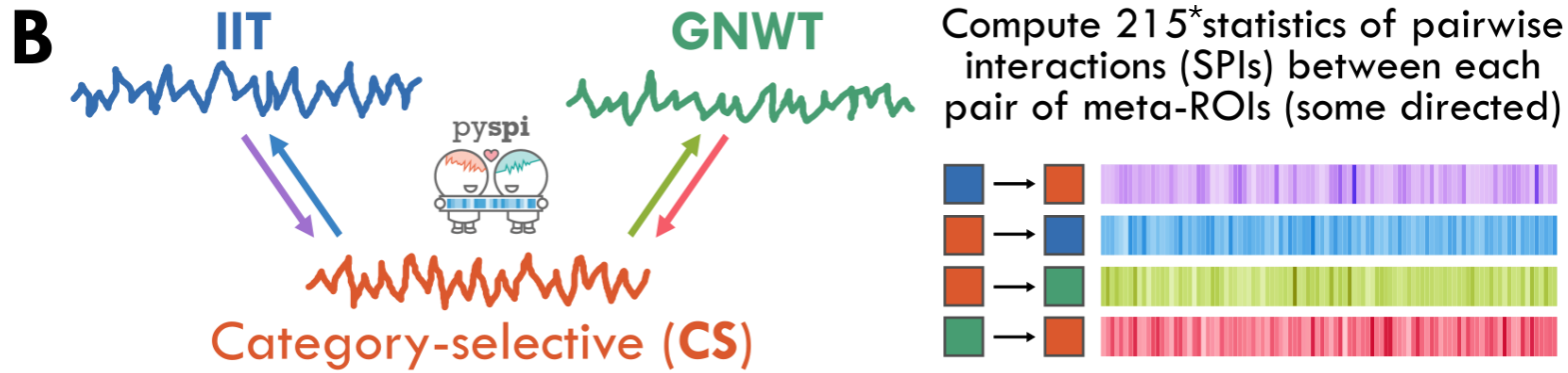
doi: https://doi.org/10.1101/2023.06.23.546249

COGITATE

https://github.com/Cogitate-consortium/cogitate-msp1

Batch 1: N=48 **Batch 2**: N=46*





Methods

Batch 1: N=48

Batch 2: N=46*

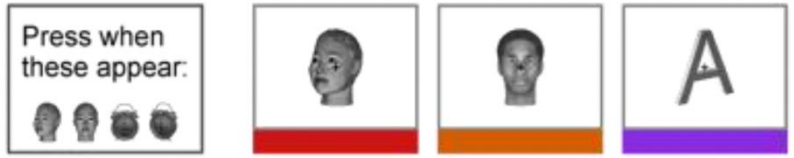
Classification aims:

1. Stimulus pairs

Face vs. Object

Letter vs. Face

2. Domain-independent task relevance

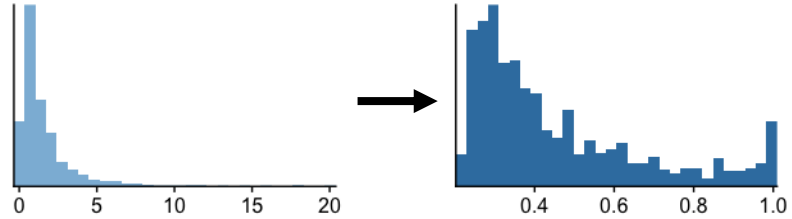


Relevant vs. Irrelevant

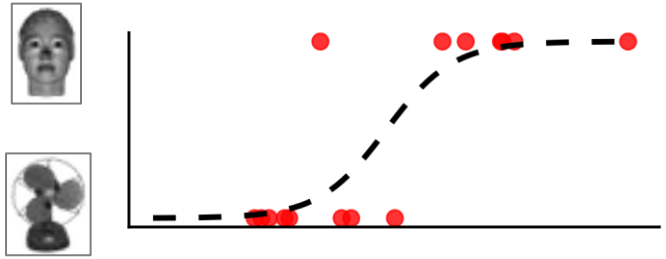
Implemented with a `Pipeline` to:

1. Partition data into 10 train/test folds for **cross-validation** using **stratified grouping**

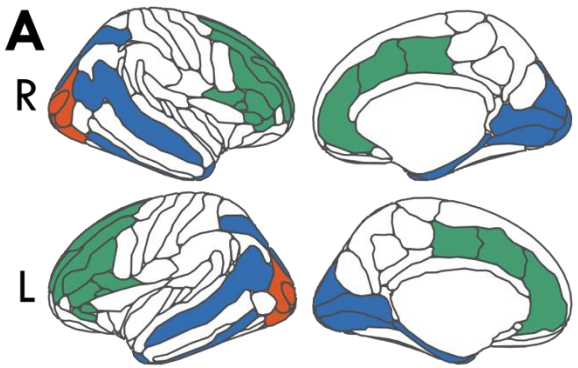
2. Normalize SPI feature values with an **outlier-robust sigmoidal transformation**



3. Fit a **logistic regression classifier** to evaluate **accuracy** across test folds for each of **199 SPIs**



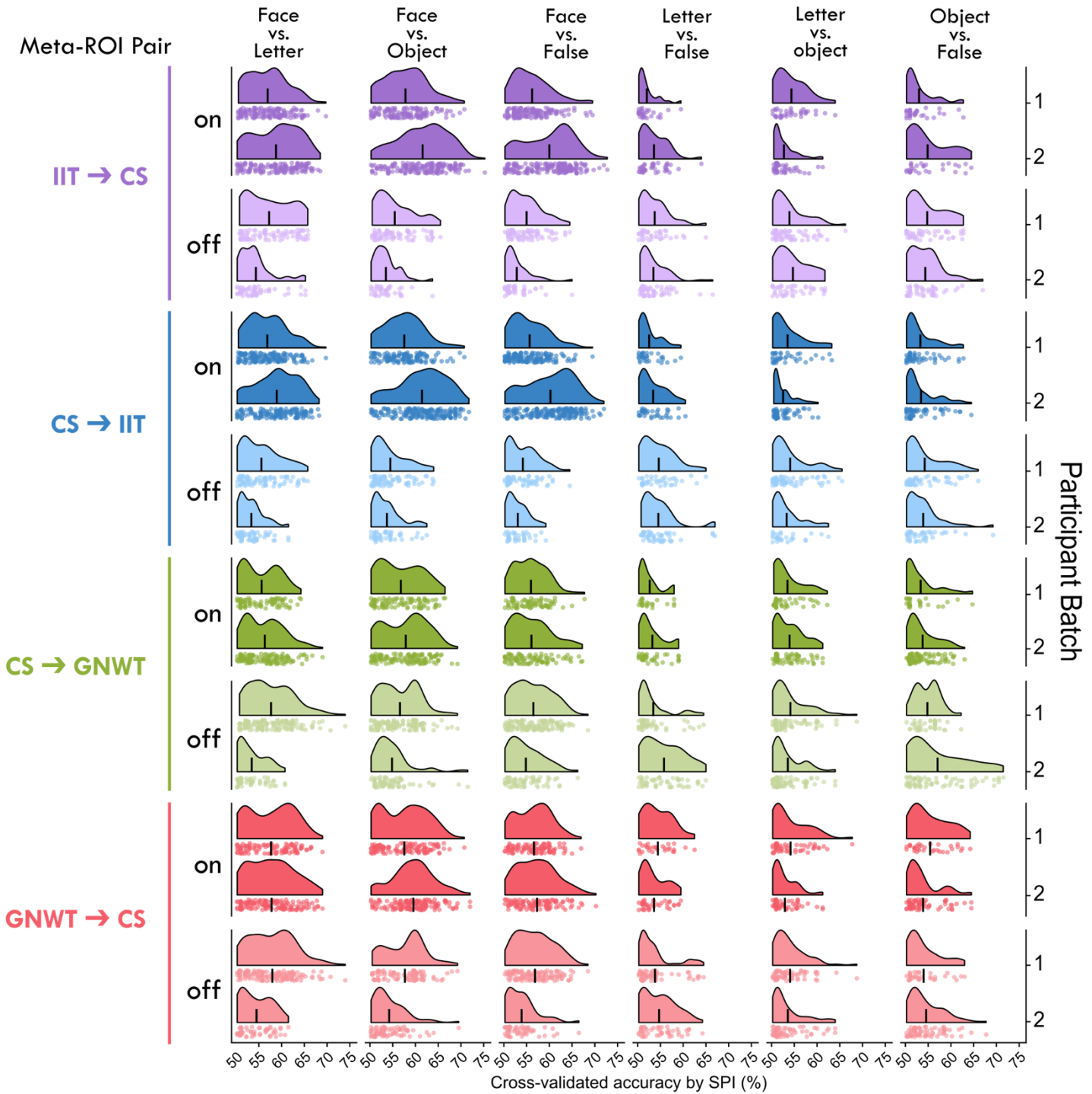
Many SPIs can distinguish between stimulus types



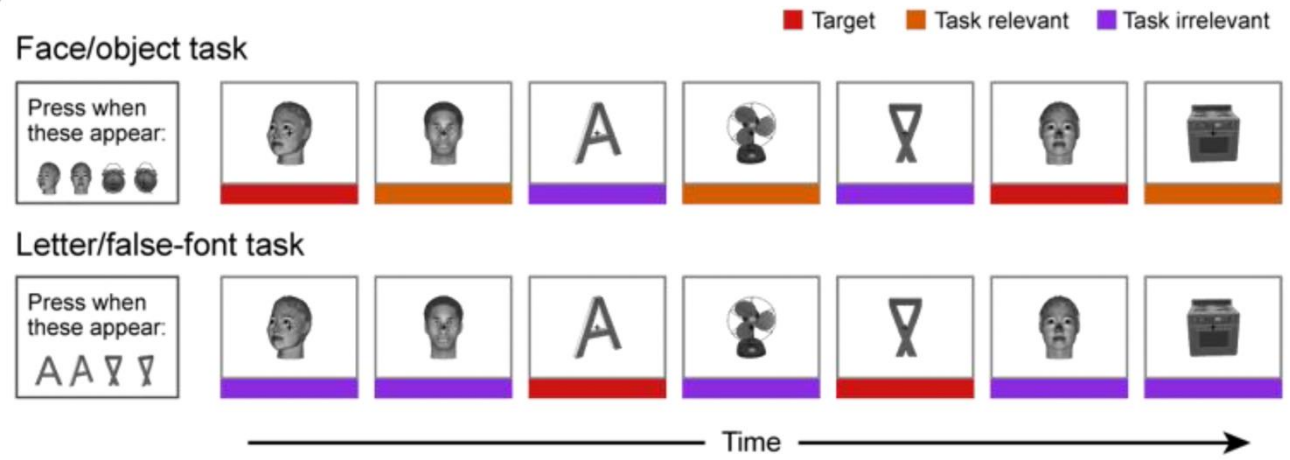
IIT: Low-level visual areas

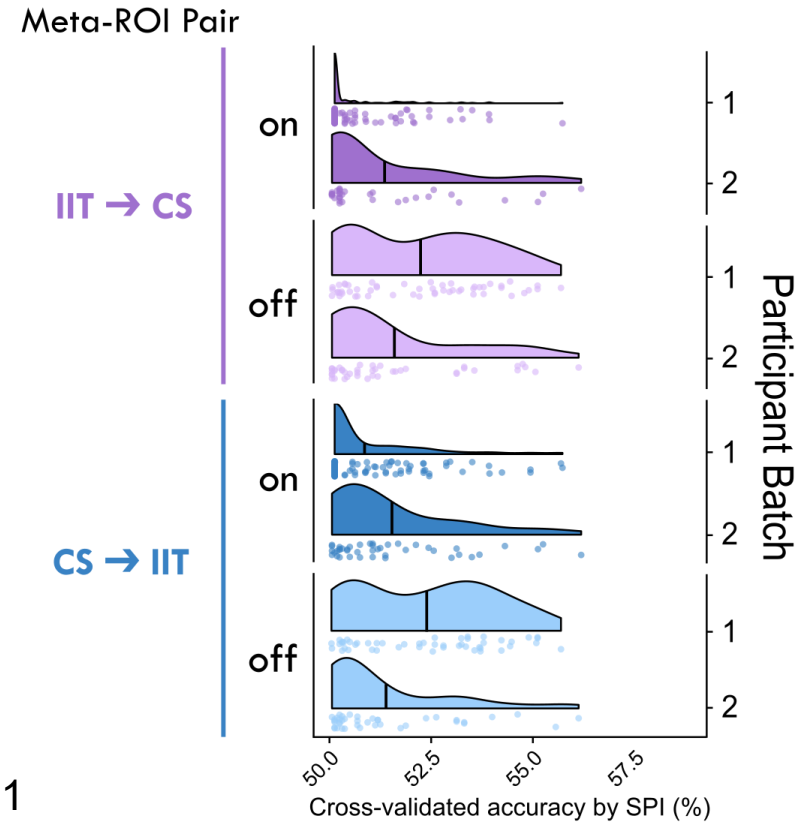
GNWT: Prefrontal cortex

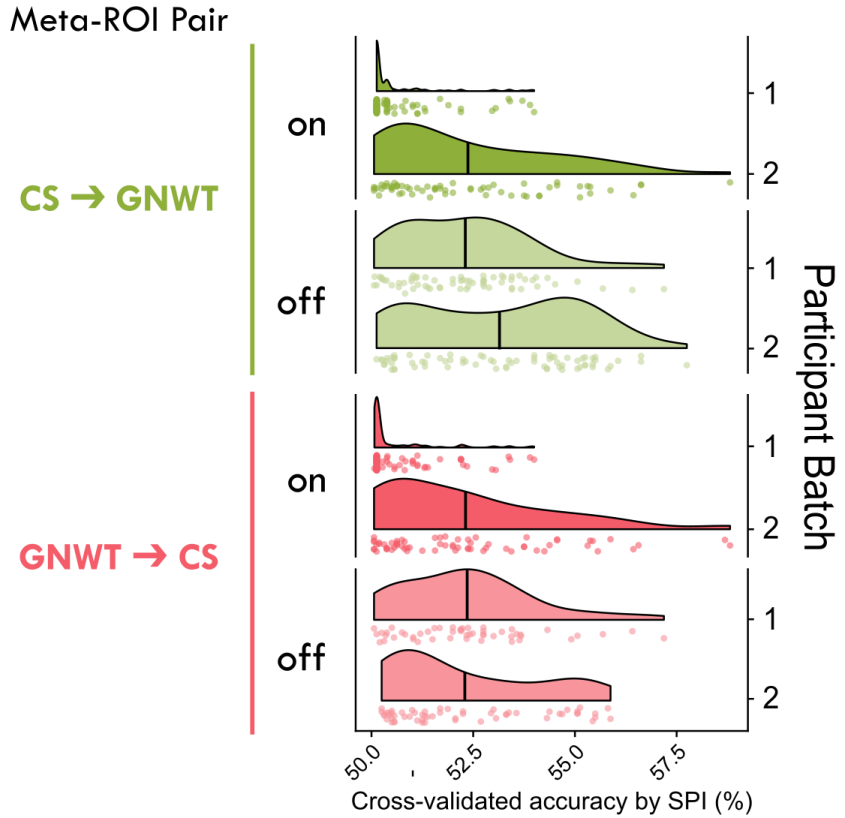
Category-selective: Higher-order visual areas (LOC and FFA)



Domain-independent **task relevance is not well classified** by any functional connectivity metric

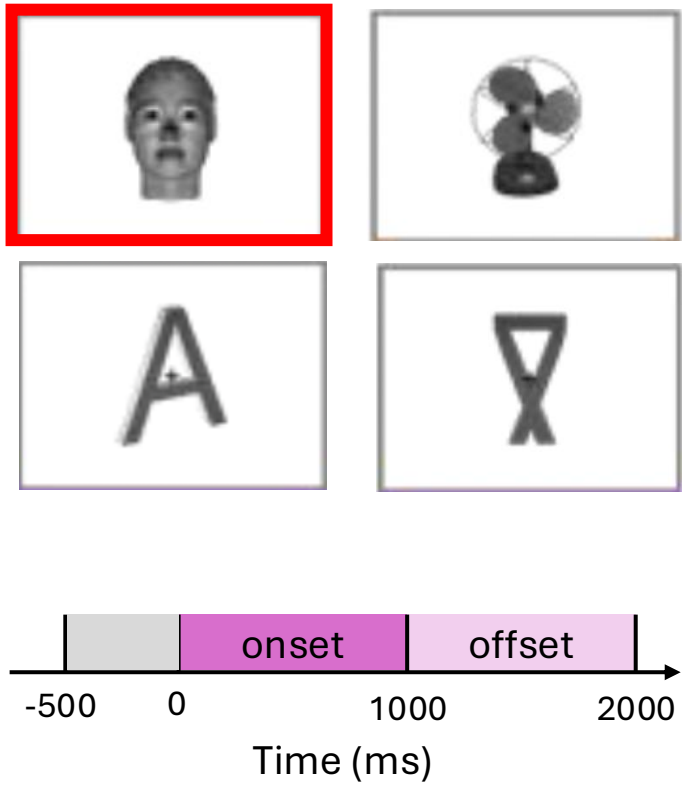


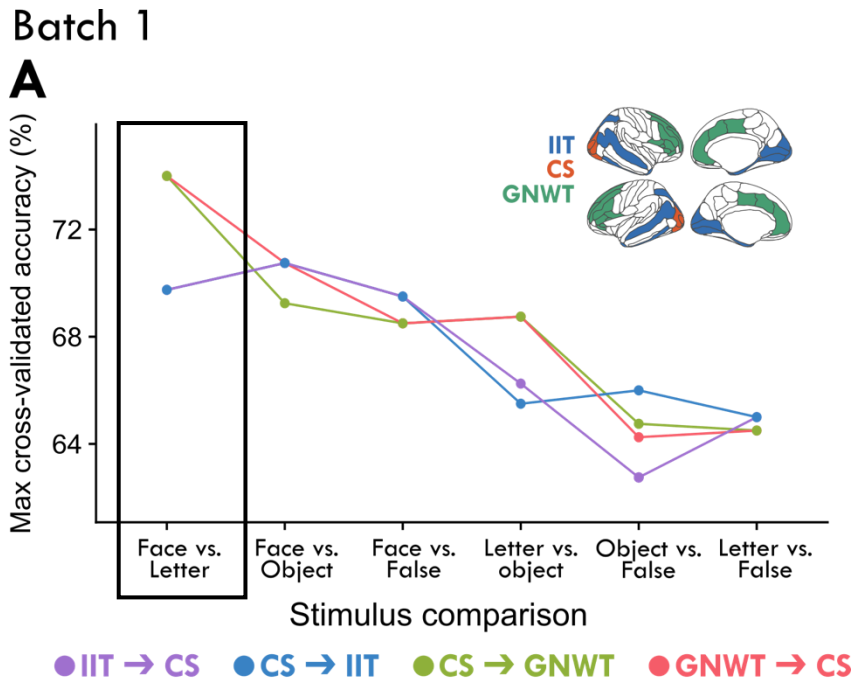


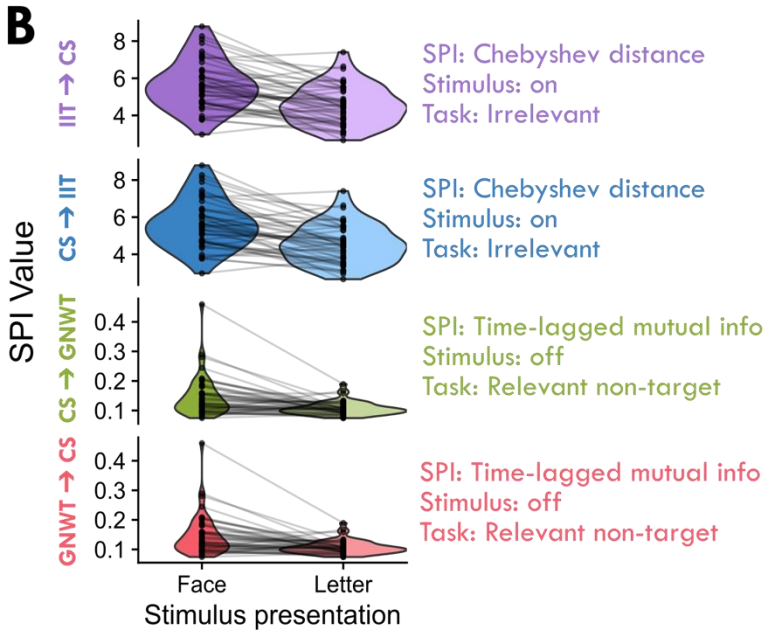


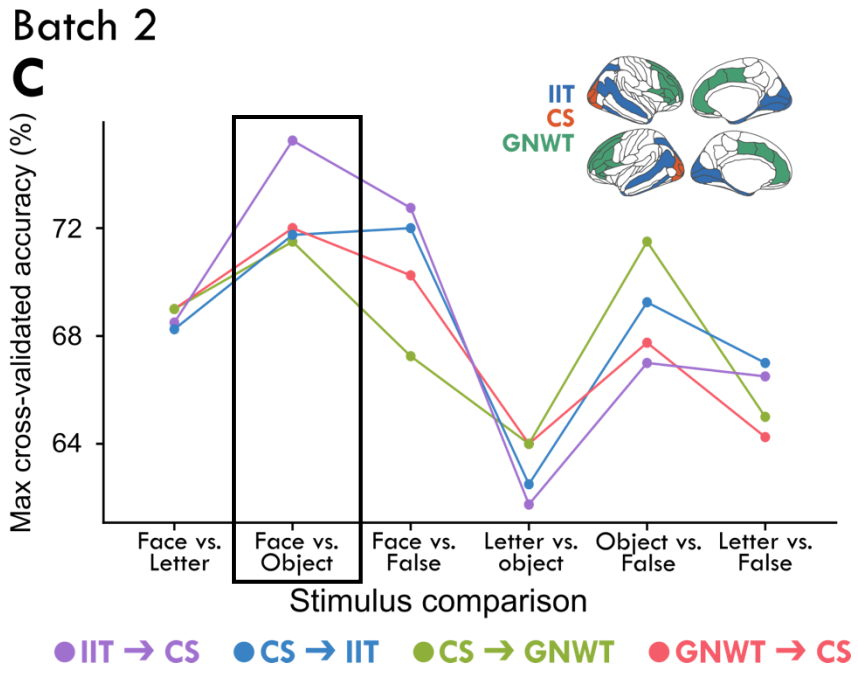
Source: Cogitate Main Scientific Paper 1

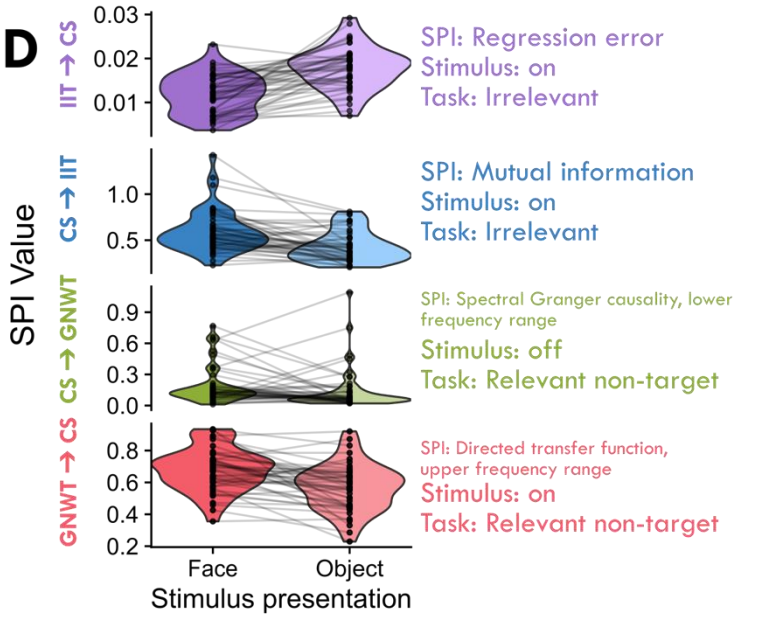
Face stimuli are **most accurately** classified from other stimulus types in **both participant batches**



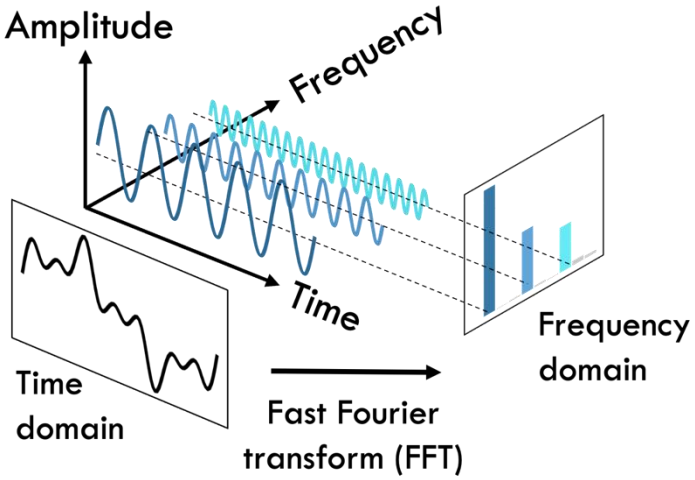


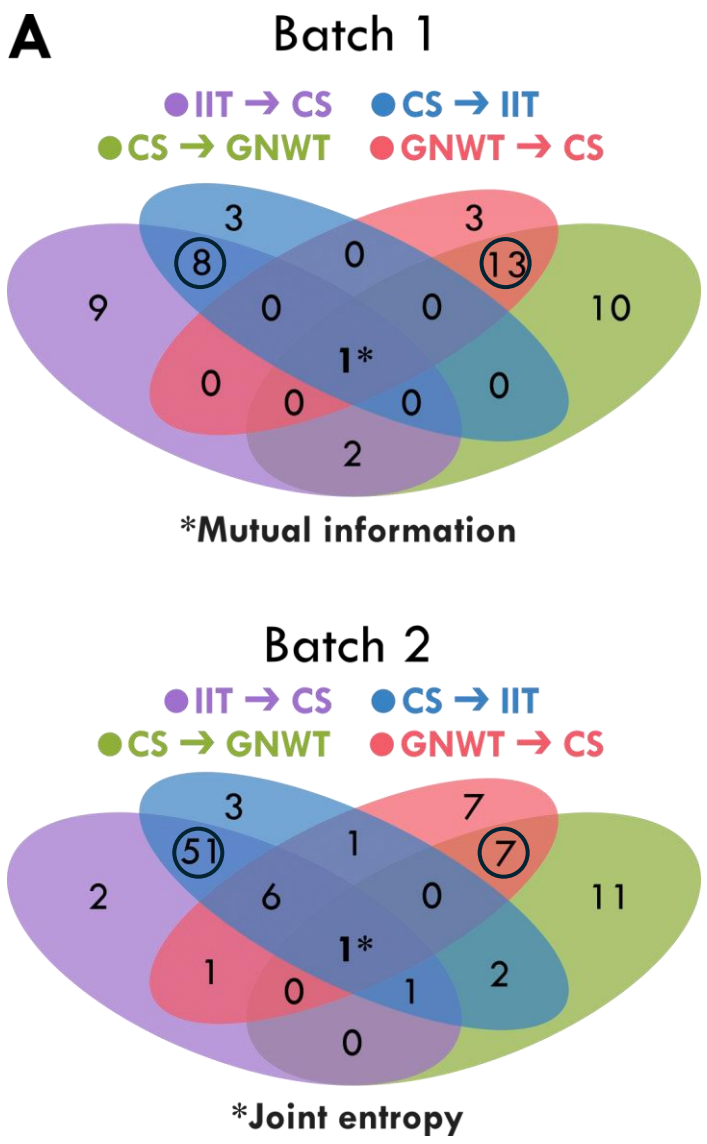


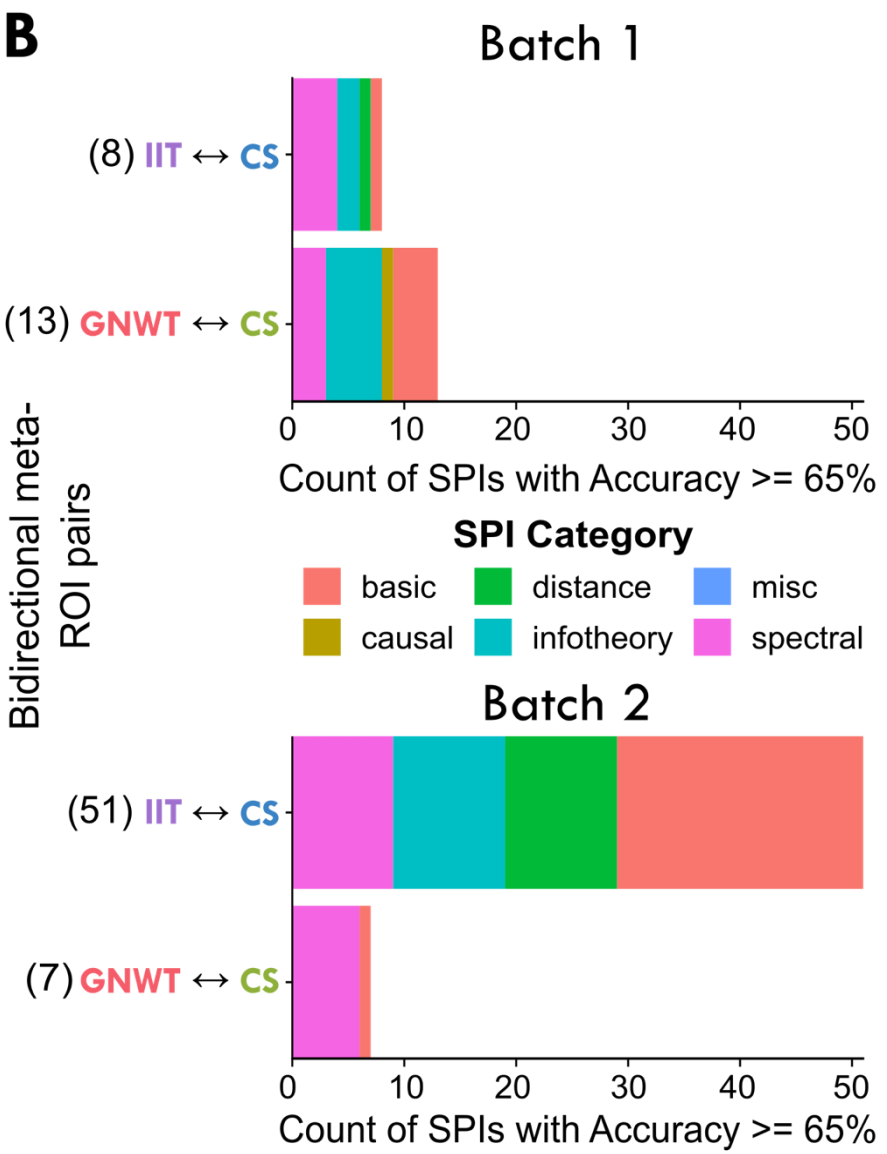




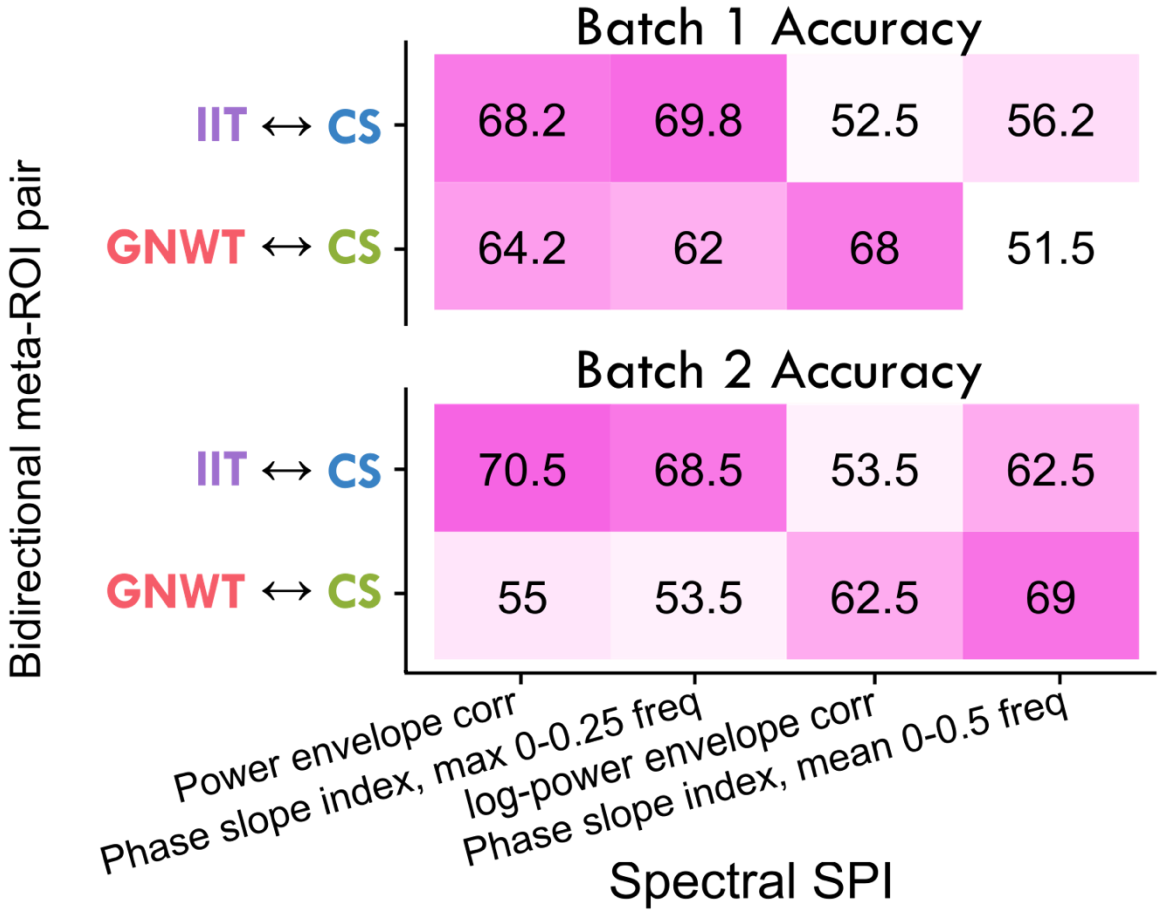
Frequency-based statistics distinguish between stimulus types well in **both cohort batches**





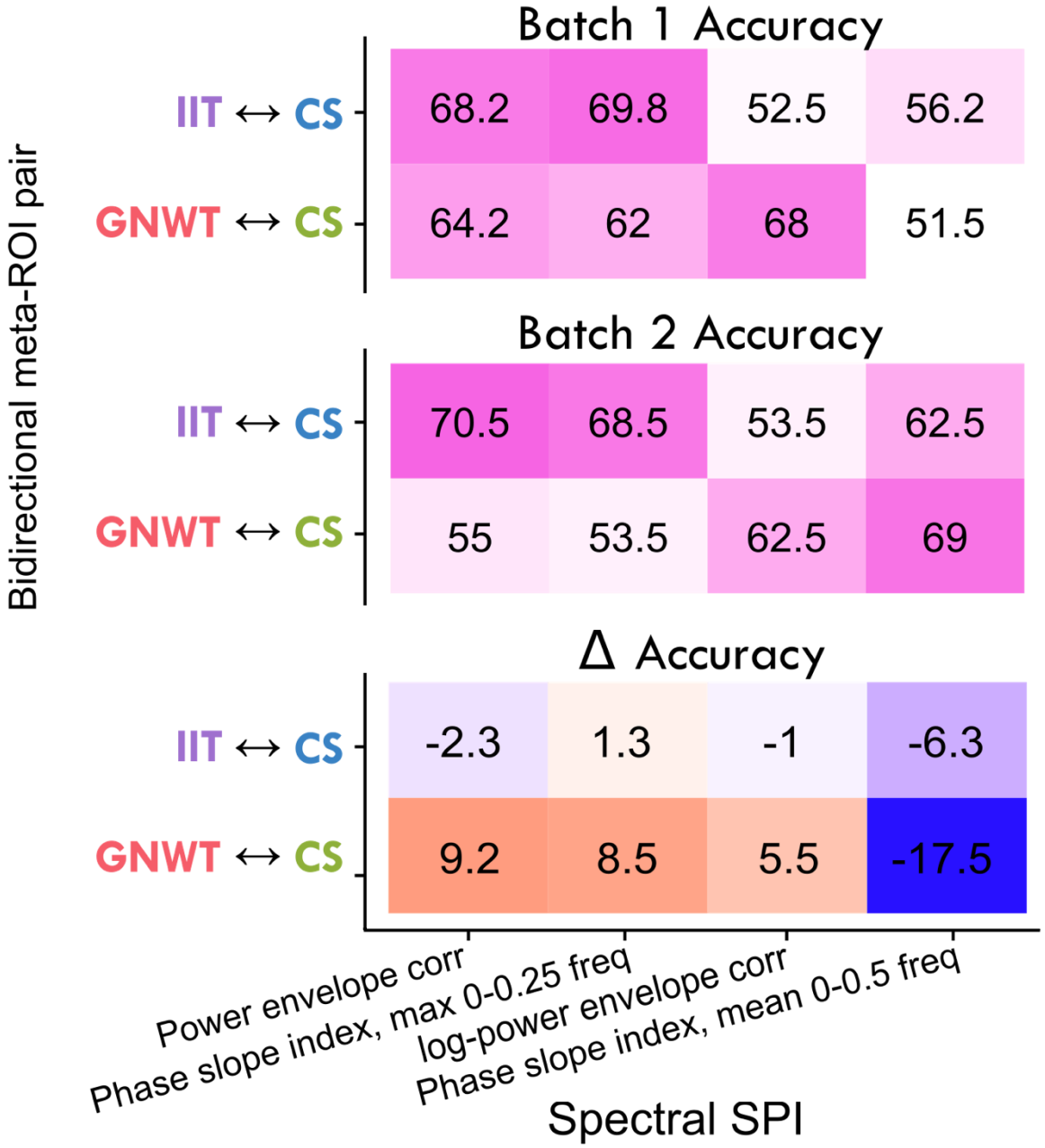


If a theory is correct, the **signatures of conscious perception** between the ROIs predicted by each theory should **generalise across batches**.



If a theory is correct, the **signatures of conscious perception** between the ROIs predicted by each theory should **generalise across batches**.

The top-performing **spectral SPIs** are more consistent between **IIT and CS regions across batches** than between CS and GNWT regions tentatively supporting IIT's predictions.

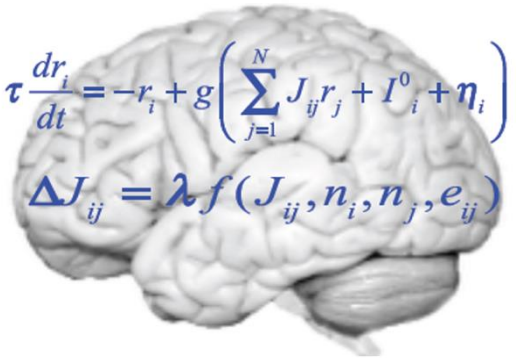


Conclusions

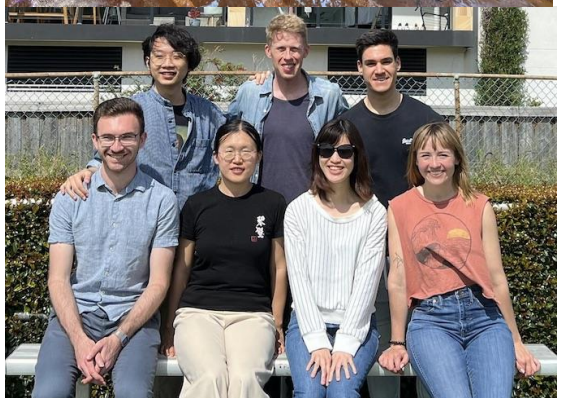
- We found tentative support for IIT: **Spectral SPIs between IIT/CS meta-ROIs generalised better** across participant batches.
- Conversely, the **lack of evidence for a domain general signature of task-relevance** is more in support of GNWT, as IIT predicts that prefrontal engagement in conscious perception should be task driven.
- No free lunch theorem – **no one optimal classifier or time series feature** for any stimulus or task condition. As researchers should be careful about placing too much emphasis on one time series signature especially when we have not run simulations ahead of time.

Next steps

- Rerun our analysis on **single individuals** and look at **variability in the signatures of conscious perception across individuals**.
- Incorporate **large-scale biophysical modeling** to see if we can reproduce and explain some of the observed signatures **mechanistically**.



Thank you Cogitate for the invitation & for your time 😊

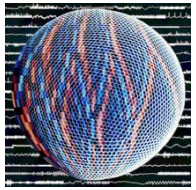


Dynamics & Neural Systems Group

Ben Fulcher
Trent Henderson
Kieran Owens
Aria Nguyen
Rishi Maran
Brendan Harris
Joshua Moore
Teresa Dalle Nogare

Shine Lab

A/Prof Mac Shine
Brandon Munn
Eli Mueller
Natasha Taylor
Gabriel Wainstein
Bella Orlando
Joshua Tan



THE UNIVERSITY OF SYDNEY

shinelab

Contact us:

Annie G. Bryant
anniegbryant@gmail.com
@anniegbryant

Christopher J. Whyte
christopherjackwhyte@gmail.com
@chrisjackwhyte