ON FINGERPRINTING AND FUNCTIONAL RECONFIGURATION OF FUNCTIONAL CONNECTOMES

Seminarios DATAI
Instituto de Ciencias de los Datos e Inteligencia Artificial
Universidad de Navarra
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Joaquín Goñi, Ph.D

CONN*plexity* Lab
Purdue University
West Lafayette, Indiana, USA
jgonicor@purdue.edu
@jgonicor

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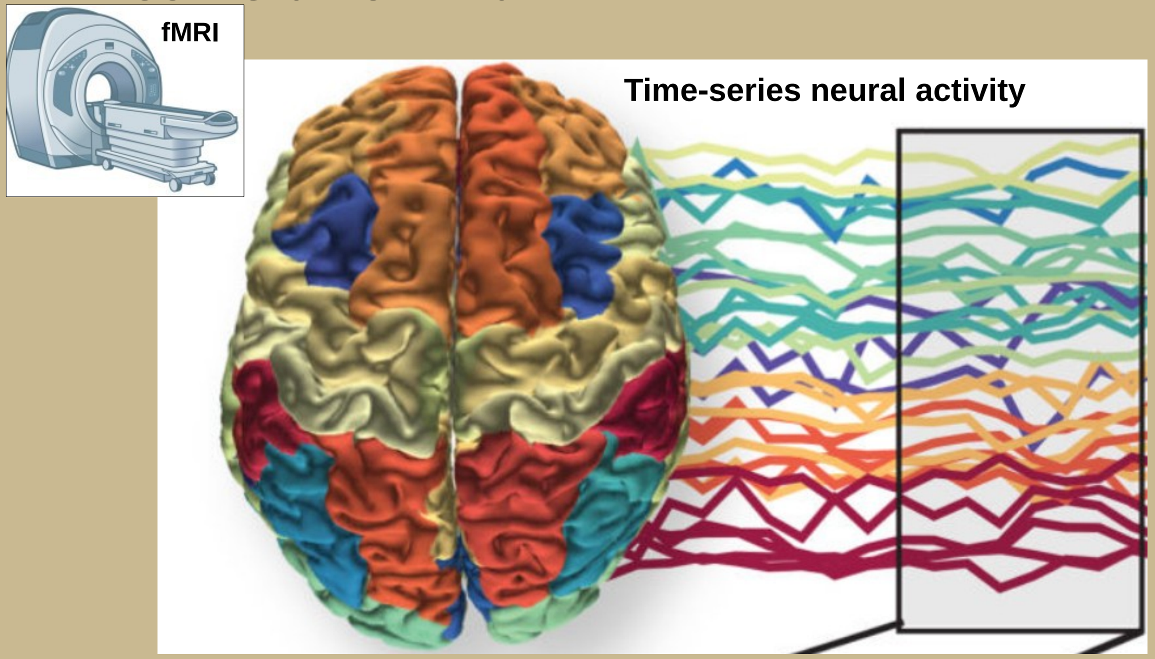
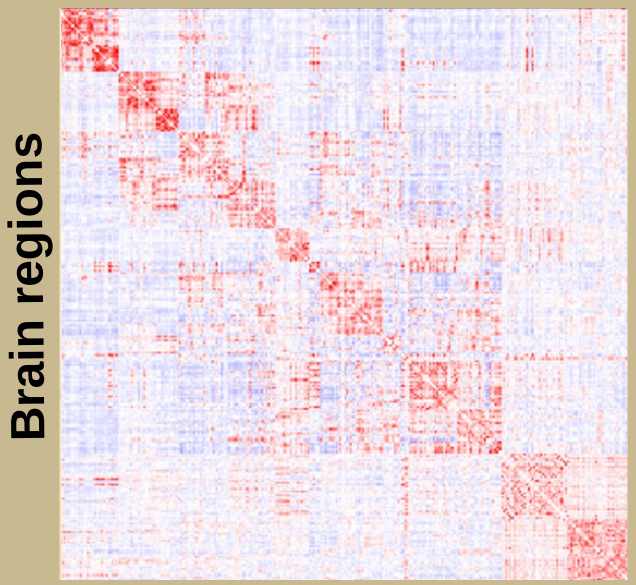
A whole-brain **functional connectome (FC)** is a representation of the level of functional coupling among pairs of brain regions for a specific subject, brain atlas, task/rest condition, and time window.

From a mathematical standpoint, when using Pearson's correlation coefficient to estimate the levels of functional coupling, a functional connectome is a **correlation matrix.**



Adapted from Garcia, J. O.,et al. (2018). Proc. of the IEEE, 106(5), 846-867.

Whole-brain Functional Connectome



Brain regions

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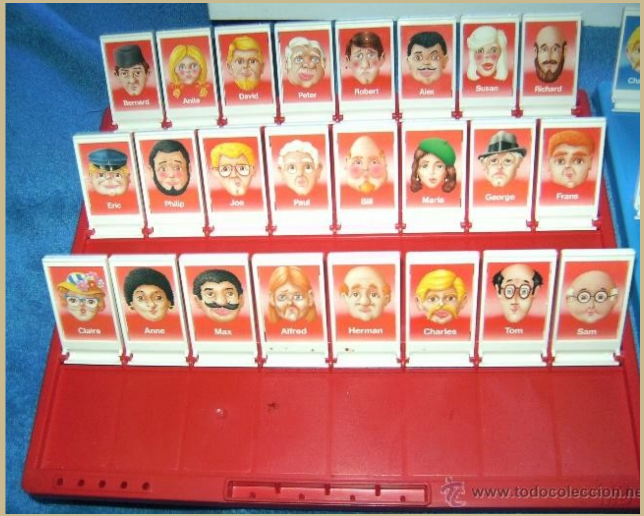
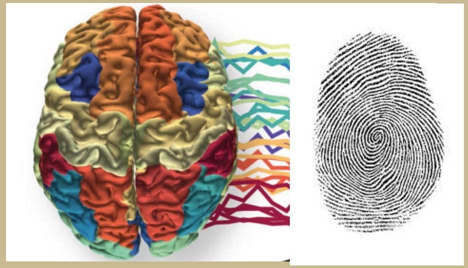
Abbas et al. (2021). Brain connectivity, 11(5), 333-348.



Brain connectivity fingerprinting



The study of whole-brain functional connectomes as an individual fingerprint.

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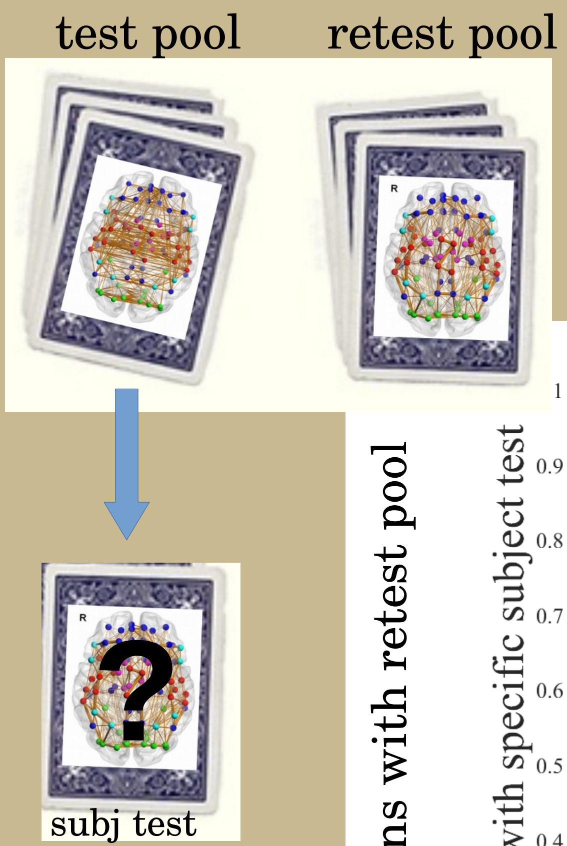
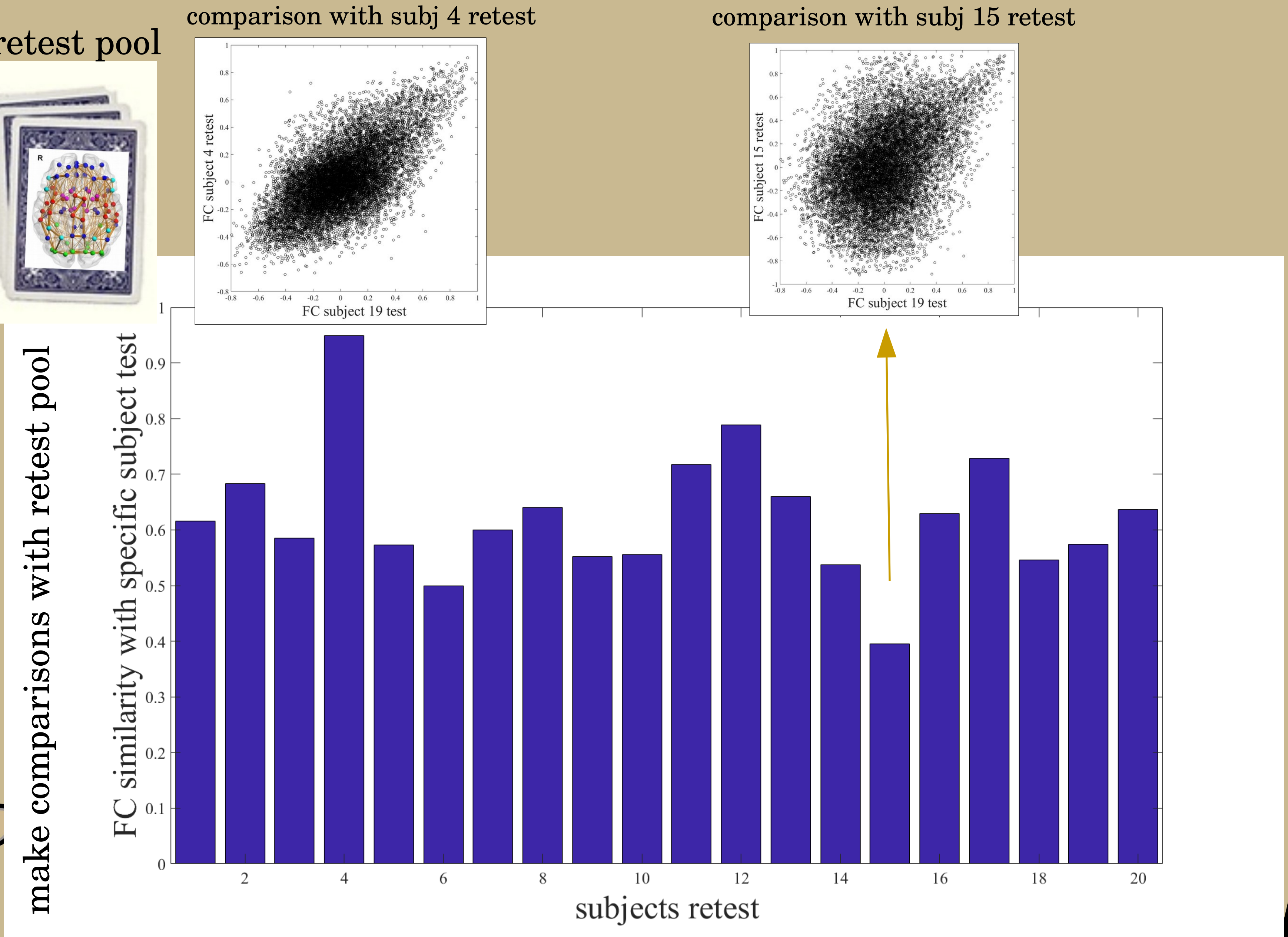
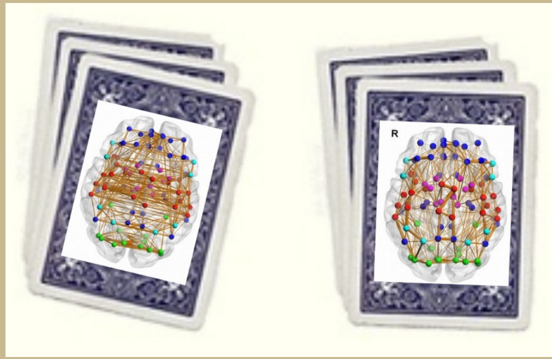
Adapted from Garcia, J. O.,et al. (2018). Proc. of the IEEE, 106(5), 846-867.

Identification rate, or how often we can match two sessions of the same subject as the most similar ones





The concept of individual fingerprinting



Finn et al. Nature Neurosci, 2015

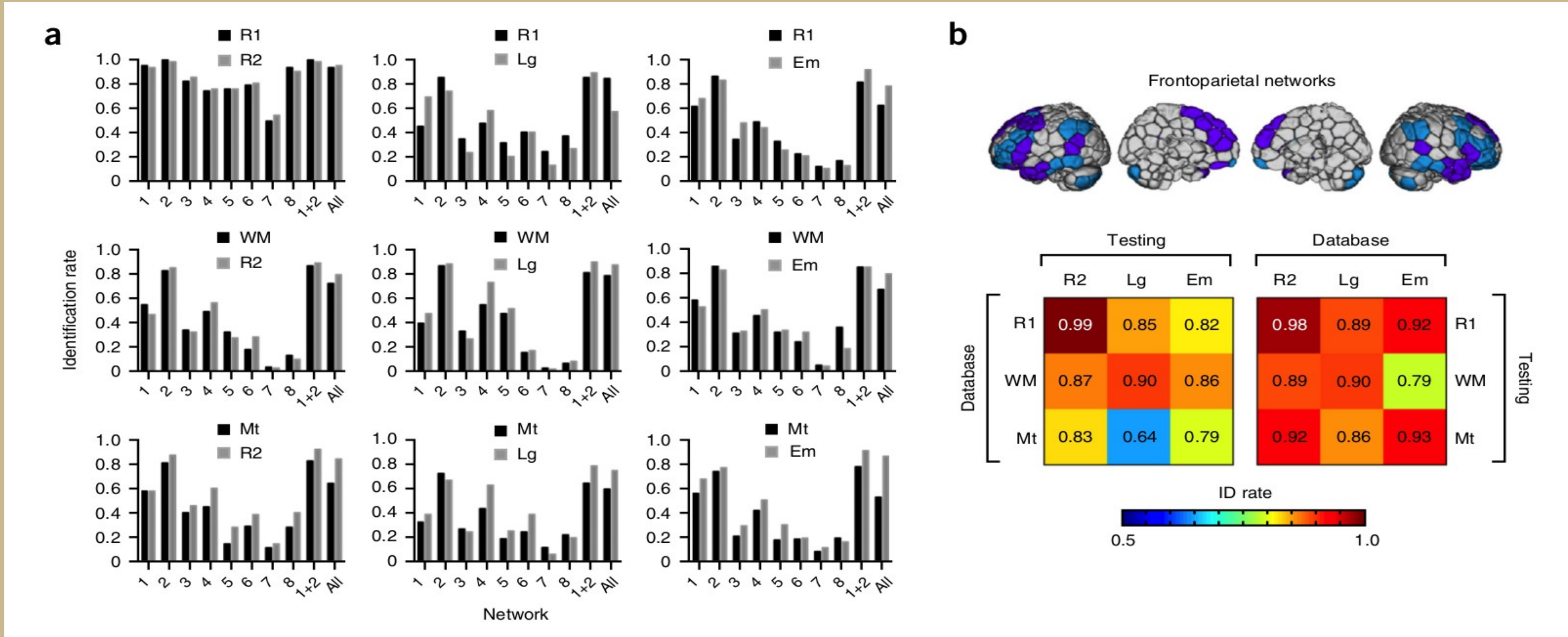
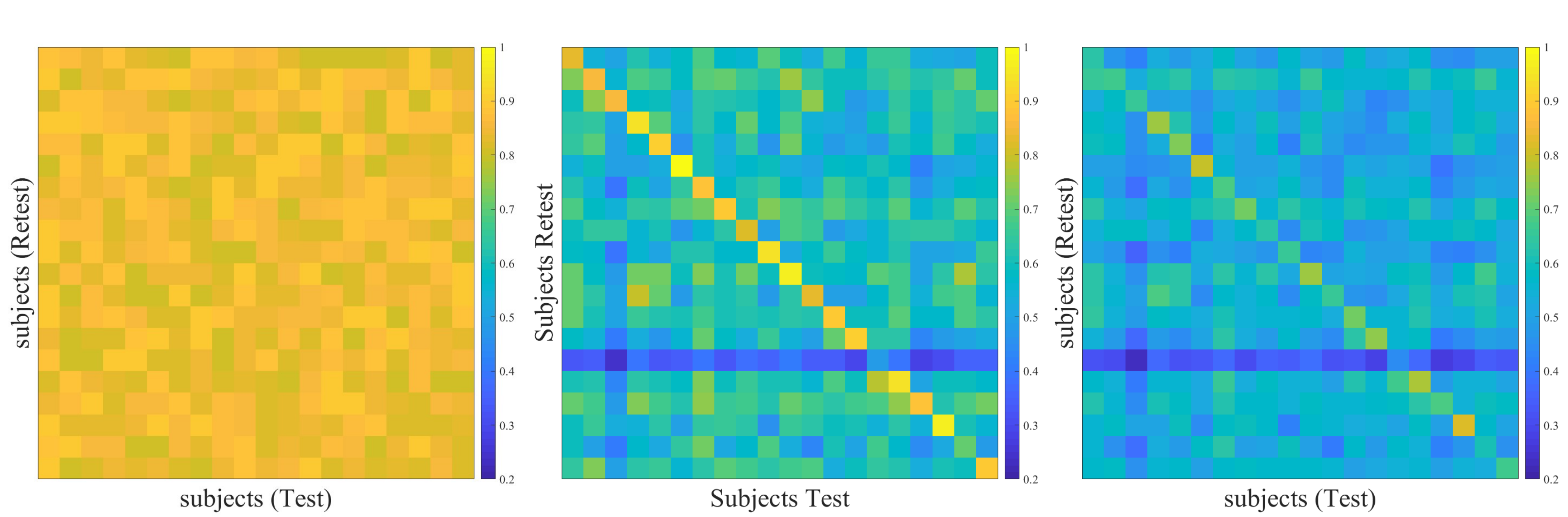


Figure 2 Identification accuracy across session pairs and networks. (**a**) Identification accuracy based on all nine database and target pairs, where each row shares the same database session and each column shares the same target session. Bar shading (black or gray) indicates which session was used as the database (with the other session serving as the target), according to the legend above each graph. Graphs show accuracy based on each

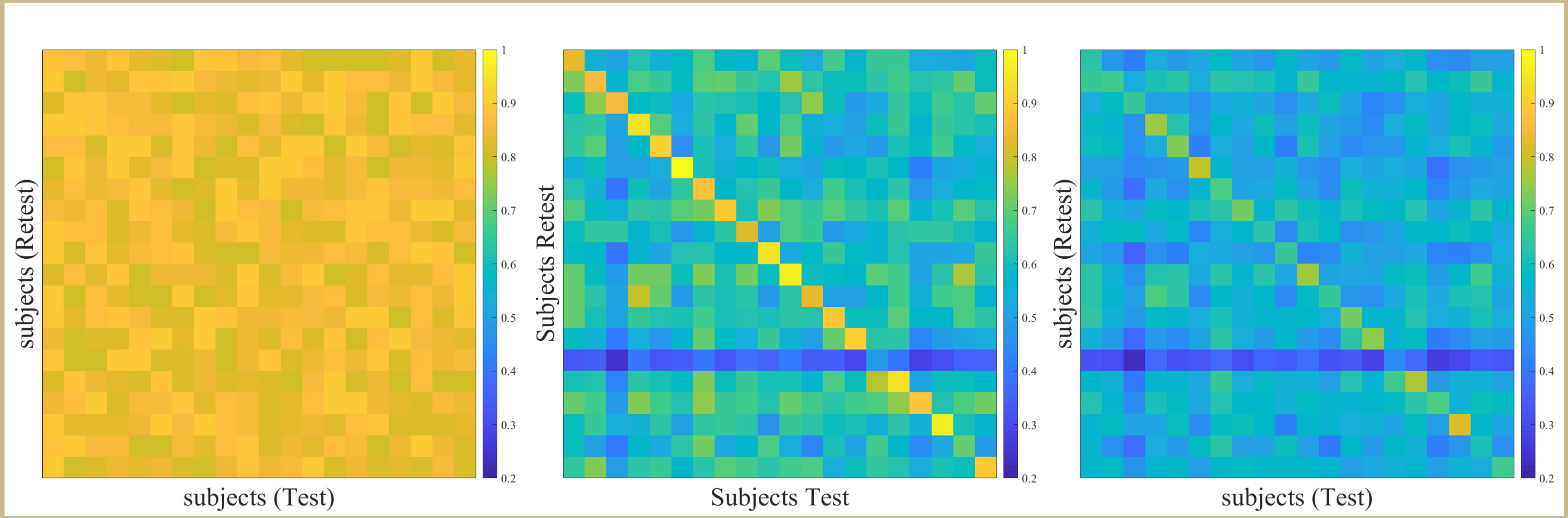
Example with 20 subjects, test-retest FCs, resting state.

Three different fingerprinting scenarios



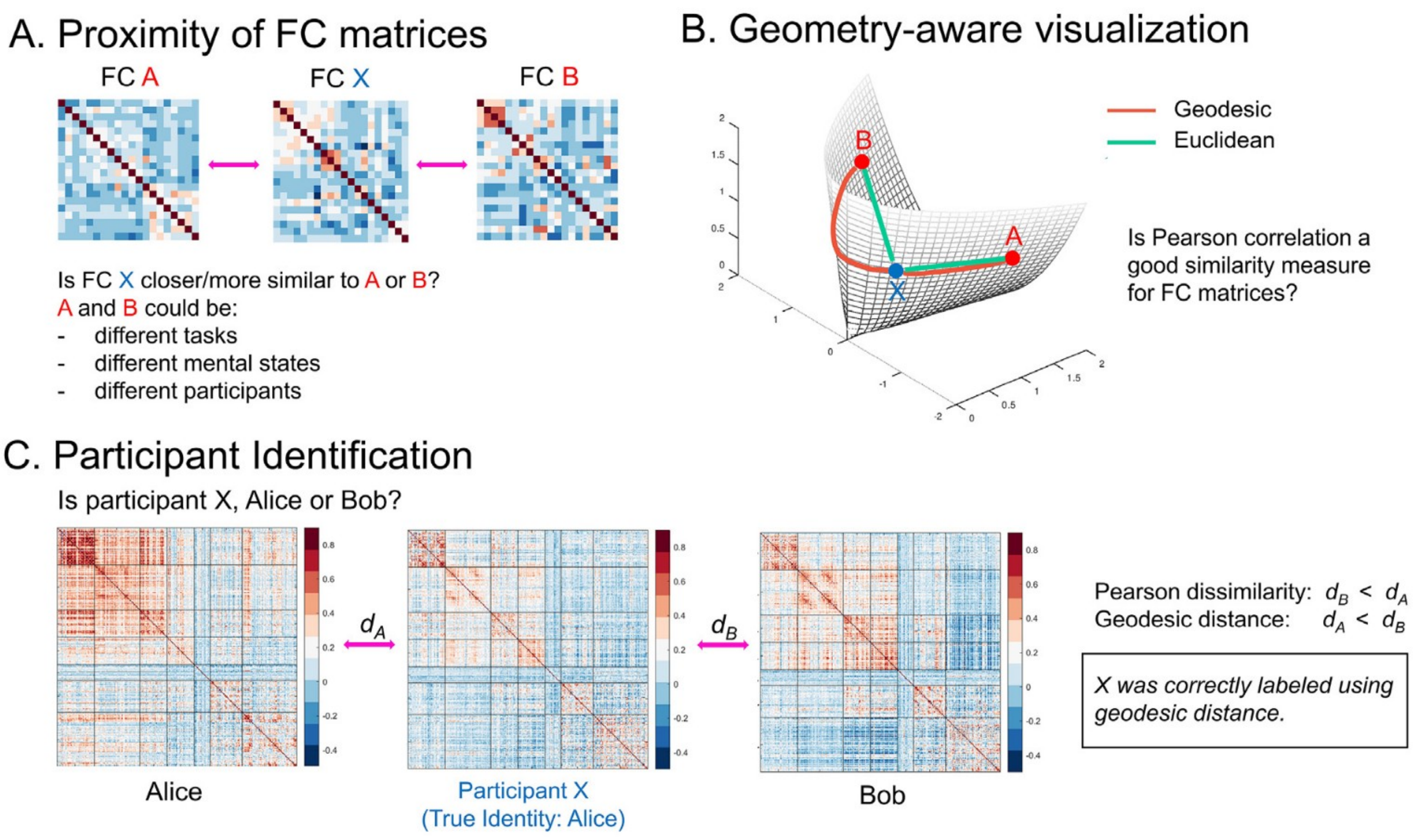
Example with 20 subjects, test-retest FCs, resting state.

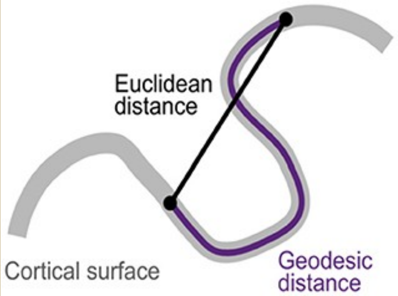
Three different fingerprinting scenarios (via identifiability matrix)

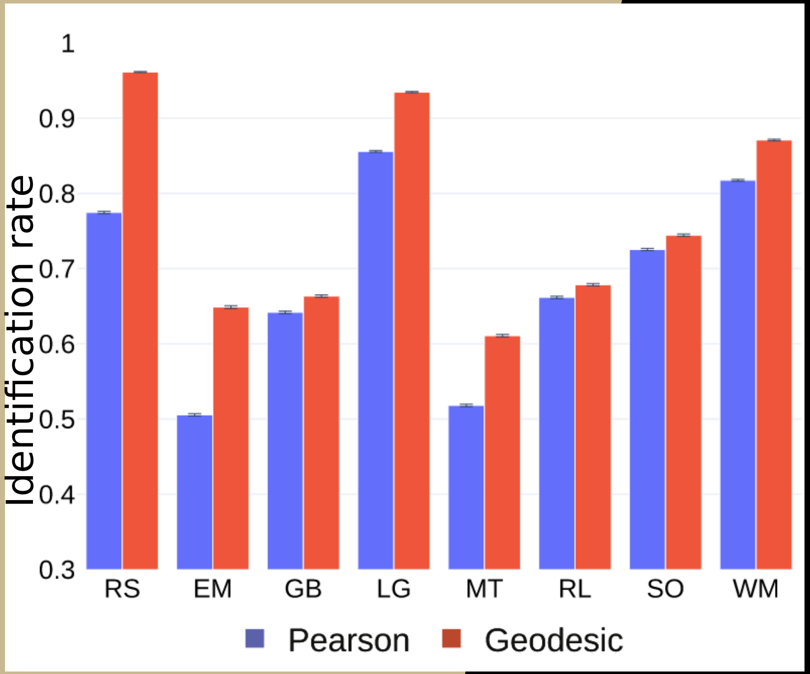


High Similarity between all FCs

Low Similarity between all FCs







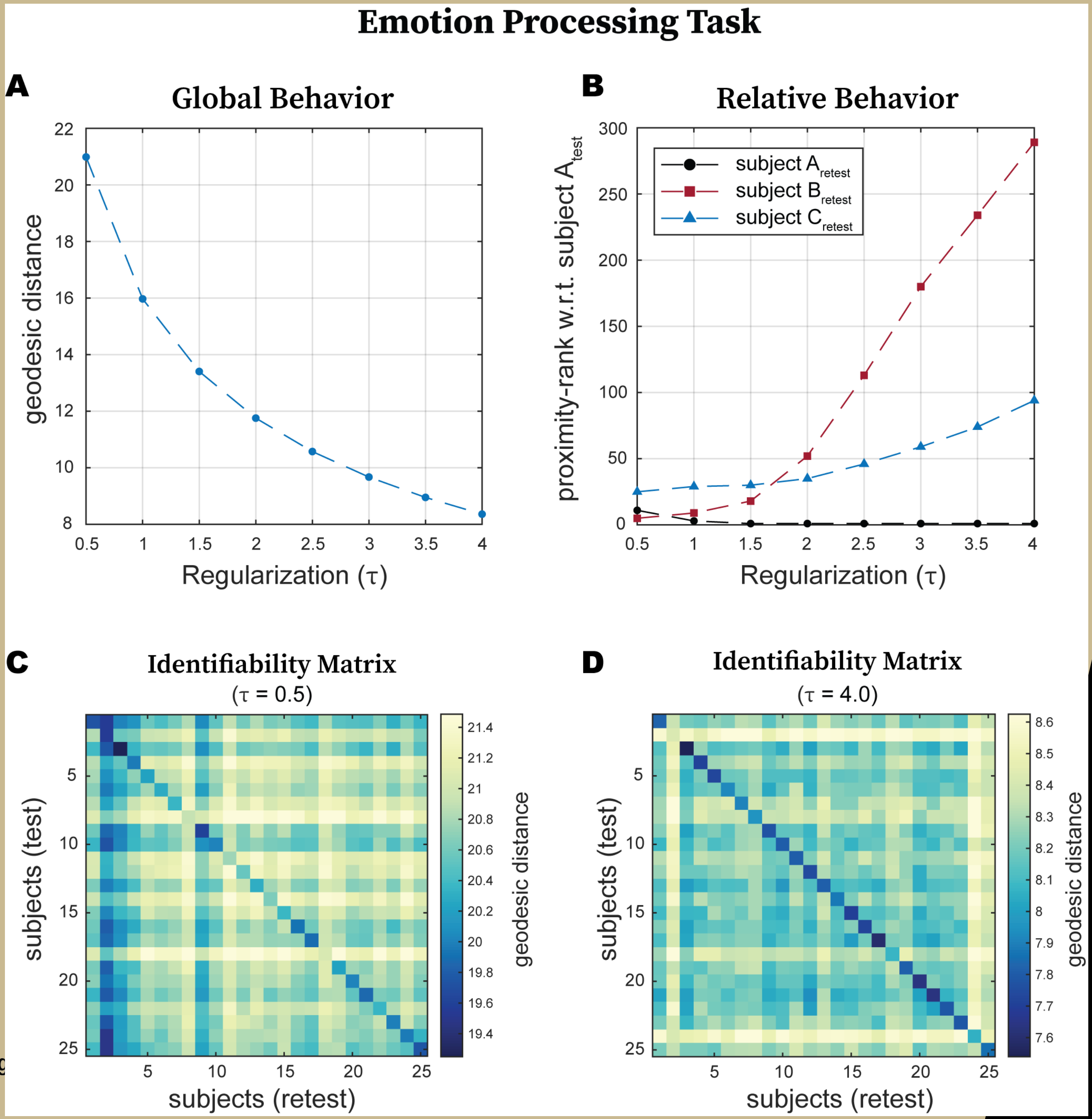
Venkatesh et al. (2020) NeuroImage, 207, 116398.

$$d_G(Q_1,Q_2)=\sqrt{\operatorname{trace}\left(\log^2\left(Q_1^{\frac{-1}{2}}Q_2Q_1^{\frac{-1}{2}}\right)\right)}=\sqrt{\sum_{i=1}^{m}\left(\log(\lambda_i)\right)^2}$$

Abbas et al. (2021). Brain connectivity, 11(5), 333-348.

- As we increase regularization, the average global distance among FCs diminishes (as expected).

As we increase regularization, the similarity ranking of FCs with respect to a reference FC keeps changing.



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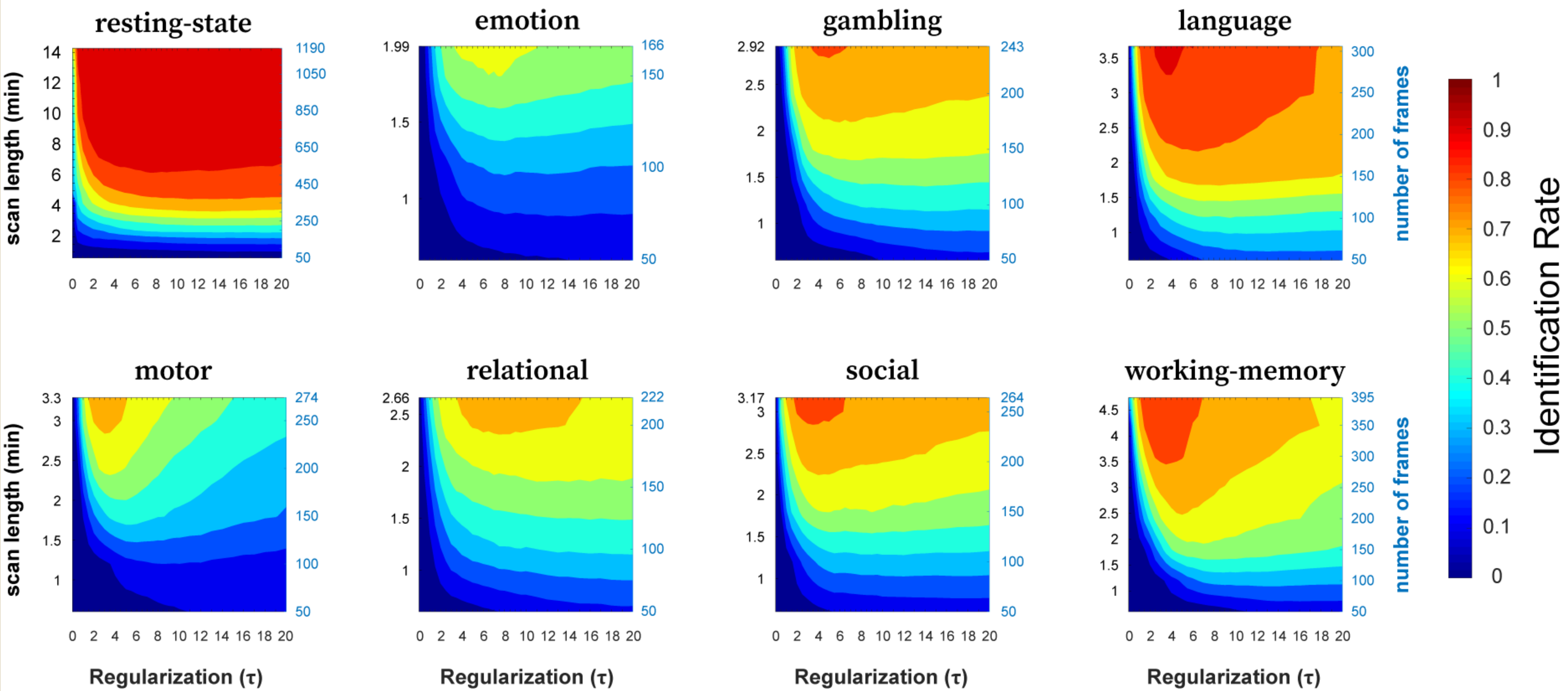
Abbas et al. (2021). Brain connectivity, 11(5), 333-348.

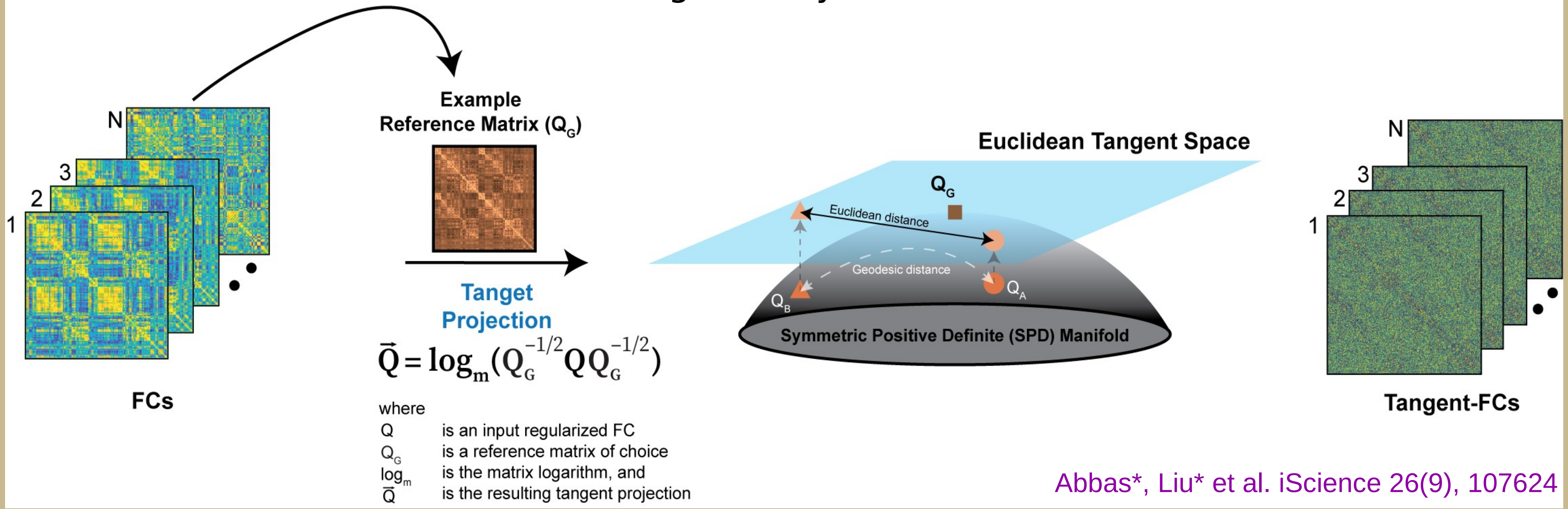
Identification Rates for MMP1.0 parcellation



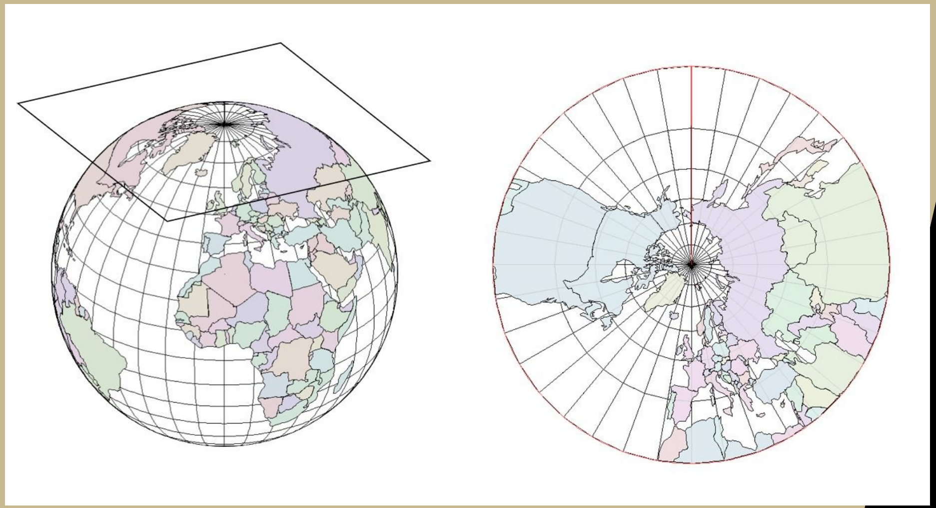
Abbas et al. (2021). Brain connectivity, 11(5), 333-348.

Tangent Space Projection

Riemannian geometry



Abbas*, Liu* et al. iScience 26(9), 107624



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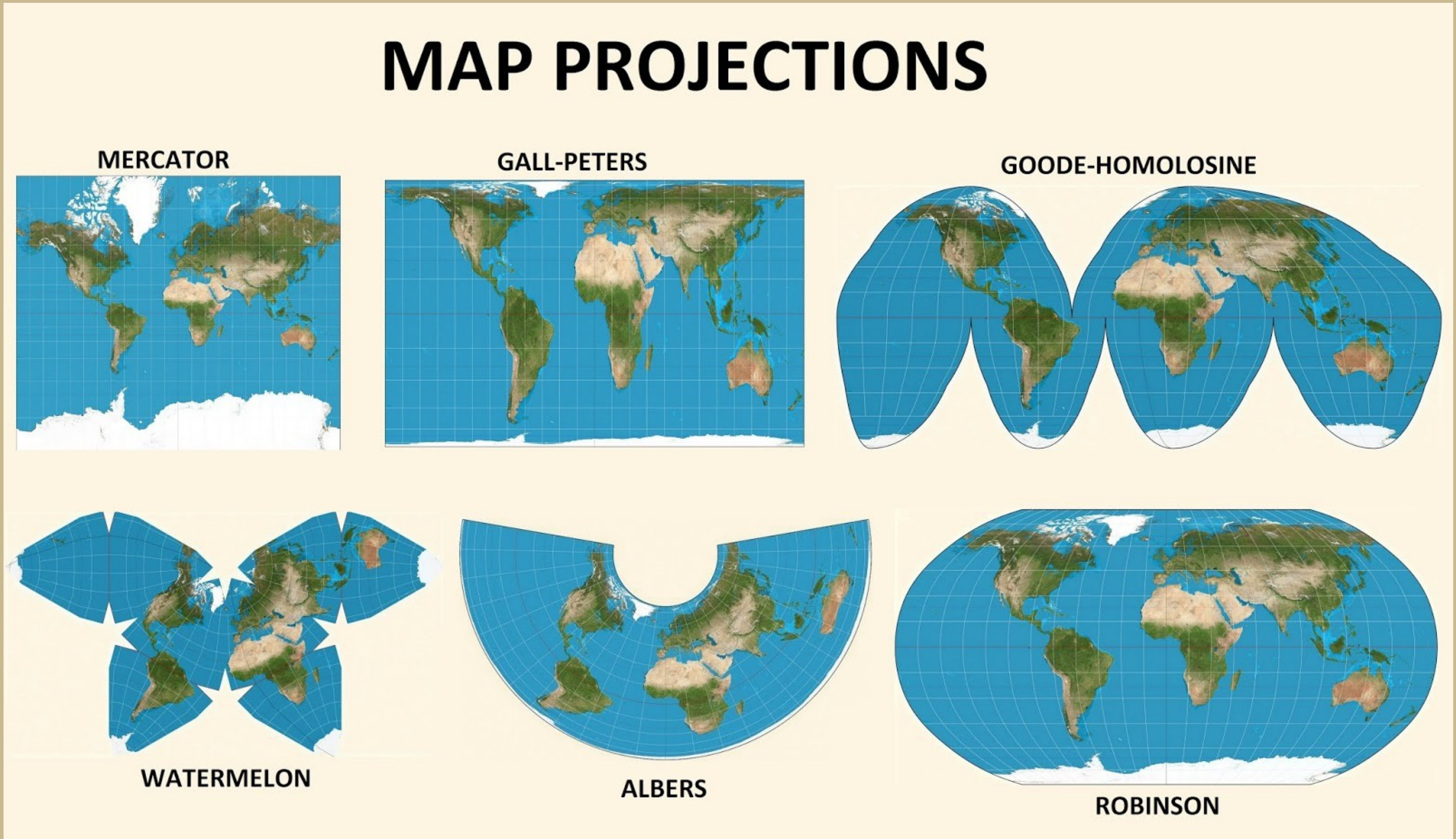
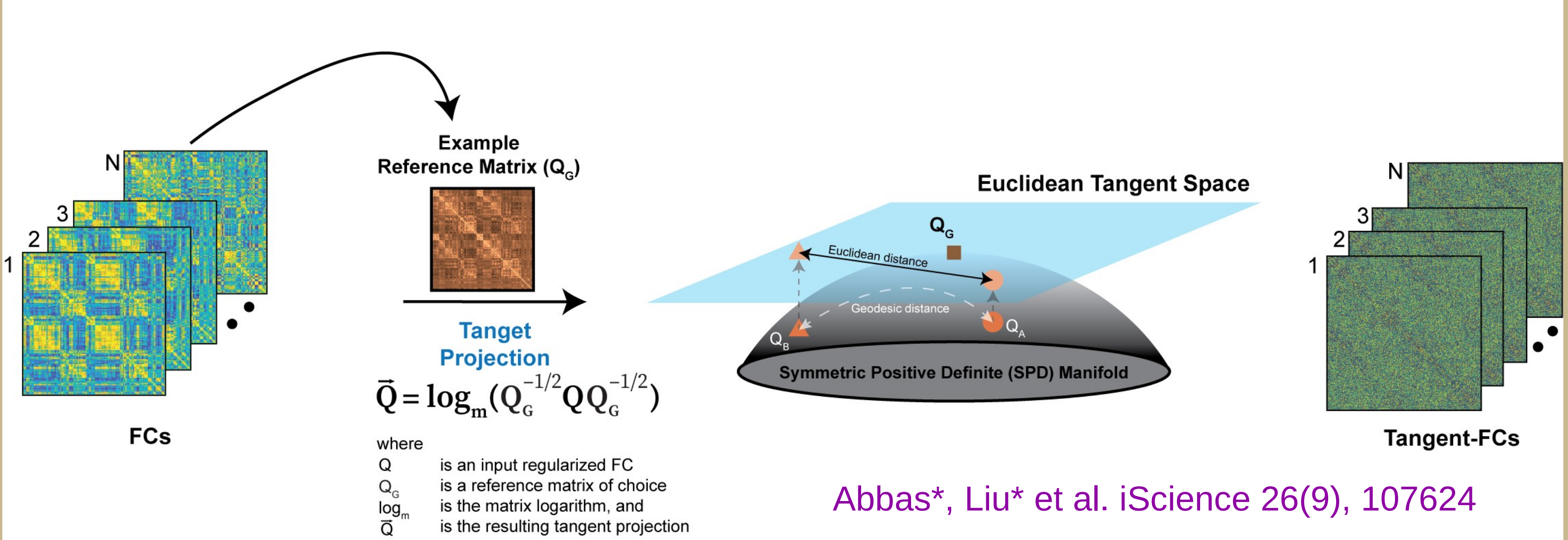

MAP PROJECTIONS
MERCATOR
GALL-PETERS
GOODE-HOMOLOSINE
WATERMELON
ALBERS
ROBINSON

Tangent Space Projection



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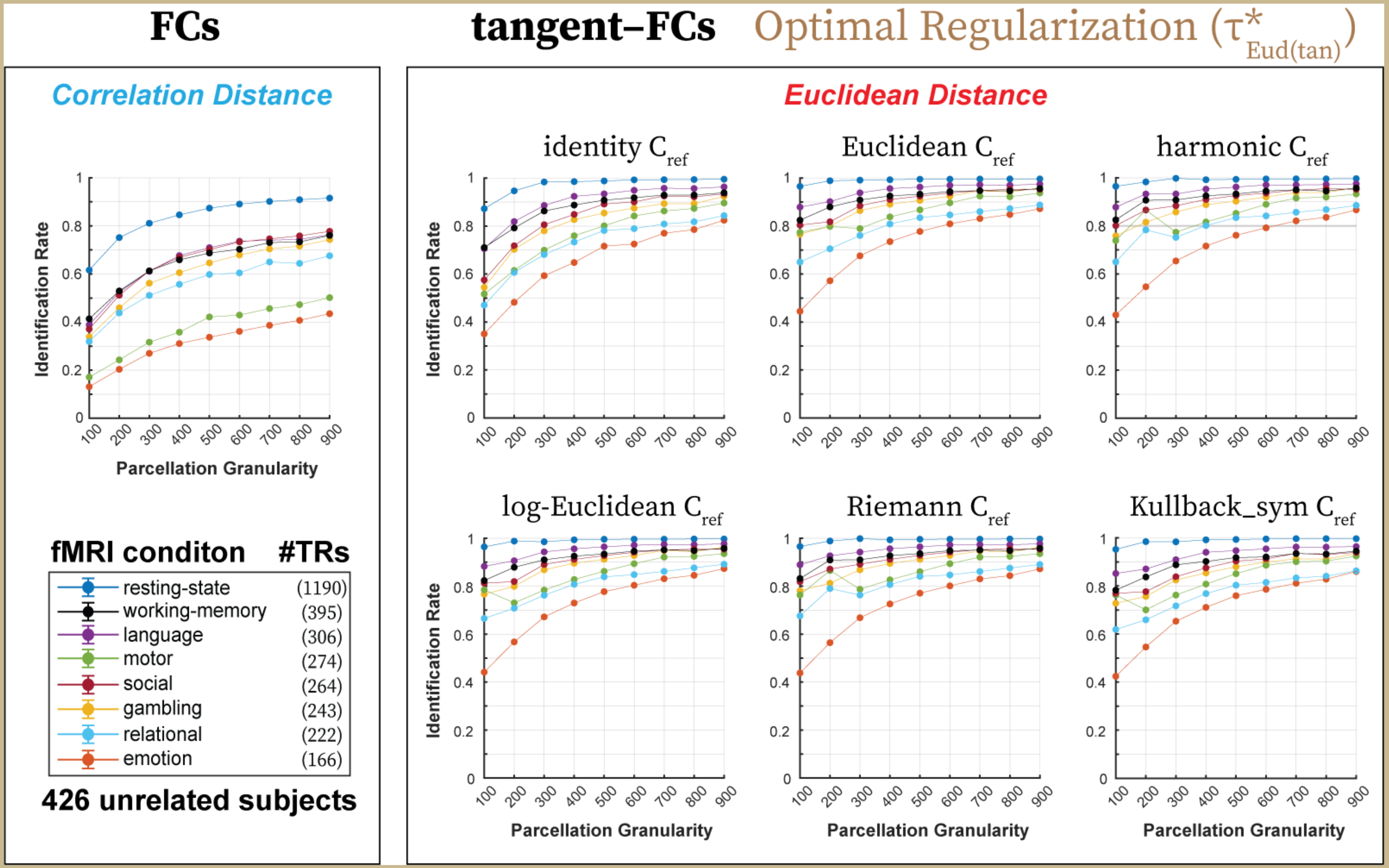
- **Euclidean distance between tangent FCs preserve the underlying geodesic distances between FCs** (in the SPD manifold)
- When performing a tangent space projection wrt a reference Q_G, **tangent FCs become orthogonal** to the reference. In essence, **we are removing common connectivity patterns** from each individual FC (also known as whitening).
- A tangent FC **is not a correlation matrix**. It is in between a correlation matrix and a precision matrix. (Dadi et al. 2019)
- **Tangent Functional couplings are i.i.d** (Varoquaux et al. 2010, Dadi et al. 2019) This is a key property for developing models that associate functional couplings with behavior, cognition or disease progression.



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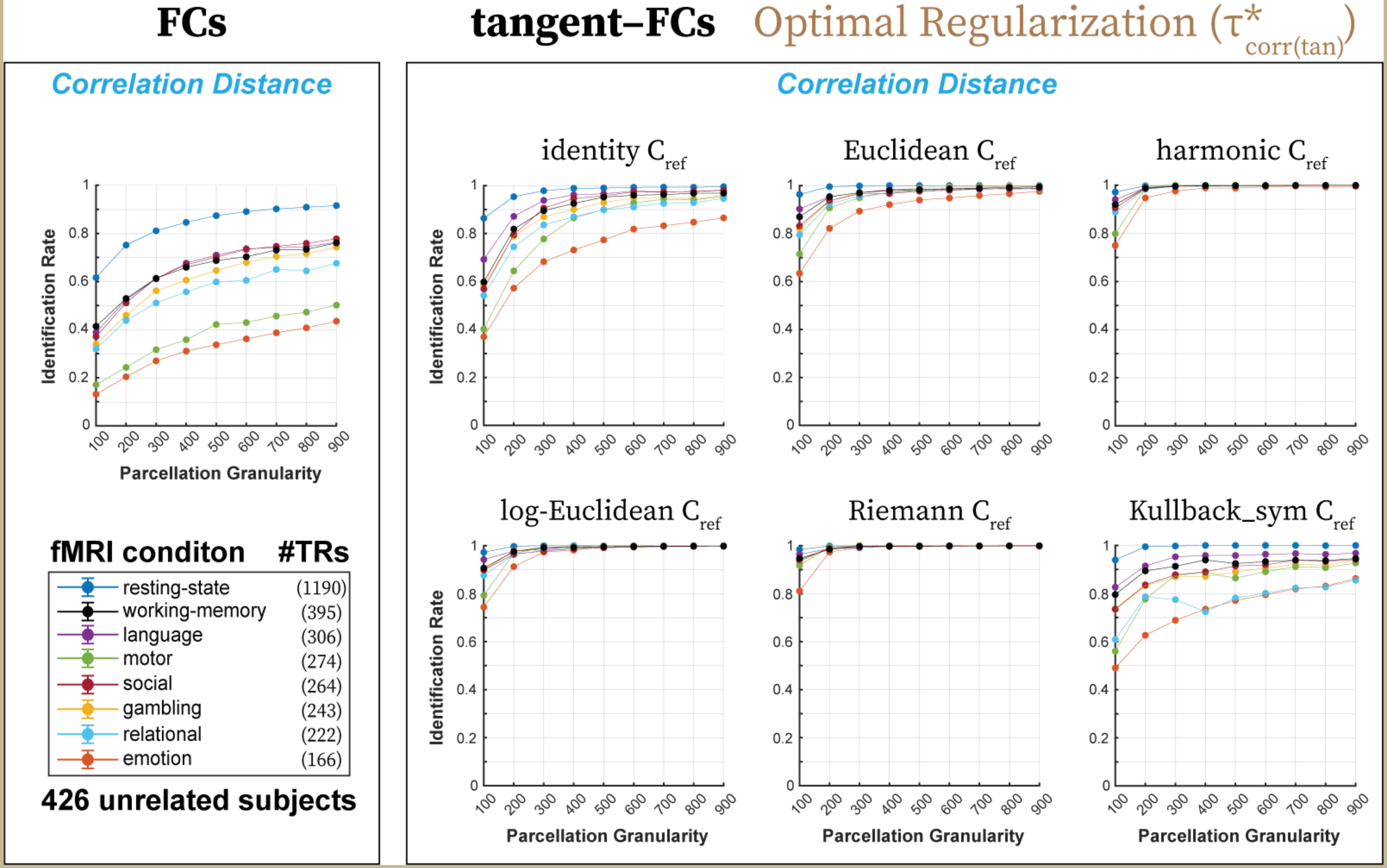

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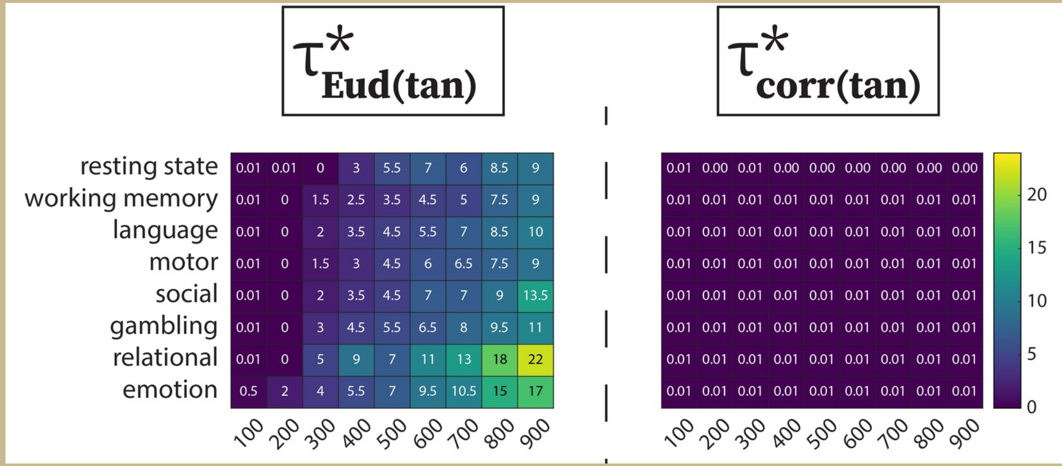
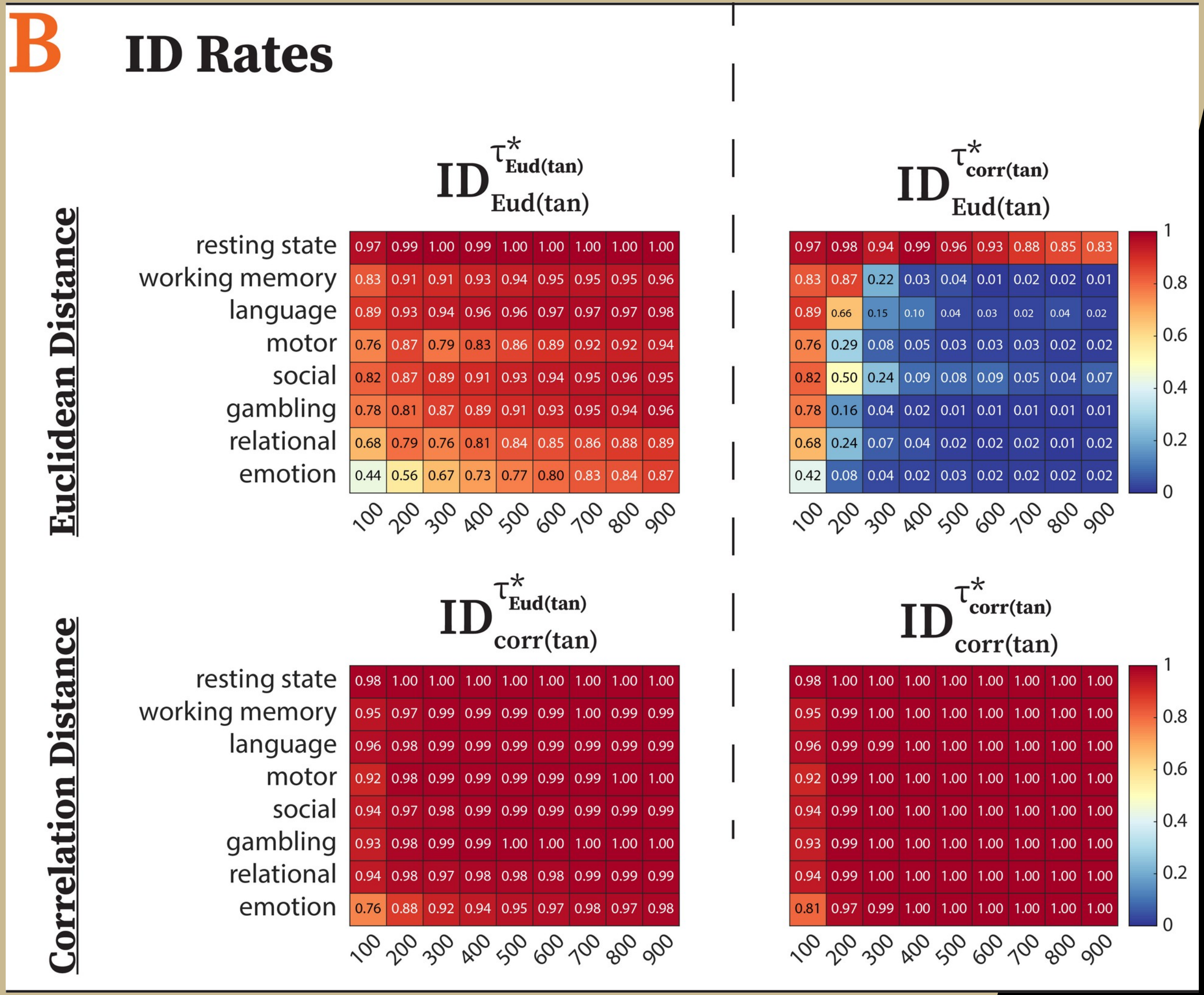


Abbas*, Liu* et al. iScience 26(9), 107624



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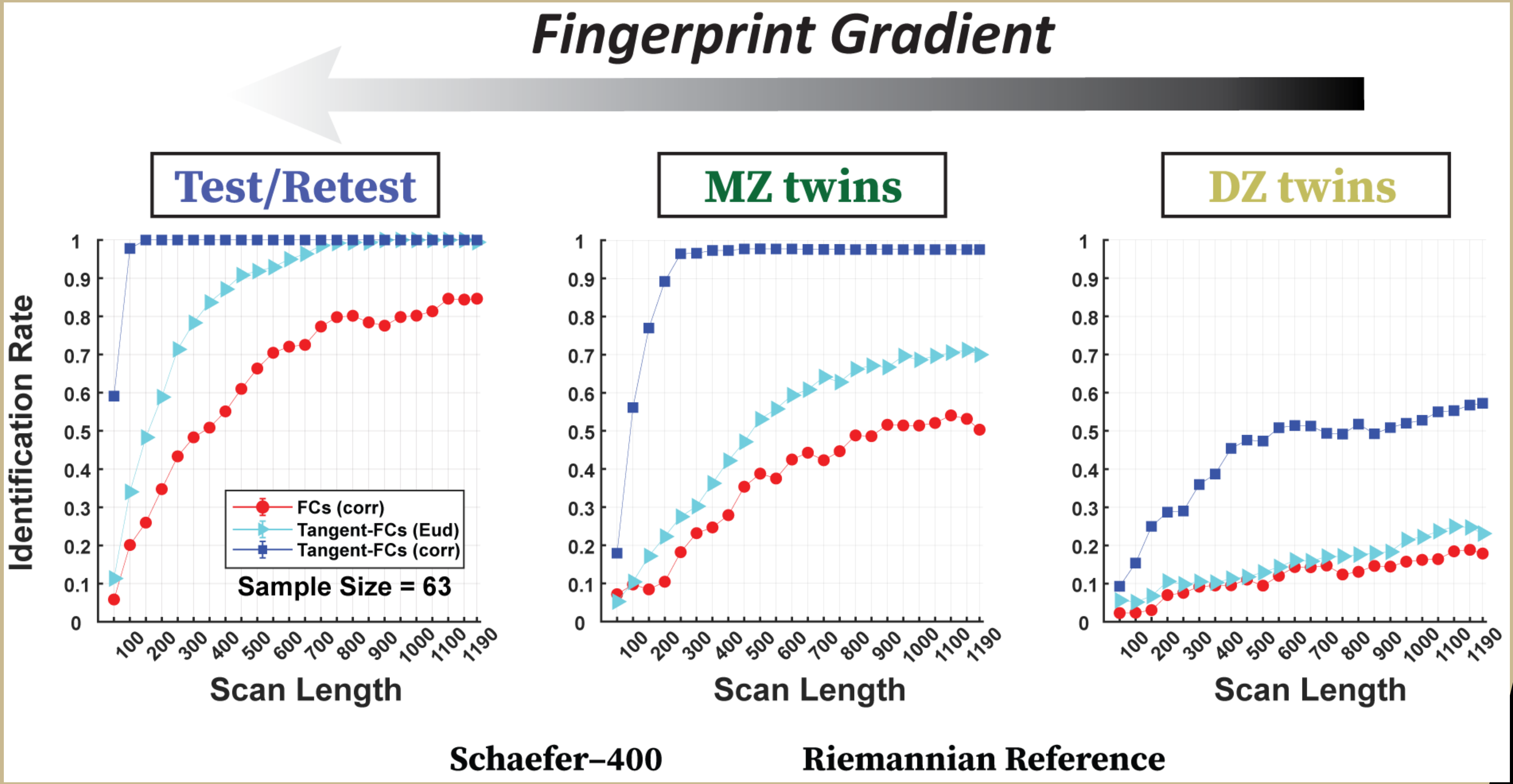

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Our results showed that identification rates are systematically higher when using tangent-FCs. Specifically, we found:

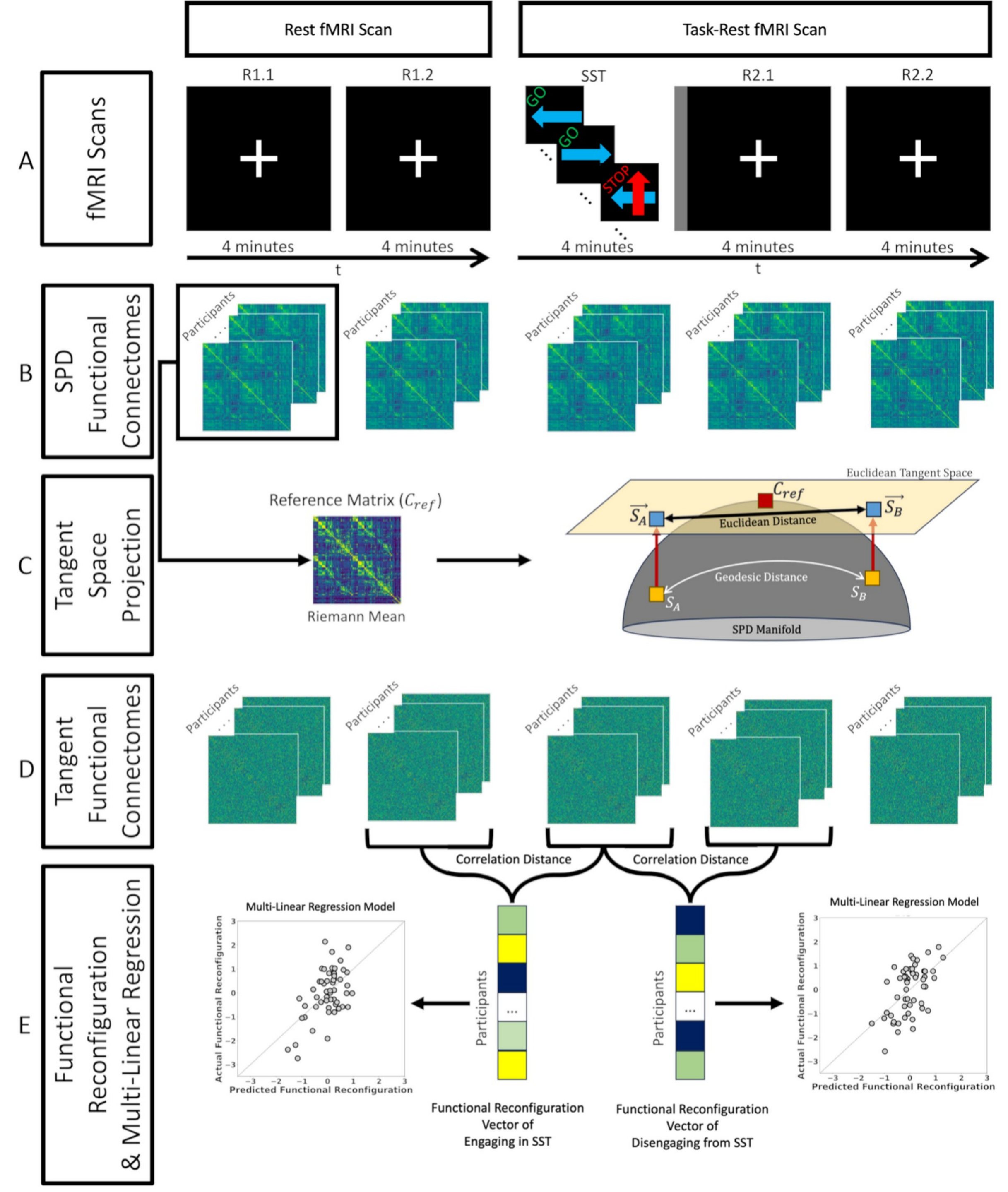
(i) **Riemann and log-Euclidean matrix references** systematically led to higher ID rates.

(ii) In tangent-FCs, main-diagonal **regularization prior to tangent space projection was critical for ID rate when using Euclidean distance**, whereas barely affected ID rates when using correlation distance.

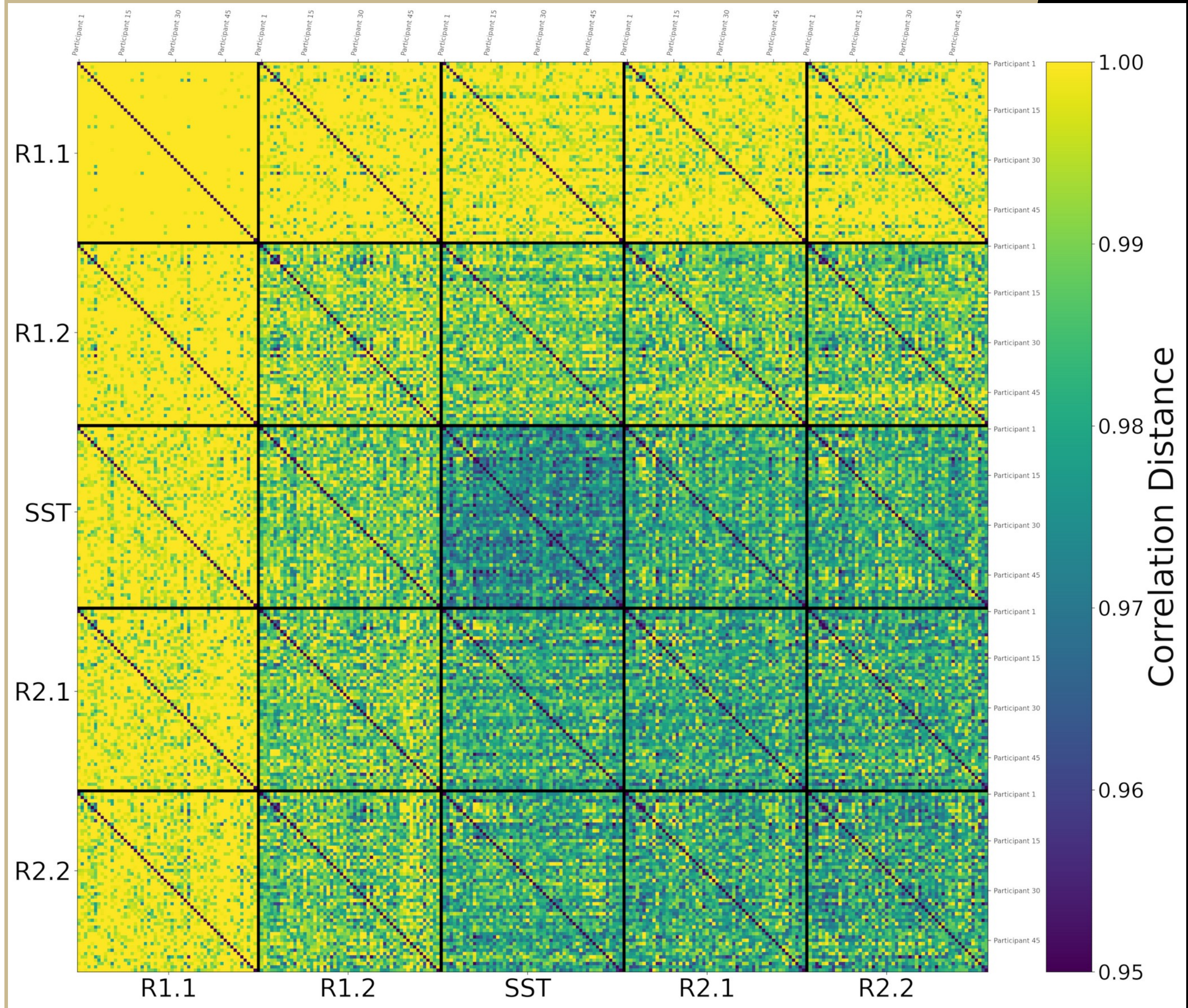
(iii) **ID rates were dependent on condition and fMRI scan length.**

(iv) **Parcellation granularity was key for ID rates in FCs, as well as in tangent-FCs with fixed regularization, whereas optimal regularization of tangent-FCs mostly removed this effect**.

(v) **Correlation distance in tangent-FCs outperformed any other configuration** of distance on FCs or on tangent-FCs across the fingerprint gradient (here sampled by assessing test-retest, Monozygotic and Dizygotic twins).



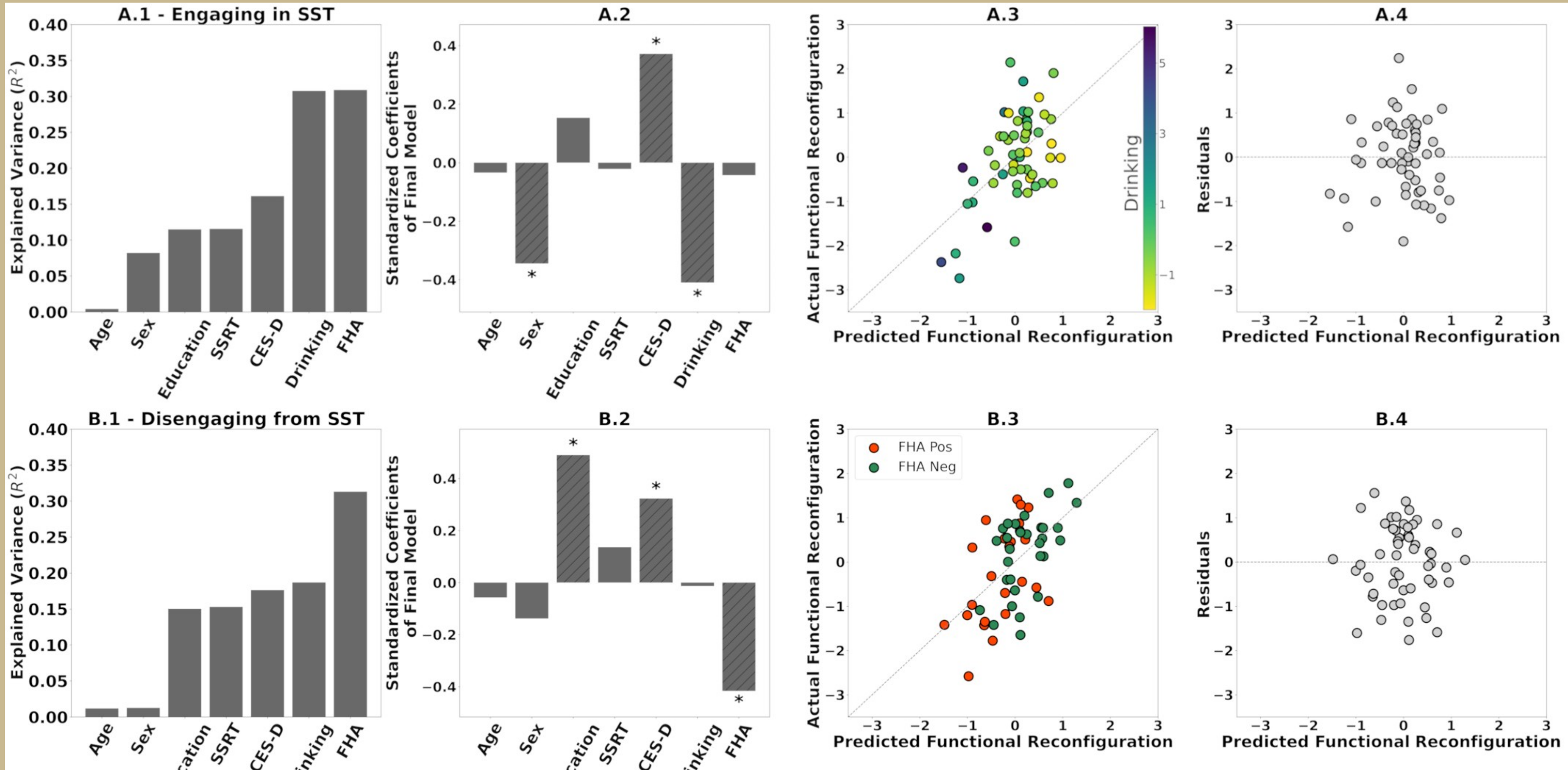
Meta identifiability matrix based on correlation distance



Moghaddam et al., under review

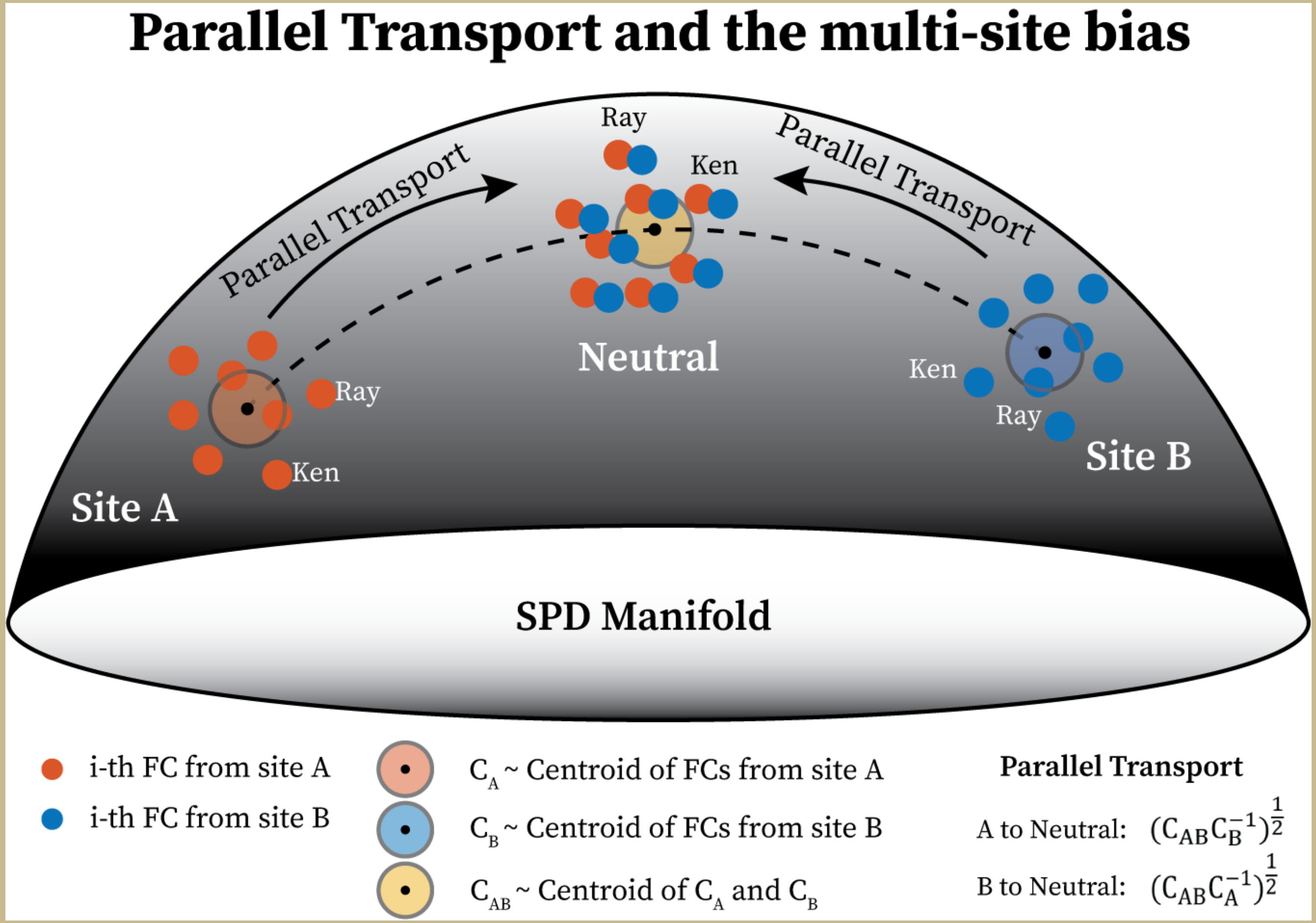
Hypothesis: functional reconfigurations when transitioning in/from a task would be influenced by family history of alcohol use disorder (FHA) and other AUD risk factors.

Results: Multilinear regression model results showed that engaging and disengaging functional reconfiguration were driven by different AUD risk factors. Functional reconfiguration when engaging in the SST was negatively associated with recent drinking. When disengaging from the SST, however, functional reconfiguration was negatively associated with FHA.



Moghaddam et al., under review

Further work/applications



Thank you team. For everything you do.

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Publications

2024

Longitudinal changes in resting state fMRI brain self-similarity of asymptomatic high school American football athletes (2024) B Fitzgerald, S Bari, Vike, TA Lee, RJ Lycke, JD Auger, LJ Leverenz, E Nauman, **J Goñi** & TM Talavage. *Scientific Reports* 14, 1747.

Homological Landscape of Human Brain Functional Sub-Circuits. (2024) D Duong-Tran, R Kaufmann , J Chen, X Wang, S Garai, FH Xu, J Bao, E Amico, AD Kaplan, G Petri, **J Goñi,** Y Zhao, L Shen. *Mathematics* 12(3):455.

2023

Matrix-variate Regression for Sparse, Low-rank Estimation of Brain Connectivities Associated with A Clinical Outcome (2023) D Brzyski, X Hu, **J Goñi**, B Ances, TW Randolph, J Harezlak. *IEEE Transactions on Biomedical Engineering. Accepted.*

Tangent functional connectomes uncover more unique phenotypic traits (2023) **K Abbas*, M Liu*, M Wang,** D Duong-Tran, U Tipnis, E Amico, AD Kaplan, M Dzemidzic, D Kareken, BM Ances, J Harezlak, **J Goñi**. *iScience* 26(9), 107624. https://doi.org/10.1016/j.isci.2023.107624 ***Download Figure 8 code and data here. Download Figure 10 code and data here.***

Intra and Inter-Individual Variability in Functional Connectomes of Patients with First Episode of Psychosis (2023) A Tepper, JV Núñez, JP Ramirez Mahaluf, JM Aguirre, D Barbagelata, E Maldonado, CD Dellarossa, R Nachar, A Gonzalez-Valderrama, J Undurraga, **J Goñi**, N Crossley. *NeuroImage Clinical 38*, 103391

2022

A comparison of techniques for deriving clustering and switching scores from verbal fluency word lists (2022) J Bushnell, D Svaldi, MR Ayers, S Gao, F Unverzagt, J Del Gaizo, VG Wadley, RK, **J Goñi,** DG Clark. *Front. Psychol* 13, 743557.

Incorporation of spatial- and connectivity-based cortical brain region information in regularized regression: Application to Human Connectome Project data (2022) A Steiner, K Abbas, D Brzyski, K Pączek, TW Randolph, **J Goñi,** J Harezlak. *Frontiers in Neuroscience* 16

Investigating cognitive ability using action-based models of structural brain networks. V Arora, **E Amico, J Goñi,** M Ventresca. *Journal of Complex Networks* 10(4)

2021

Functional Connectome Fingerprint Gradients in Young Adults (2021) **U Tipnis, K Abbas,** E Tran, E Amico, L Shen, AD Kaplan, **J Goñi.** *arXiv preprint.*

A structural connectivity disruption one decade before the typical age for dementia: a study in healthy subjects with family history of Alzheimer´s disease (2021). Ramírez-Toraño, **K Abbas**, R Bruña, S Marcos de Pedro, N Gómez-Ruiz, A Barabash, E Pereda, A Marcos, R Lopez Higes, F Maestu*, **J Goñi***. *Cerebral Cortex Communications* 2(4), tgab051

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Optimizing Differential Identifiability Improves Connectome Predictive Modeling of Cognitive Deficits in Alzheimer's Disease (2021) DO Svaldi, **J Goñi, K Abbas, E Amico**, DG Clark, C Muralidharan, M Dzemidzic, JD West, SL Risacher, AJ Saykin, LG Apostolova (for the Alzheimer's Disea Neuroimaging Initiative). *Human Brain Mapping* 42 (11) 3500-3516. ***Download Idiff-CPM code here***

Improving functional connectome fingerprinting with degree-normalization (2021) B Chiêm, **K Abbas**, E Amico, **DA Duong-Tran**, F Crevecoeur, **Goñi**. *Brain Connectivity* 12(2), 180-192. ***Download degree-normalization code here***

A morphospace framework to assess configural breadth based on brain functional networks.(2021) **D Duong-Tran, K Abbas, E Amico**, B Corominas-Murtra, M Dzemidzic, D Kareken, M Ventresca, **J Goñi**. *Network Neuroscience 5*(3), 666-688.

Geodesic distance on optimally regularized functional connectomes uncovers individual fingerprints (2021) **K Abbas, M Liu,** M Venkatesh, E Amico, AD Kaplan, M Ventresca, L Pessoa, J Harezlak, **J Goñi.** *Brain Connectivity* 11(5), 333-348. ***Download regularization code here***

Towards an information theoretical description of communication in brain networks (2021) **E Amico, K Abbas, D Duong-Tran, U Tipnis, M Rajapandian,** E Chumin, M Ventresca, J Harezlak, **J Goñi.** *Network Neuroscience* 5(3), 646–665.

Interactive Visualization of Deep Learning for 3D Brain Data Analysis (2021) **H Li, S Fang, J Goñi, AJ Saykin, L Shen.** *IEEE 20th International Conference on Cognitive Informatics & Cognitive Computing* pp. 85-91, Banff, AB, Canada,

2020

Identifiability of structural networks of nonlinear electronic oscillators (2020) VP Vera-Avila, R Sevilla-Escoboza, **J Goñi**, RR Rivera-Durón, JM Buldú, *Scientific Reports*, 10(1), 1-11.

A Sparsity Inducing Nuclear-Norm Estimator (SpINNEr) for Matrix-Variate Regression in Brain Connectivity Analysis (2020) D Brzyski, X Hu, **J Goñi**, B Ances, TW Randolph, J Harezlak, *arXiv preprint*

Functional network connectivity in early-stage schizophrenia (2020). TA Hummer,, MG Yung, **J Goñi**, J, SK Conroy, MM Francis, NF Mehdiyoun, Breier, *Schizophrenia Research*, 18, 107-115.

GEFF: Graph Embedding for Functional Fingerprinting (2020) **K Abbas, E Amico**, DO Svaldi, **U Tipnis, DA Duong-Tran, M Liu, M Rajapandia** J Harezlak, BM Ances, **J Goñi,** *NeuroImage 221, 117181.* ***Download GEFF code here***

Multi-timescale hybrid components of the functional brain connectome: A bimodal EEG-fMRI decomposition (2020) J Wirsich, **E Amico**, AL Gira **J Goñi.** S Sadaghiani. *Network Neuroscience* 4(3), 658-677.

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Universidad de Navarra
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Joaquín Goñi, Ph.D

CONN*plexity* Lab
Purdue University
West Lafayette, Indiana, USA
jgonicor@purdue.edu
@jgonicor

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