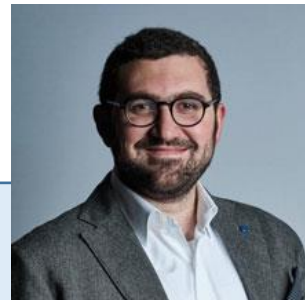


RECENT ADVANCES IN WHOLE-BRAIN, CONNECTOME-BASED NEUROPHYSIOLOGICAL MODELLING: THEORETICAL PERSPECTIVES AND CLINICAL IMPLICATIONS



Davide Momi

Centre for Addiction and Mental Health
University of Toronto
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Samir Simon Suweis

Padova Neuroscience Center
University of Padova
Padova, Italy



Pierpaolo Sorrentino

Institut de Neurosciences des Systèmes,
Aix-Marseille University
Marseille, France

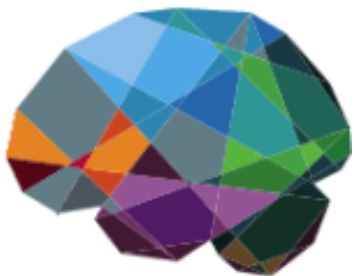
Growing interest in Whole-brain modelling

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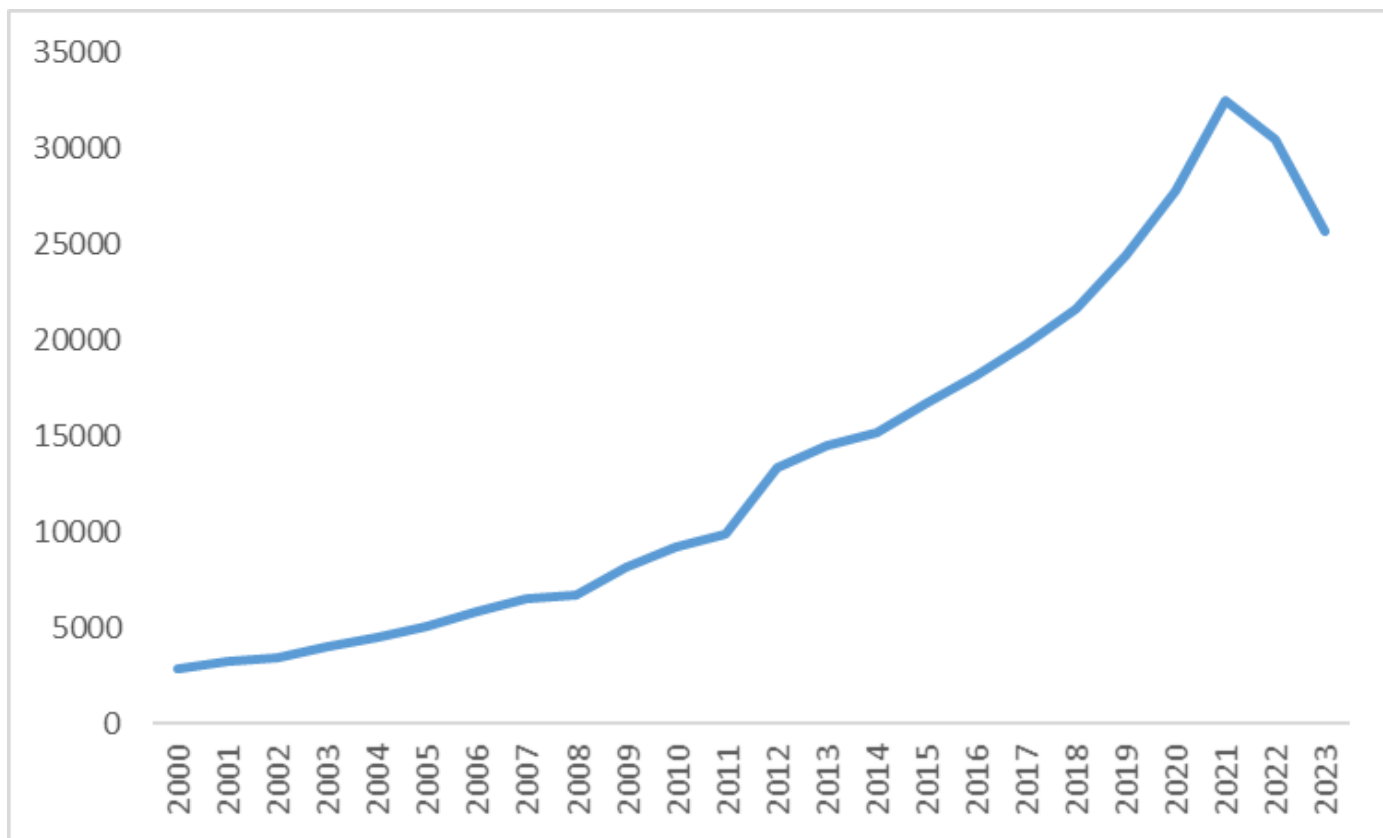


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THEVIRTUALBRAIN.

Google Scholar search “Whole-brain modelling”



OHBM's Educational Course 2023



Whole-brain, Connectome-based Models of Brain Dynamics: From Principles to Applications

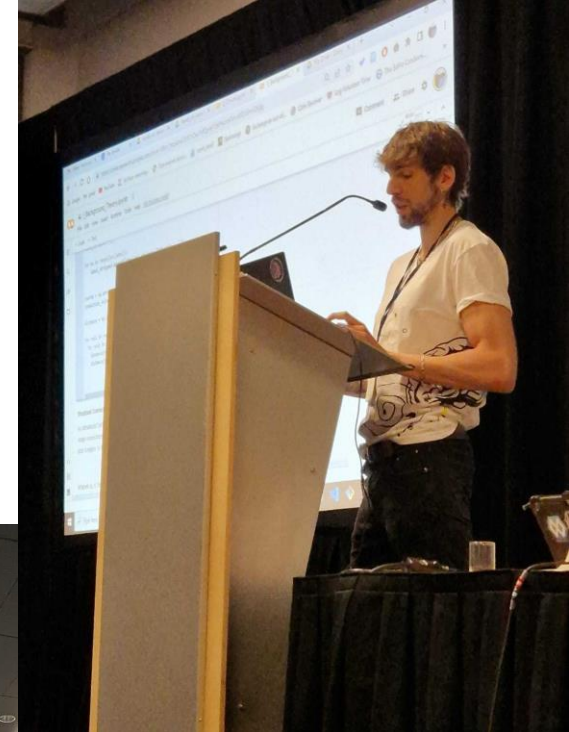
OHBM Educational Course on Whole-brain Models

OHBM 2023

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 **H B M**
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MONTRÉAL • JULY 22-26, 2023



Materials

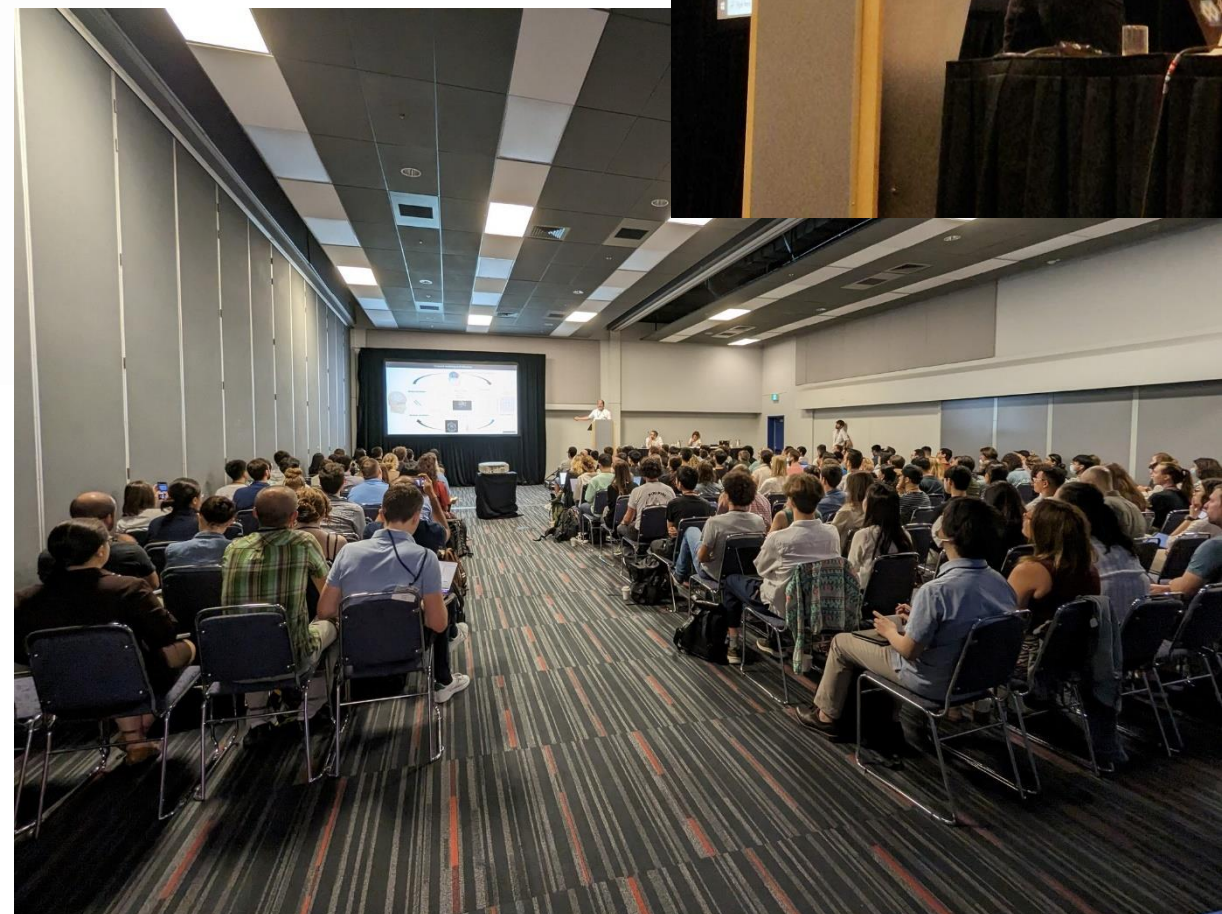
Educational Course Hands-on Materials

The entire course can be easily run in Google Colab. However, if you prefer to run the notebook on your local machine, please ensure that you have installed all the necessary dependencies.

The Google Colab can be downloaded at the following link:

LINK

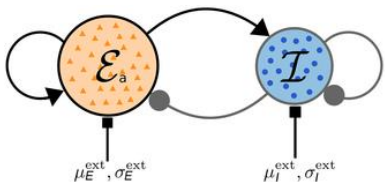
In the 'hands_on_session' folder, you will find all three notebooks necessary to follow along with the session. Additionally, the 'Talk_short_Demo' folder contains the notebooks used by some of the speakers during their theoretical talk.



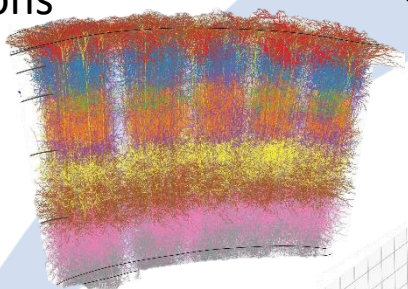
Spatial Scale in Computational Neuroscience

Structure

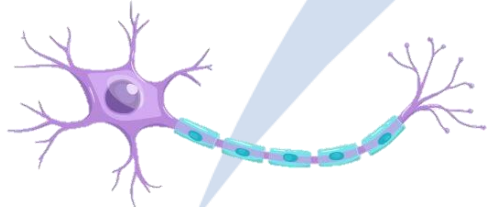
Mean-field approximation



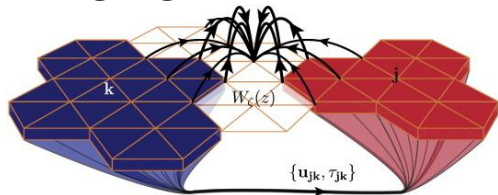
Neural Populations



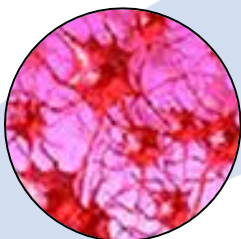
Neurons



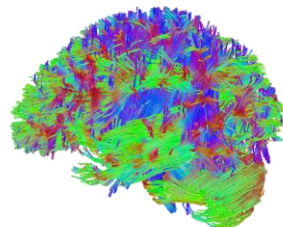
Local spatial kernel



Local Patches



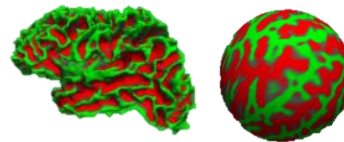
Large-range connectivity



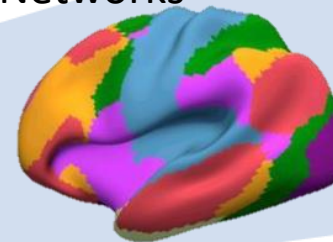
Regions



Spherical approximation



Large-scale Networks



Spatial scale

Mode 2
 ψ_2



Mode 3
 ψ_3



Mode 4
 ψ_4

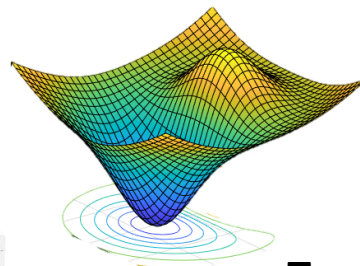


Mode N
 ψ_N

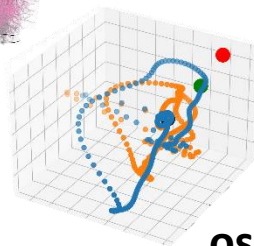


Connectivity Eigenvectors

Travelling waves



oscillations



Dynamics

Spatial Scale in Computational Neuroscience

MICROSCOPIC

MACROSCOPIC

Cell

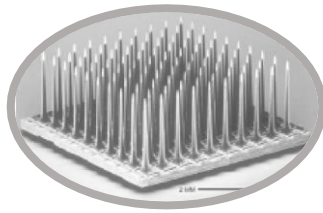
Multiple cells

Cortex region

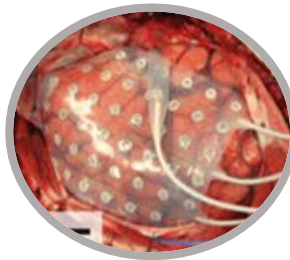
Whole brain



Single-cell recording



Microelectrode Array



ECoG



EEG



MEG



fMRI

Spatial Scale in Computational Neuroscience

MICROSCOPIC

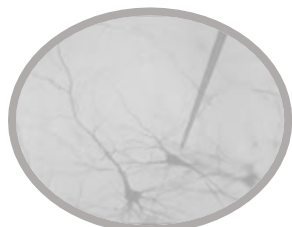
MACROSCOPIC

Cell

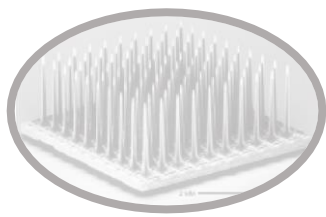
Multiple cells

Cortex region

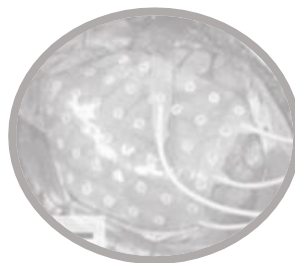
Whole brain



Single-cell recording



Microelectrode Array



ECoG



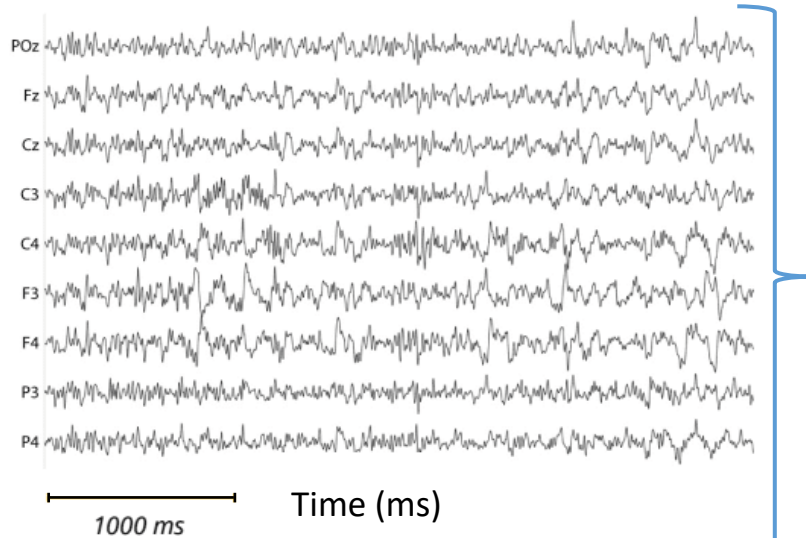
EEG



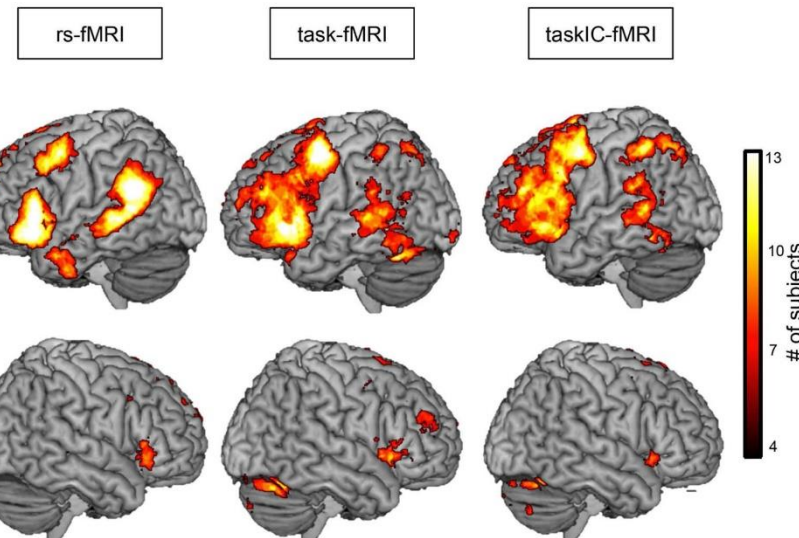
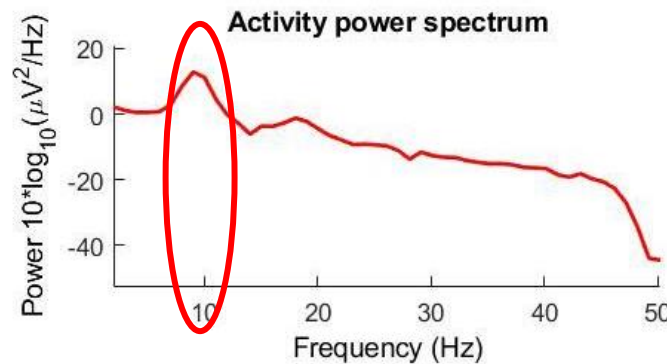
MEG



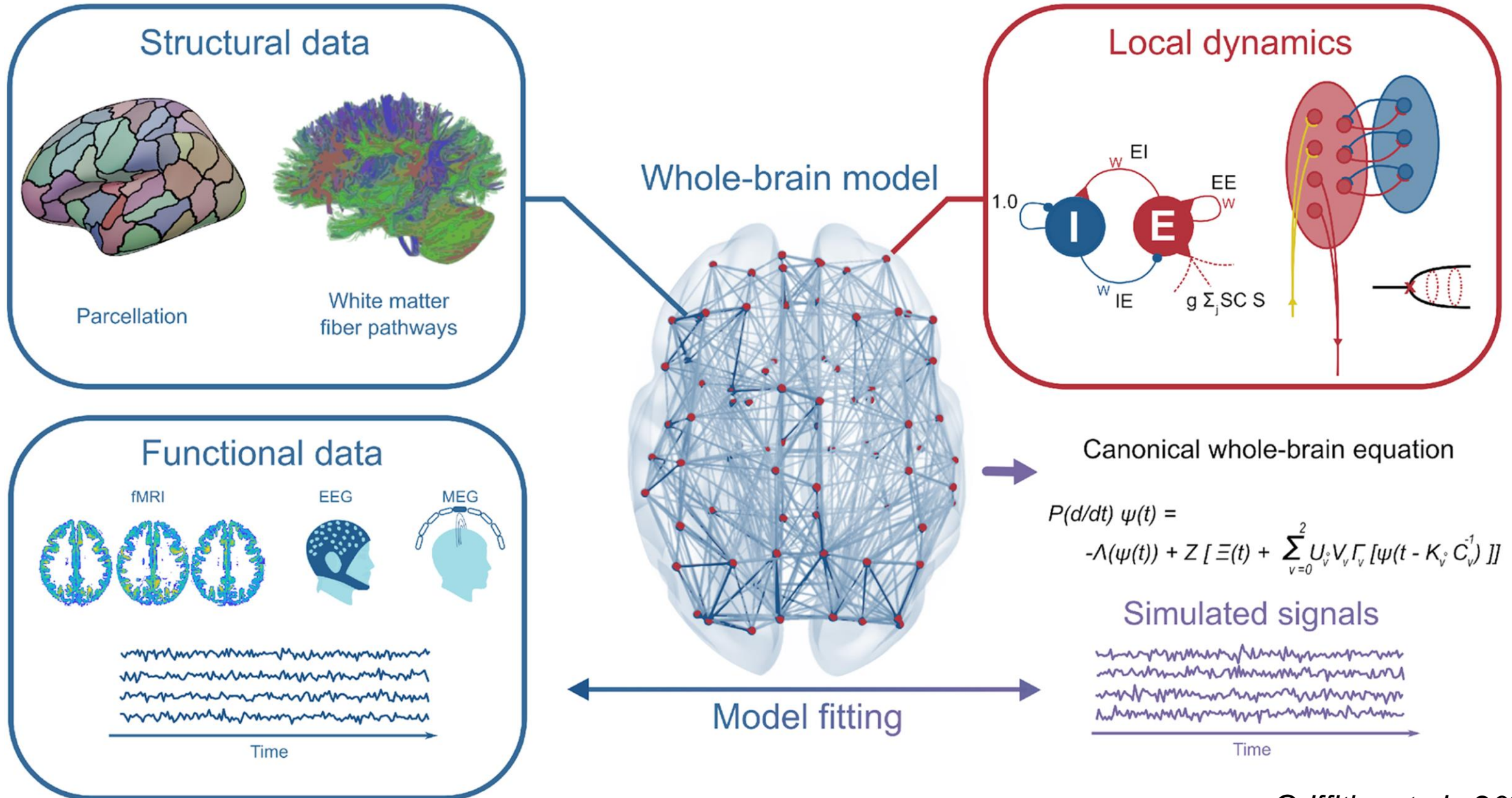
fMRI



Alpha



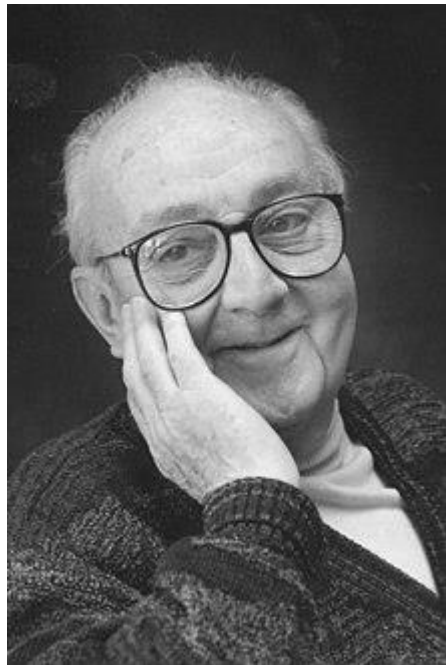
Whole-brain Modelling



We have work to do....



*“Past, Present and **Future Brains**”*




George E.P. Box

*“All models are wrong
But some are useful”*

[Home](#) > [Computational Modelling of the Brain](#) > Chapter

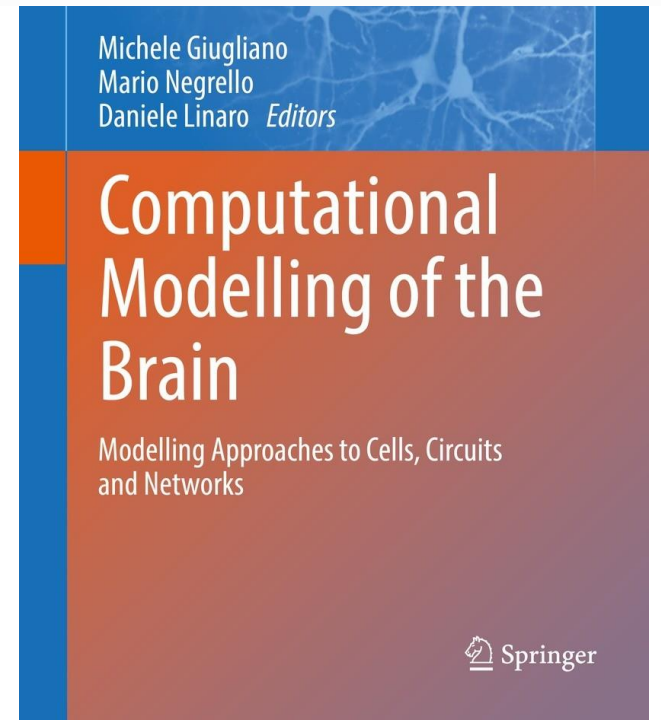
Whole-Brain Modelling: Past, Present, and Future

[John D. Griffiths](#) , [Sorenza P. Bastiaens](#) & [Neda Kaboodvand](#)

Chapter | [First Online: 08 October 2021](#)

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camh

Krembil Centre for
Neuroinformatics



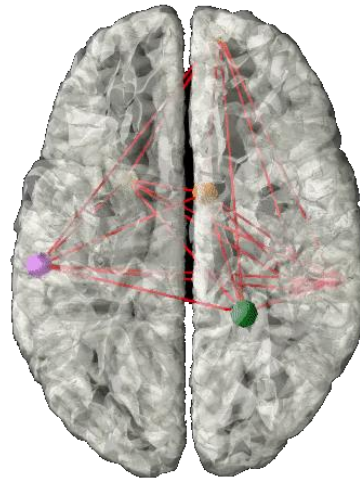
UNIVERSITY OF
TORONTO

Stanford | Keller Laboratory
PERSONALIZING NEUROTHERAPEUTICS

Dissecting the spatio-temporal connectivity dynamics of the stimulation induced signal

DAVIDE MOMI

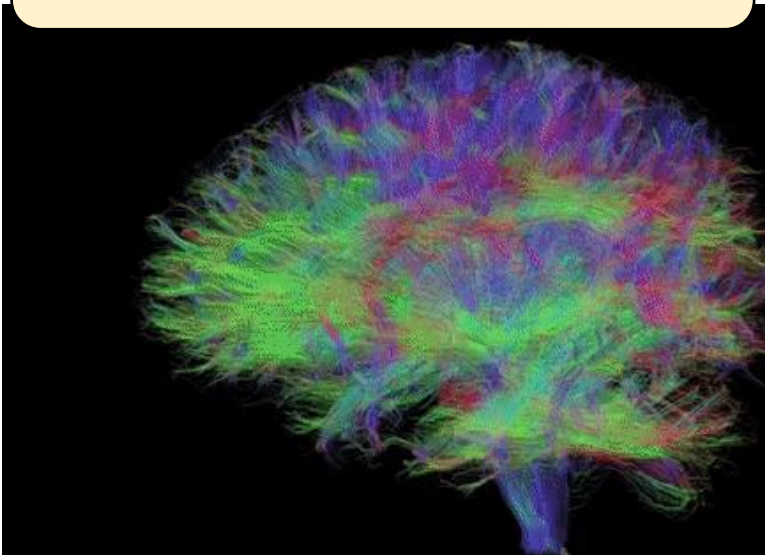
Post-Doctoral Research Fellow
Whole Brain Modelling Group
Krembil Centre for Neuroinformatics
Centre for Addiction & Mental Health(CAMH)
<https://davi1990.github.io/>
250 College St., Toronto, ON M5T 1R8



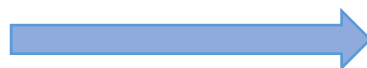
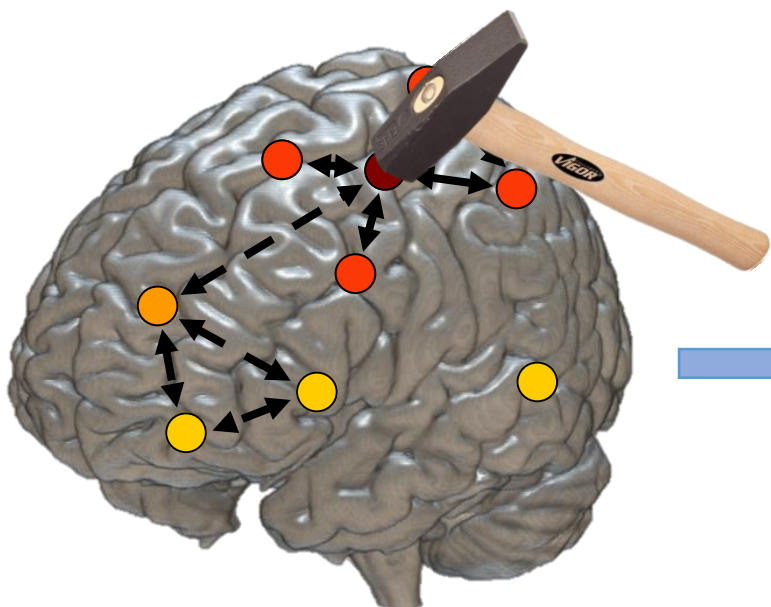
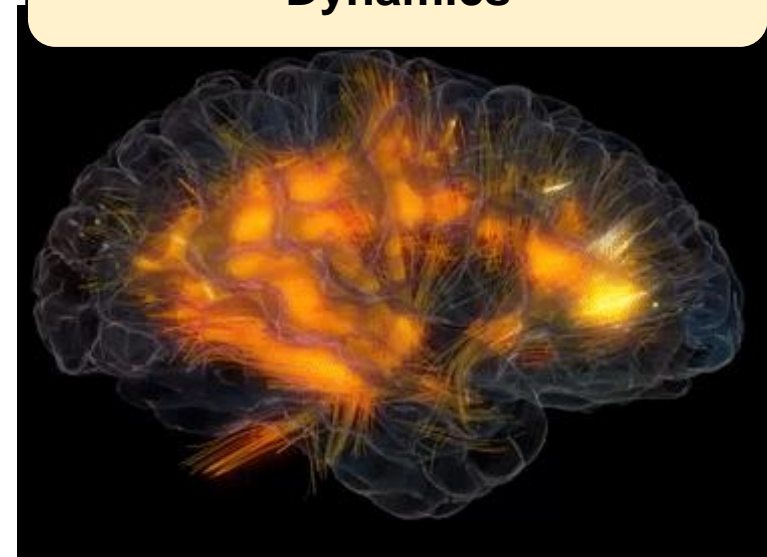
SIPF 2023
Saturday, November 11th 2023
Siena, Italy

The Perturbative Method in Neuroscience

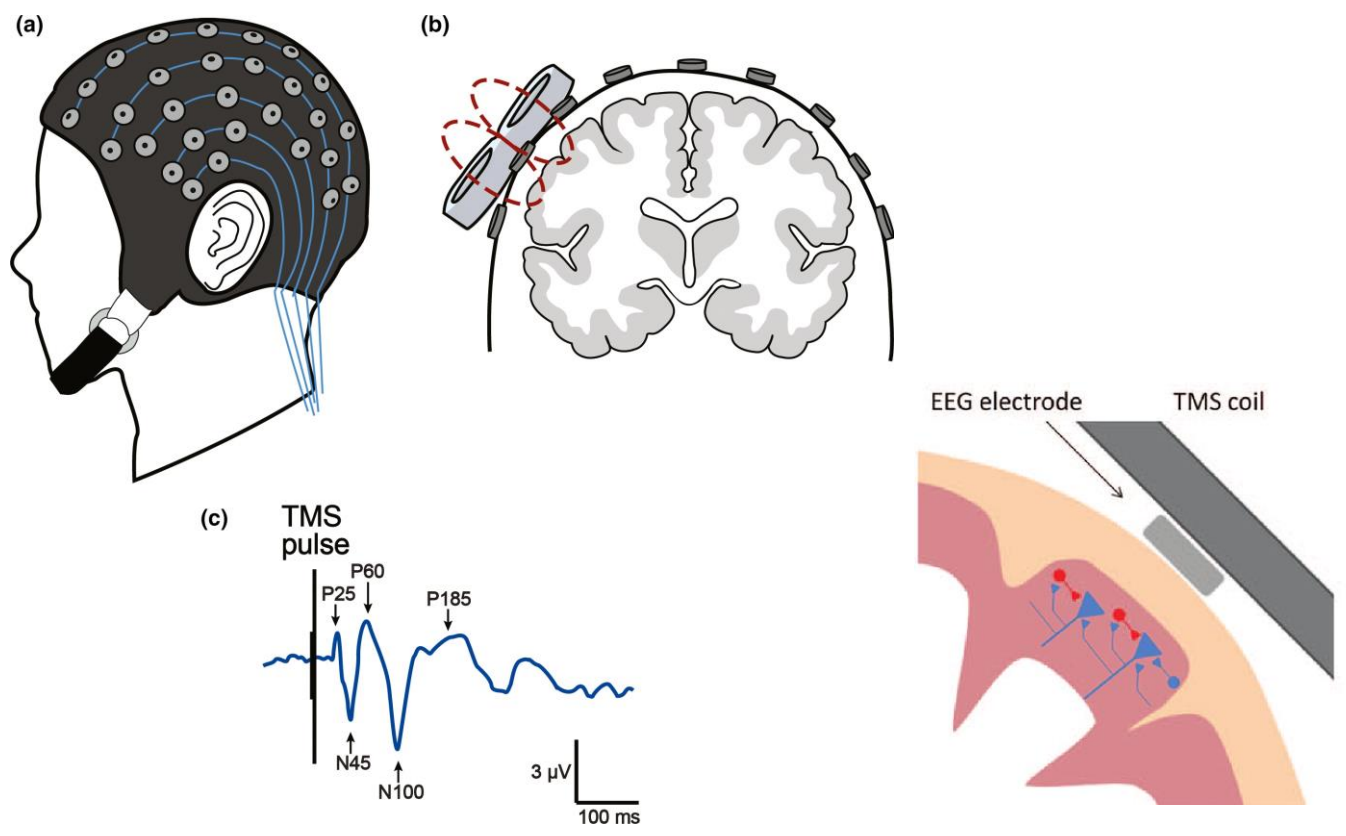
Anatomical
Connections



Functional
Dynamics



Combining Brain stimulation with ongoing EEG recordings

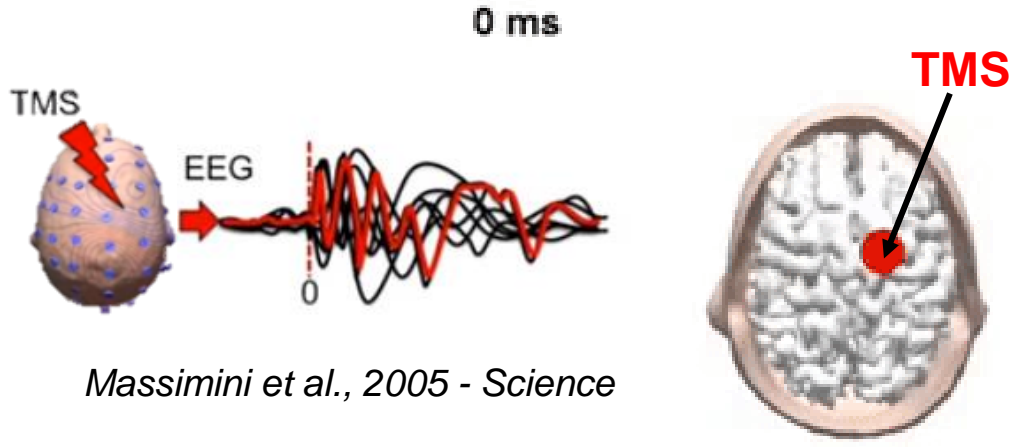


Hui et al., 2019 - Clin Pharmacol Ther

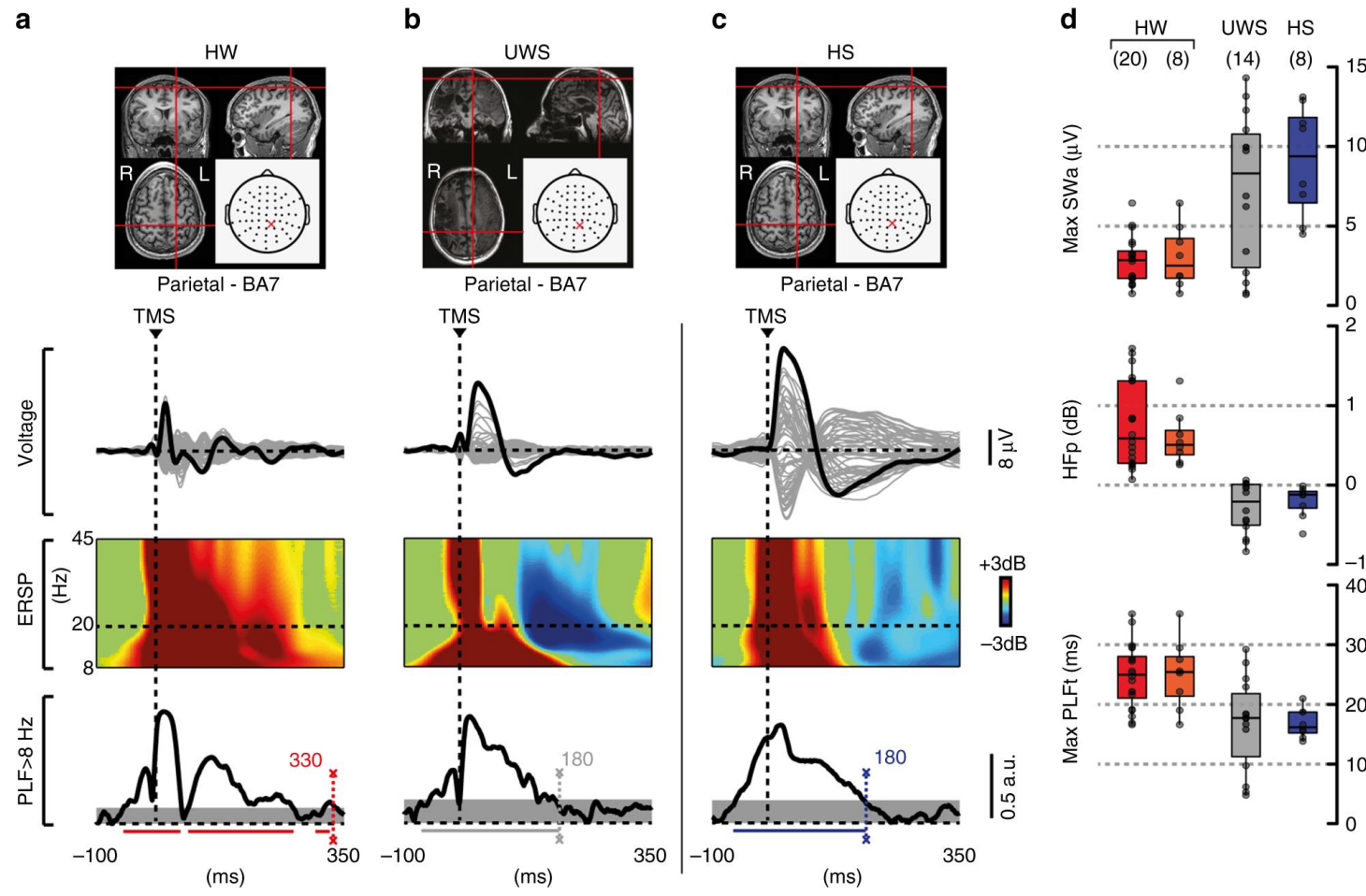
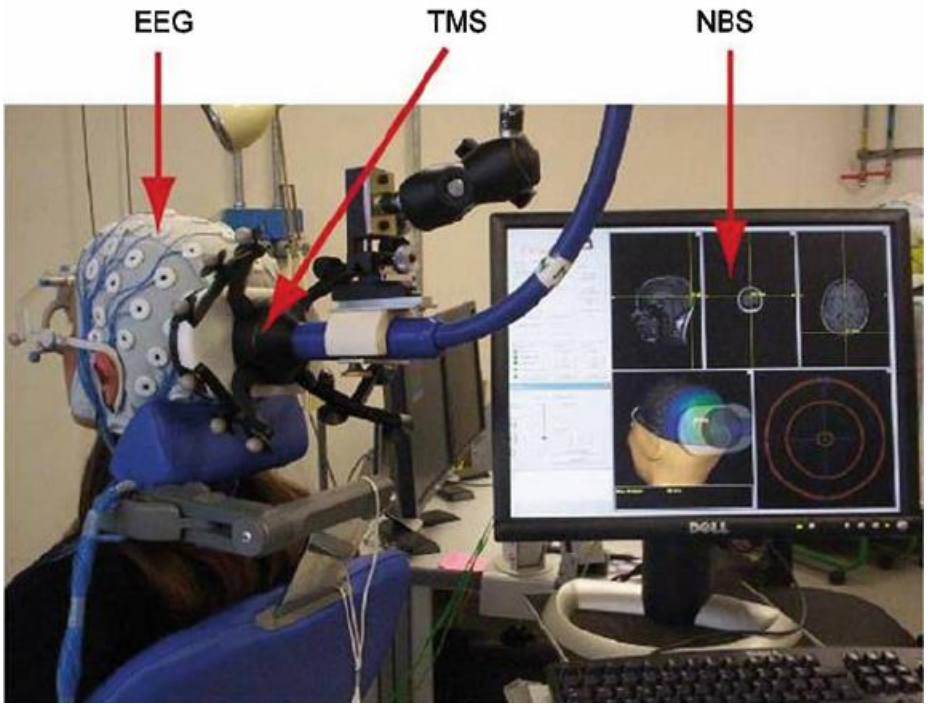


```
from TMS_memories import unprofessional_picture
```

TMS-EEG for studying brain complexity



Massimini et al., 2005 - Science



Rosanov, Fecchio et al., 2018 – Nature Communications

Recurrence is everywhere



*“Everything goes, **everything comes back**; eternally rolls the wheel of being. Everything dies, everything blossoms again; eternally runs the year of being”*

Friedrich Nietzsche



*“...poetry cannot speak without remembering the turns of the sun and moon, and the rhythm of the ocean, and the **recurrence** of human generations, the **returning waves** of life and death.”*

Robinson Jeffers



Paperman

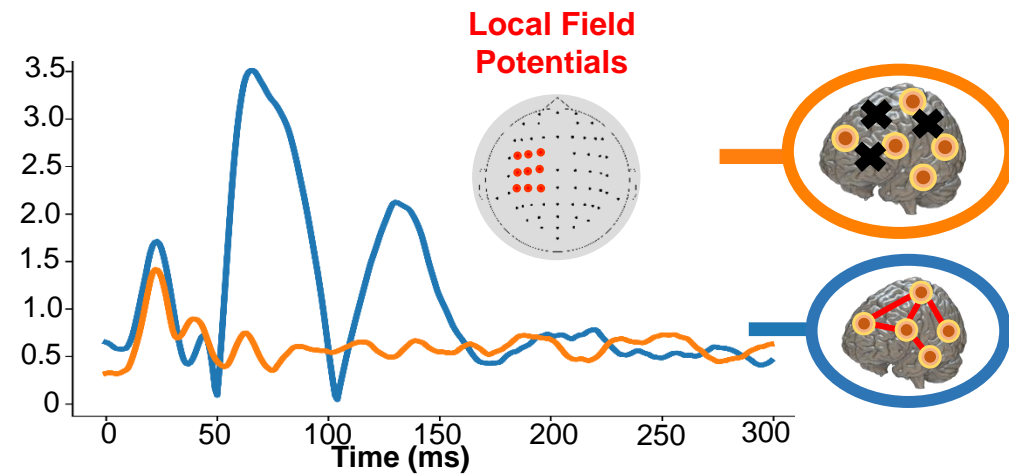
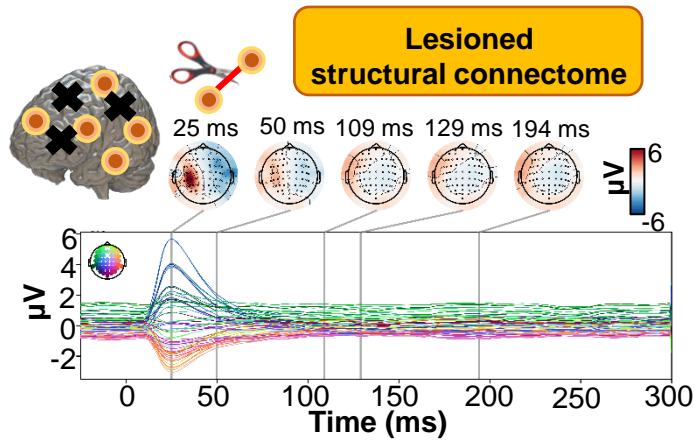
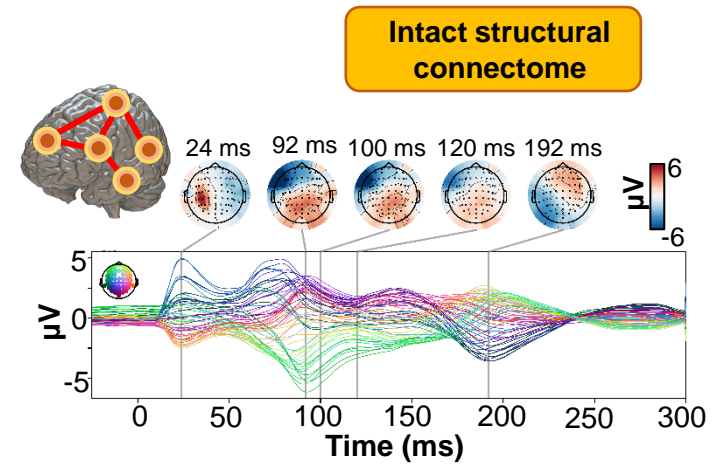
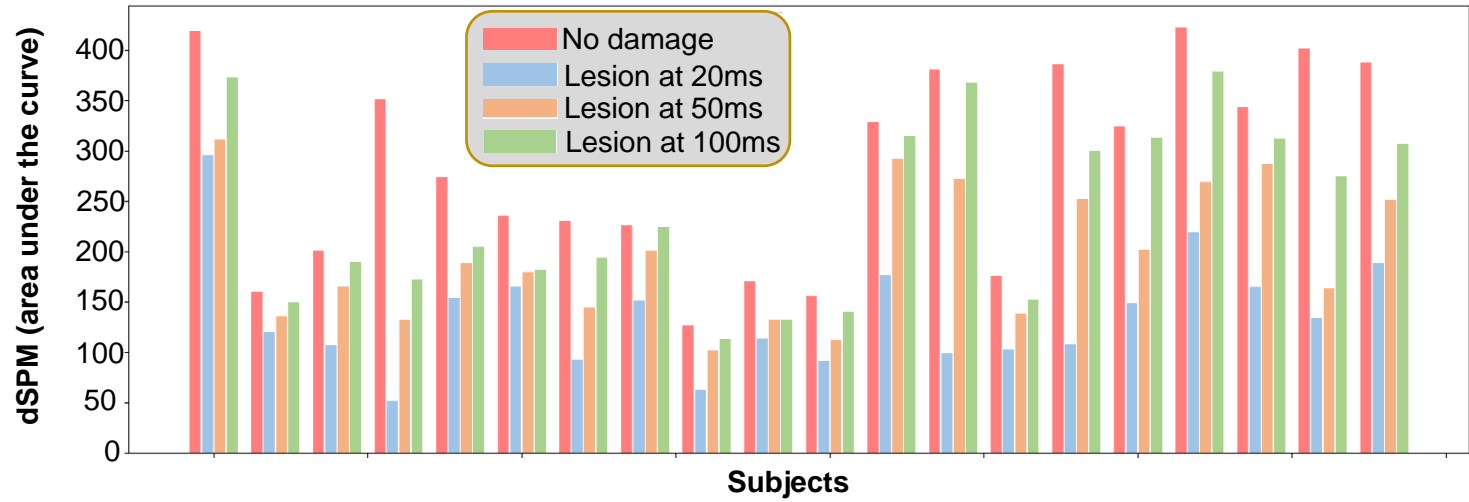
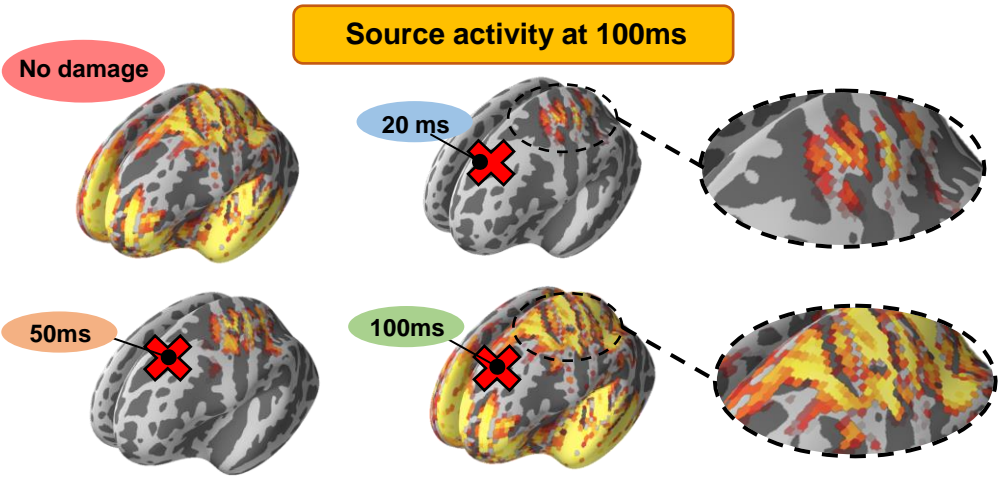


The Starry Night

What is the physio-dynamical nature of this recurrent activity?

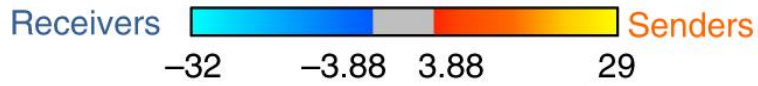
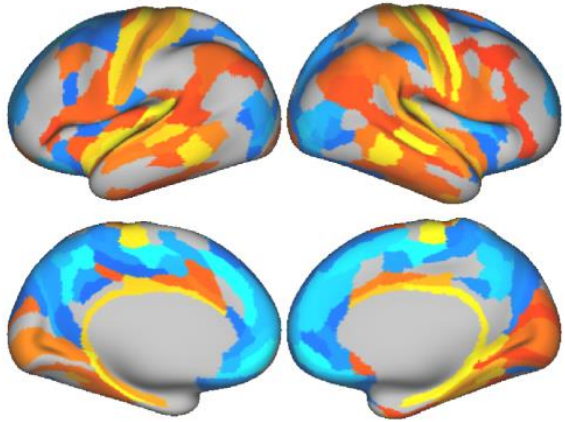


Networks propagation is affected by earlier lesions

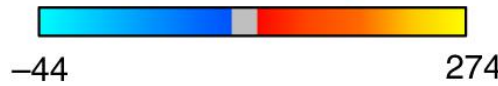
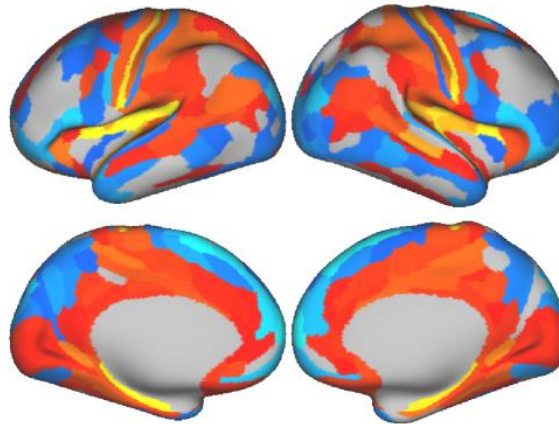


Overarching organization of large-scale brain networks

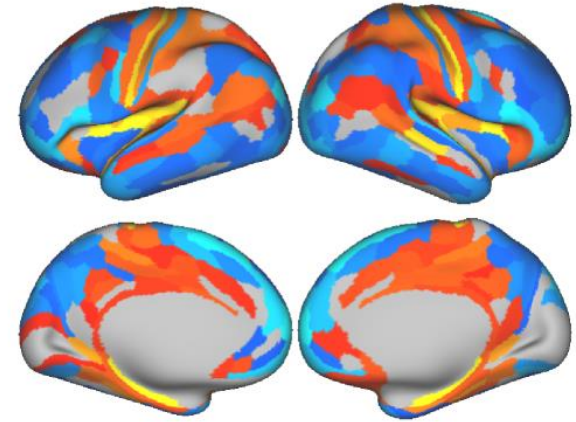
Navigation asymmetry



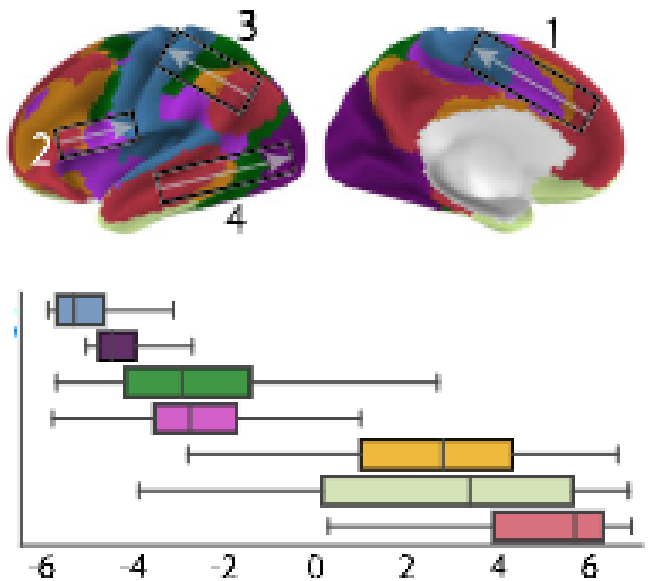
Diffusion asymmetry



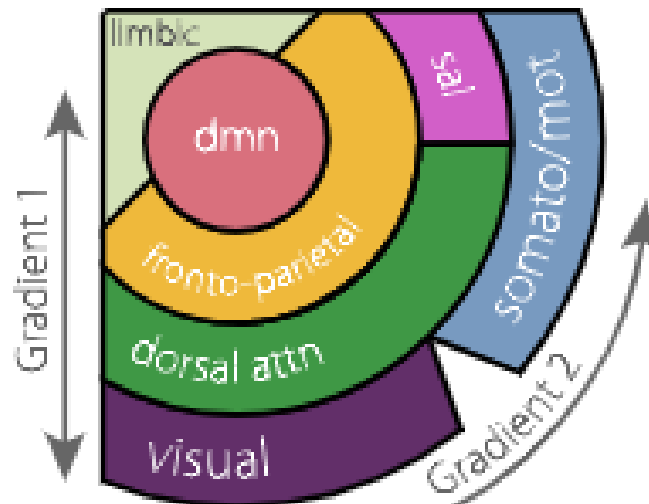
Search information asymmetry



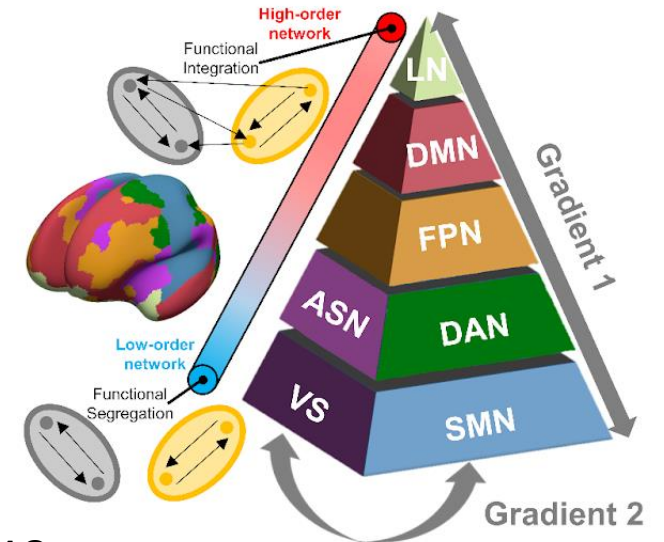
Seguin et al., 2019 – Nat Comm



Gradient 1

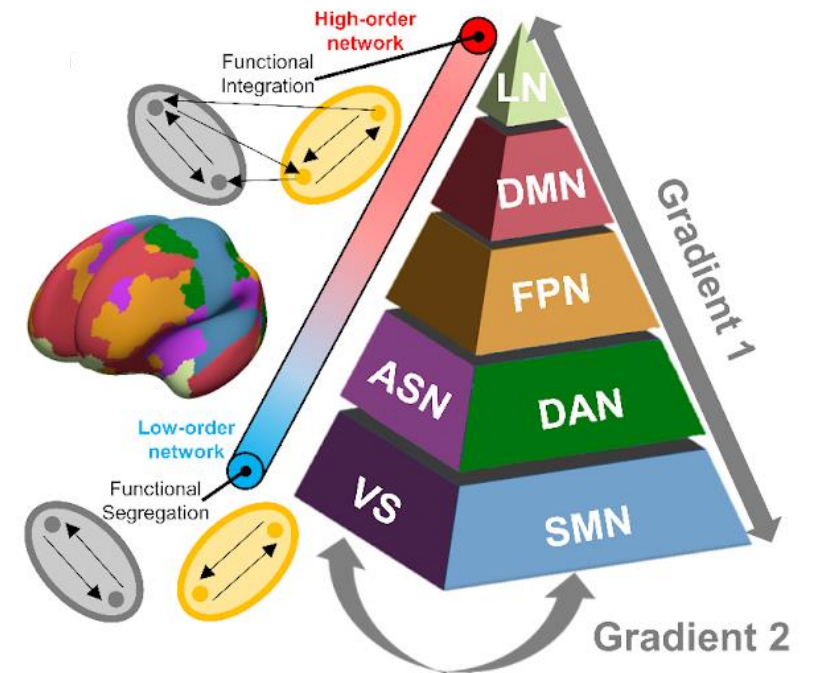
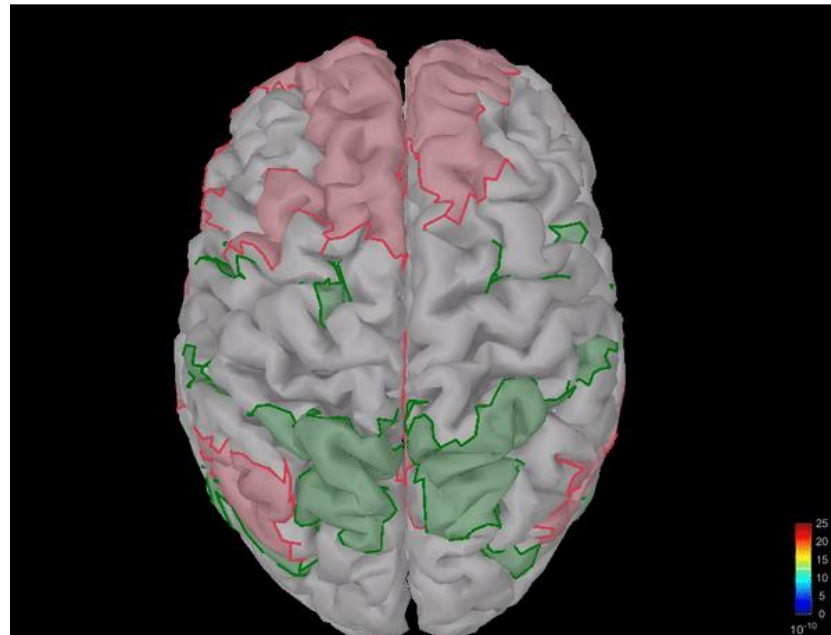


Margulies et al., 2016 - PNAS

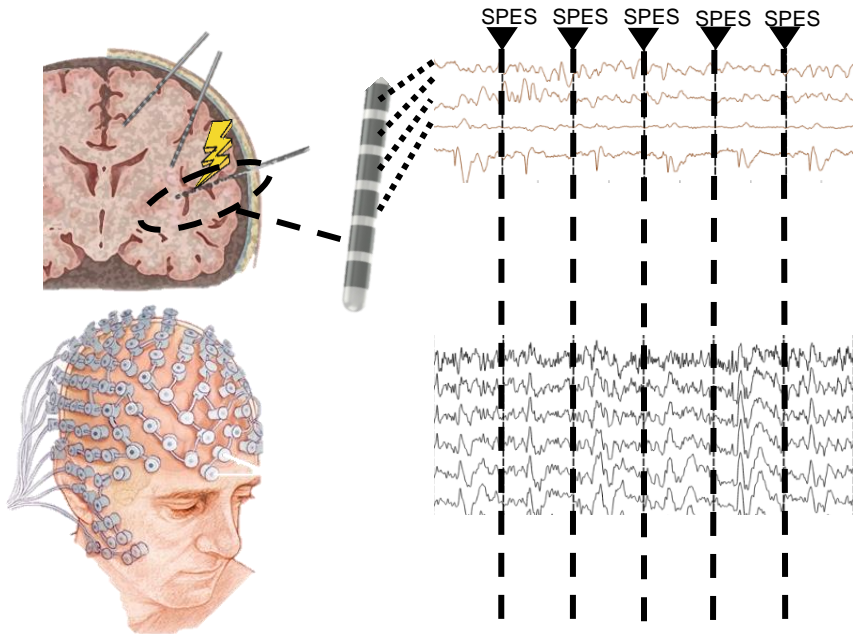


Scientific Questions

Q#1: What are the differences in the propagation pattern between networks?

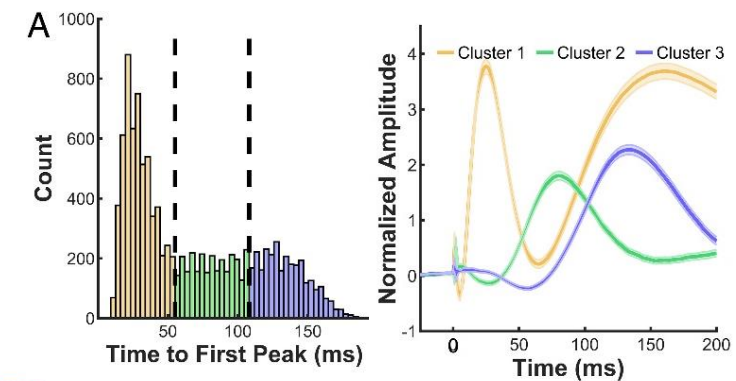
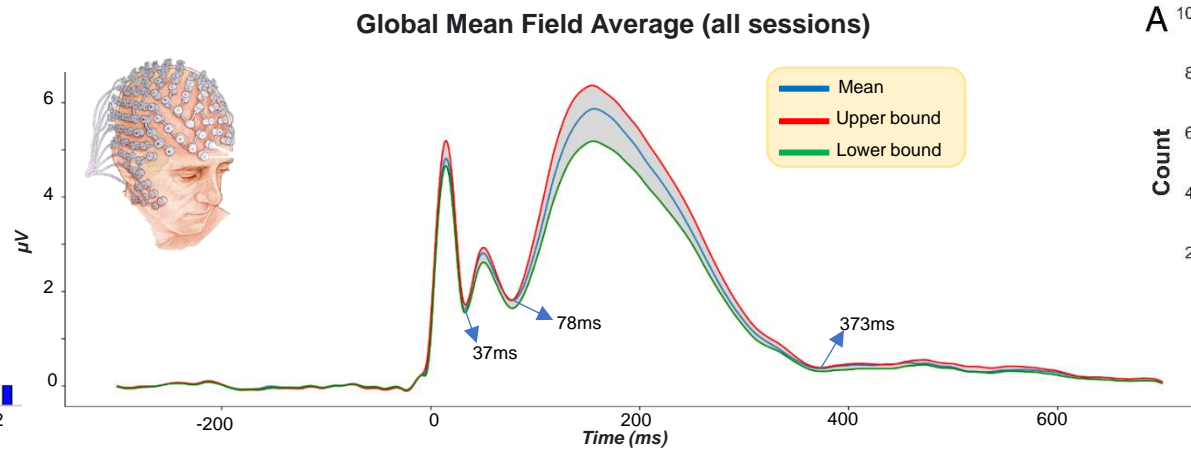
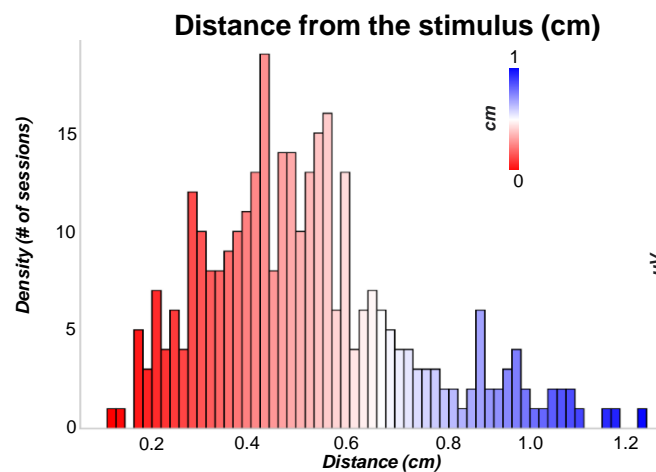
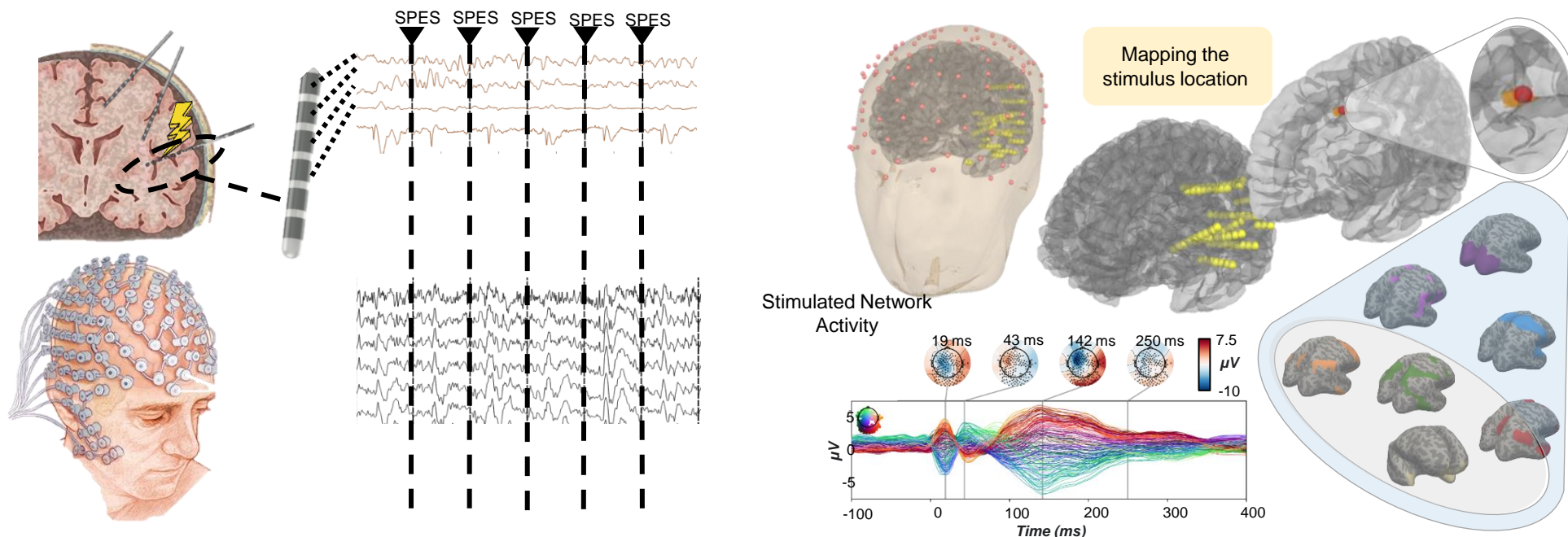


Simultaneous hd-EEG and sEEG dataset



- Simultaneous stereotactic electroencephalography (sEEG) and high-density scalp EEG (hd-EEG) during intracortical single pulse electrical stimulation
- 36 patients – 323 sessions
- Dataset collected at the “Claudio Munari” Epilepsy Surgery Center of Milan in Italy

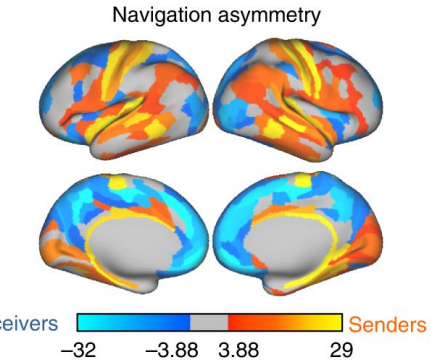
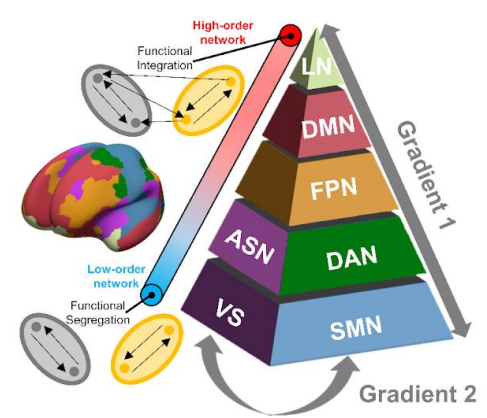
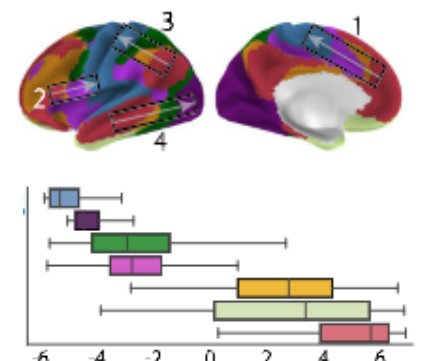
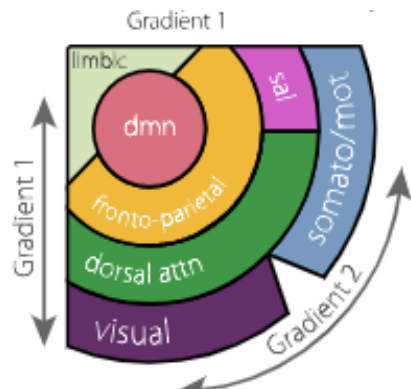
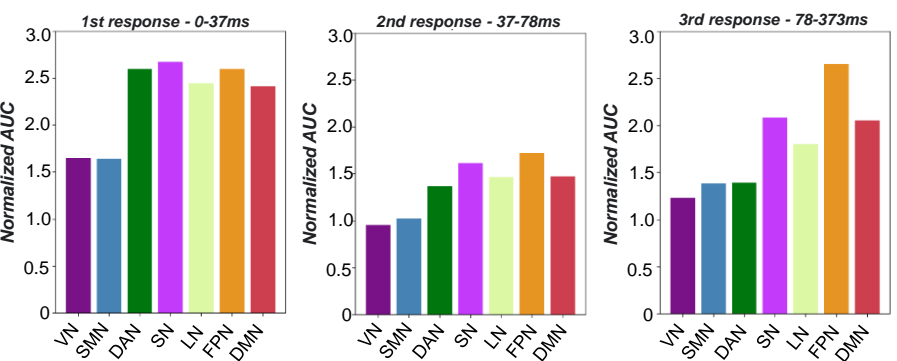
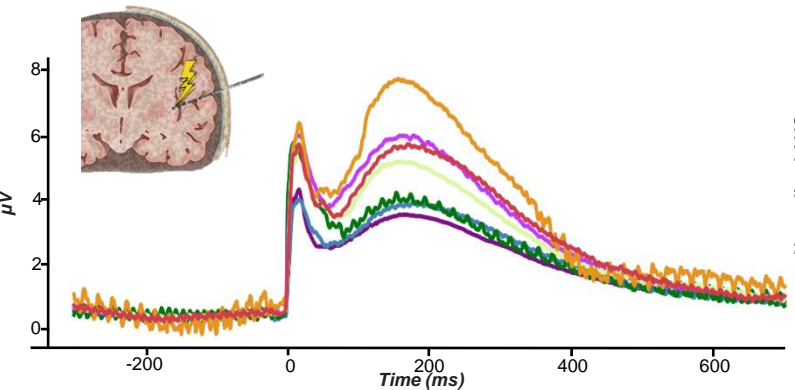
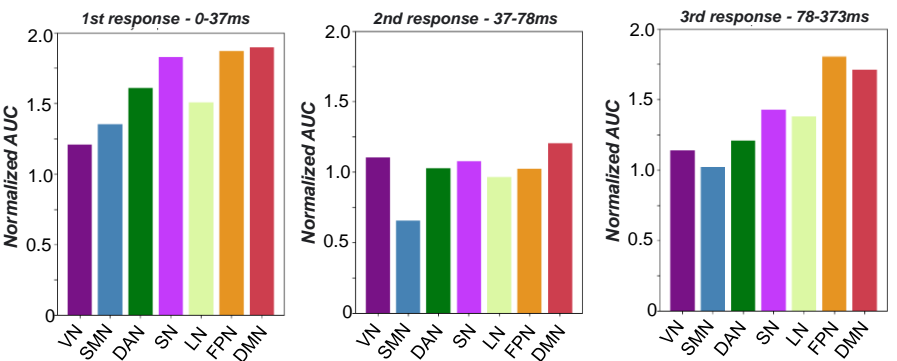
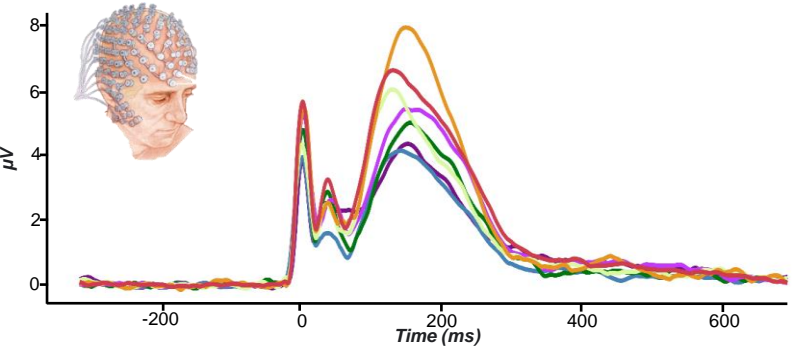
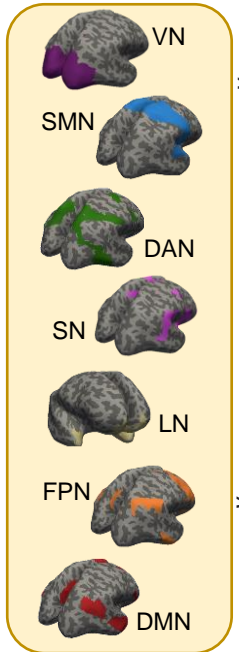
Mapping stimulation location with high-resolution



Veit,, Parvizi, 2021 - PNAS

Stronger propagation pattern when external stimulation targets high-order multimodal networks

Resting-state Networks (Yeo et al. 2011)



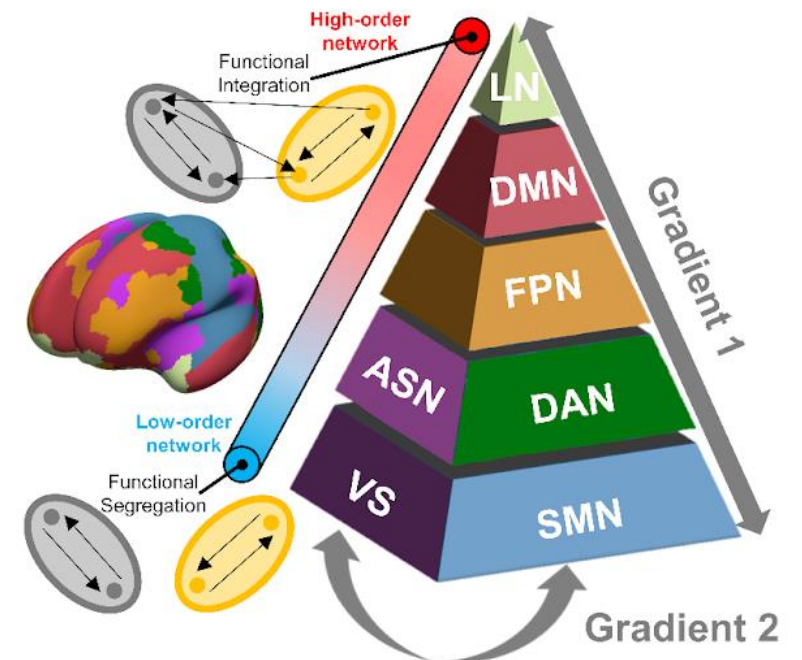
Scientific Questions

Q#1: What are the differences in the propagation pattern between networks?



- Intracranial electrical stimulation (iES) leads to downstream electrophysiological evoked responses which nature follows the RSNs cortical gradient hierarchical structure demonstrated using neuroimaging data
- A significantly stronger propagation pattern when the stimulus was targeted at high-order networks (e.g. Default and Frontoparietal networks), particularly for the late evoked responses
- This trend was found both in the hd-EEG and sEEG data, testifying the replicability using different scales of spatial

Q#2: Does this difference rely on different process (integration vs segregation)?



Jansen-Rit model (1995)

$$\dot{y}_0(t) = y_3(t)$$

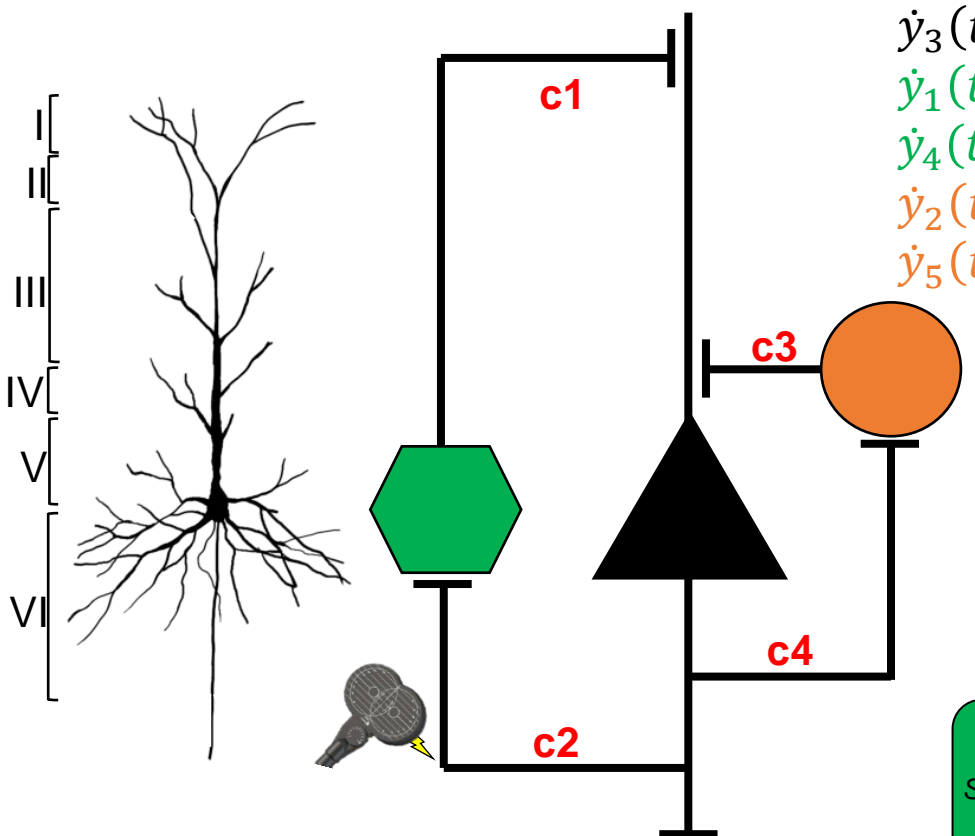
$$\dot{y}_3(t) = Aa \text{Sigm}[y_1(t) - y_2(t)] - 2ay_3(t) - a^2y_0(t)$$




$$\dot{y}_1(t) = y_4(t)$$

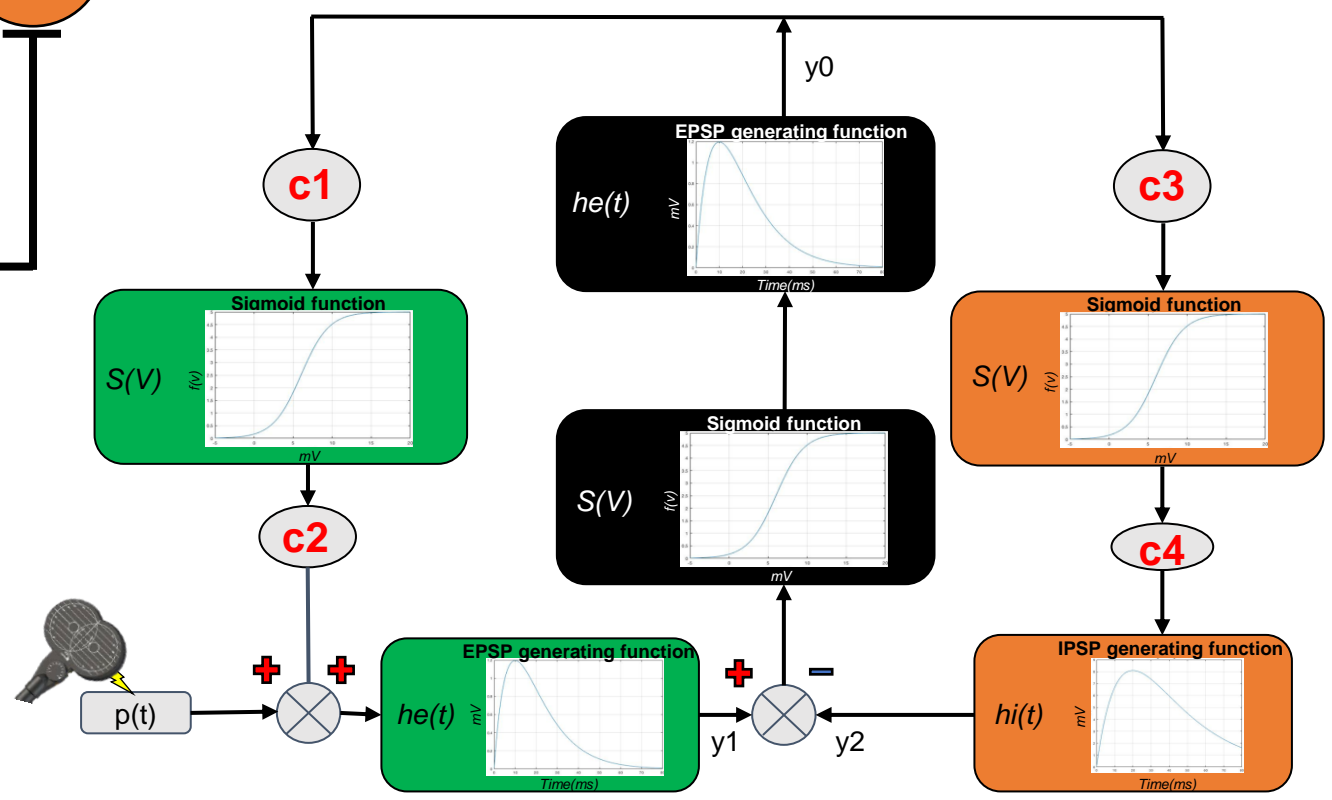
$$\dot{y}_4(t) = Aa(p(t) + C_2 \text{Sigm}[C_1y_0(t)]) - 2ay_4(t) - a^2y_1(t)$$

$$\dot{y}_2(t) = y_5(t)$$

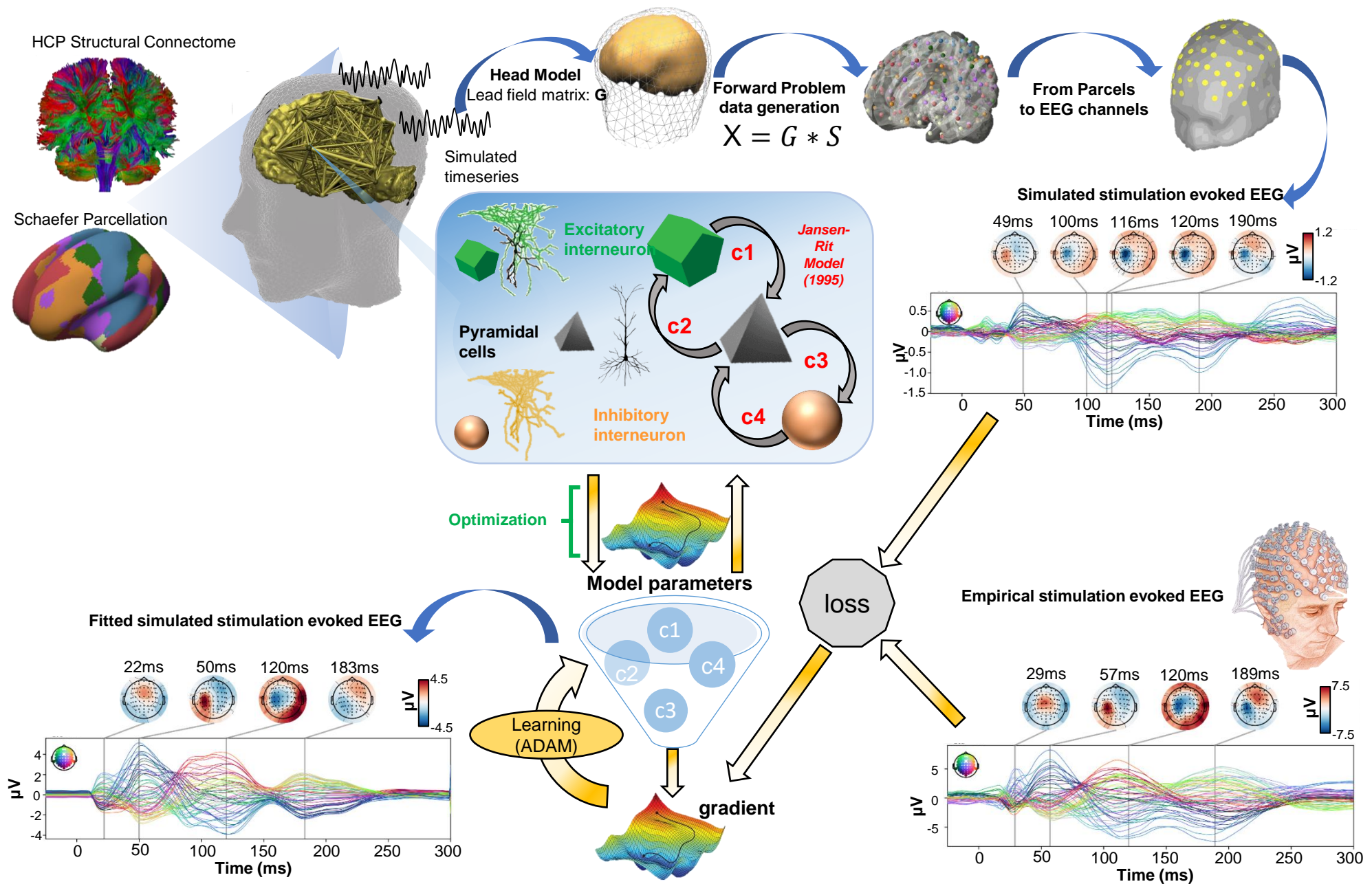
$$\dot{y}_5(t) = Bb(C_4 \text{Sigm}[C_3y_0(t)]) - 2by_5(t) - b^2y_2(t)$$



-  Pyramidal cells
-  Excitatory interneuron
-  Inhibitory interneuron

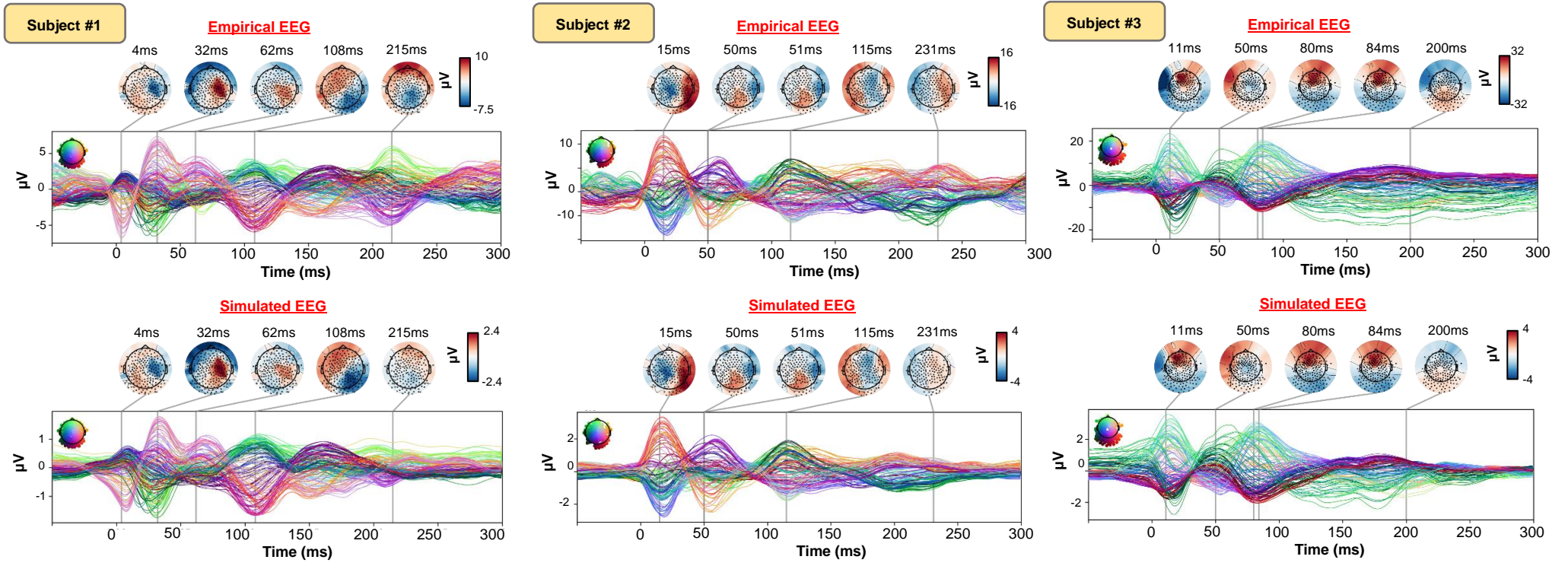


Schematic Overview



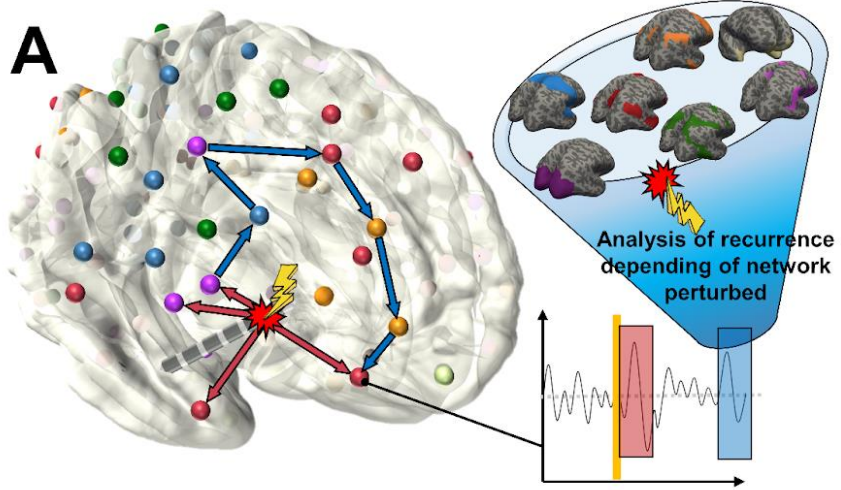
“Goodness” of Fit

A



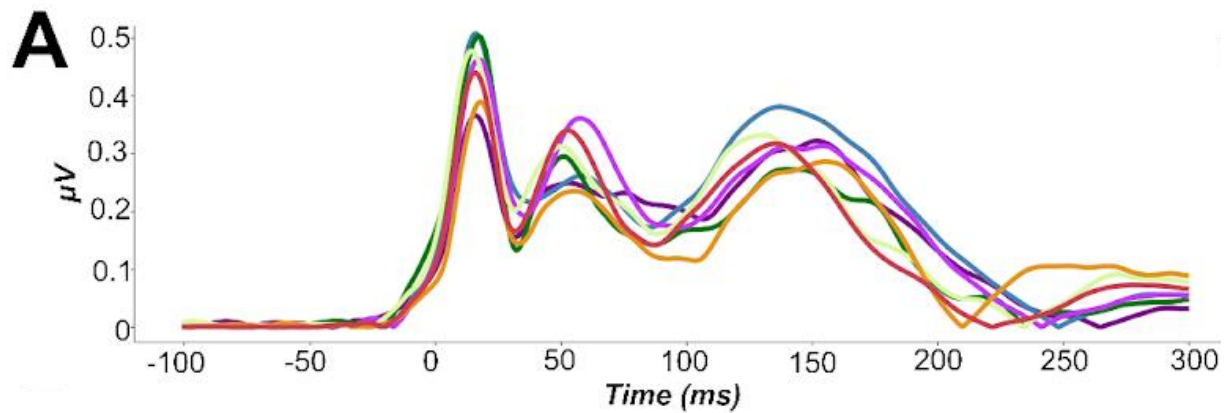
Virtual Lesion Approach

Q#2: Does this difference rely on different process (integration vs segregation)?

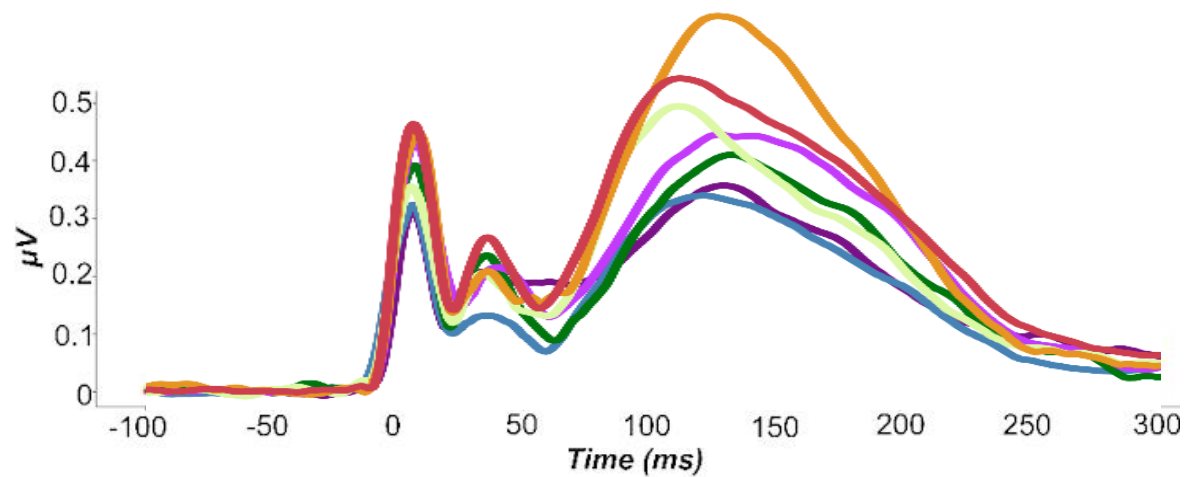


Late responses are either locally or globally driven

Global Mean Field Power after virtual lesion



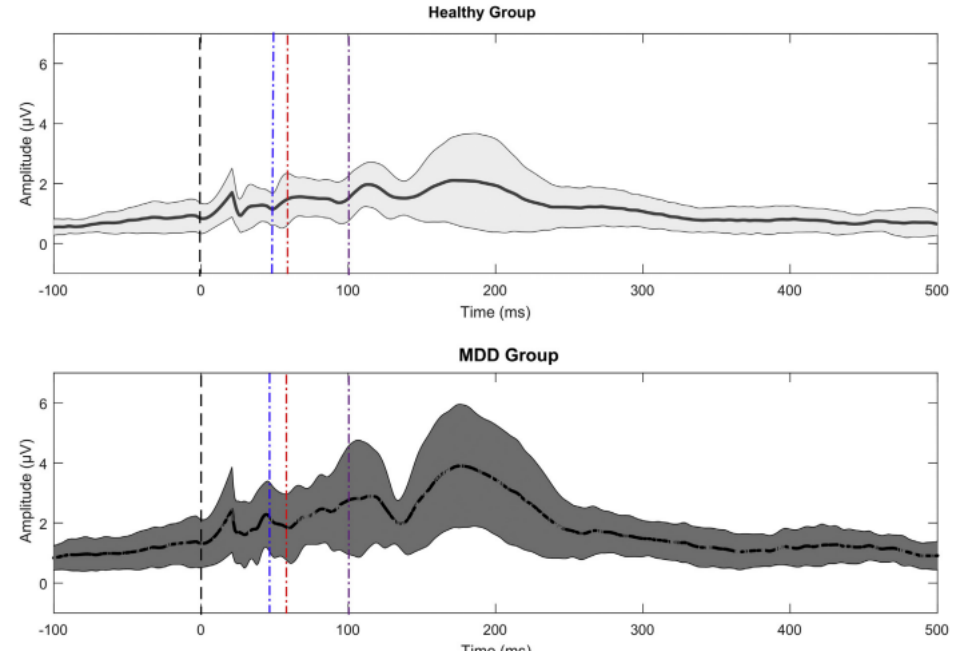
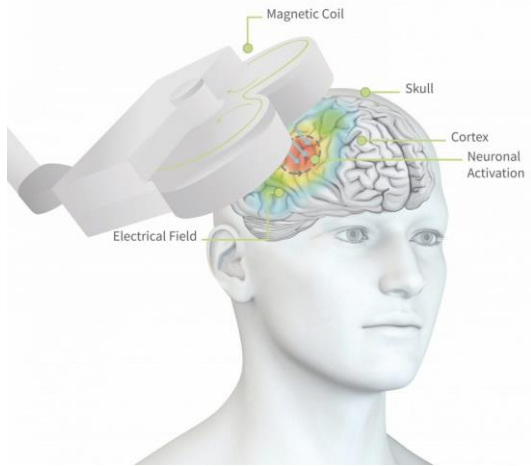
Global Mean Field Power Intact Connectome



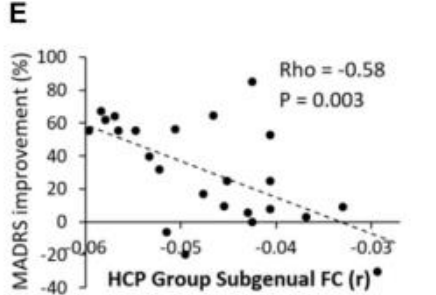
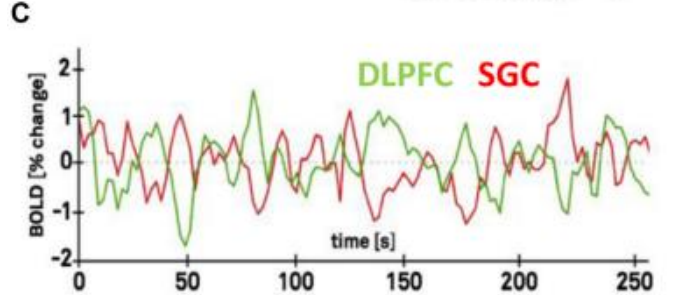
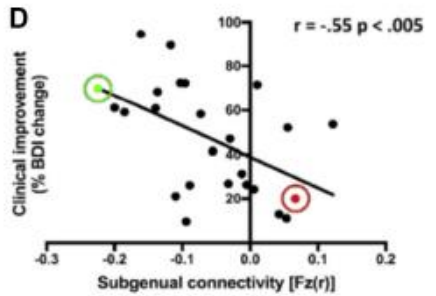
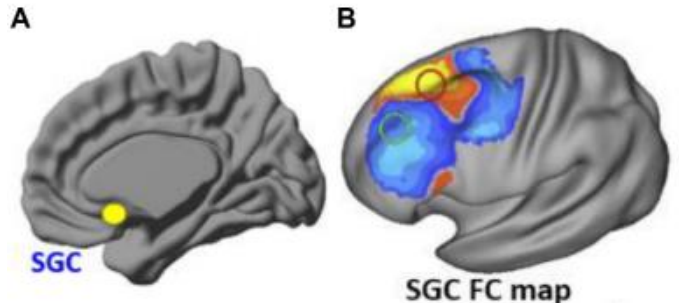
Future Perspective: Why is that important?



Courtesy of Dr. Williams



Voineskos et al., 2019 – Biological Psychiatry



Cash et al., 2021 – Biological Psychiatry

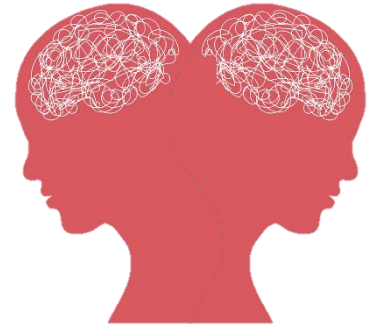
Can we use the model to predict patients' clinical outcome?



Manifold predicts clinical outcome



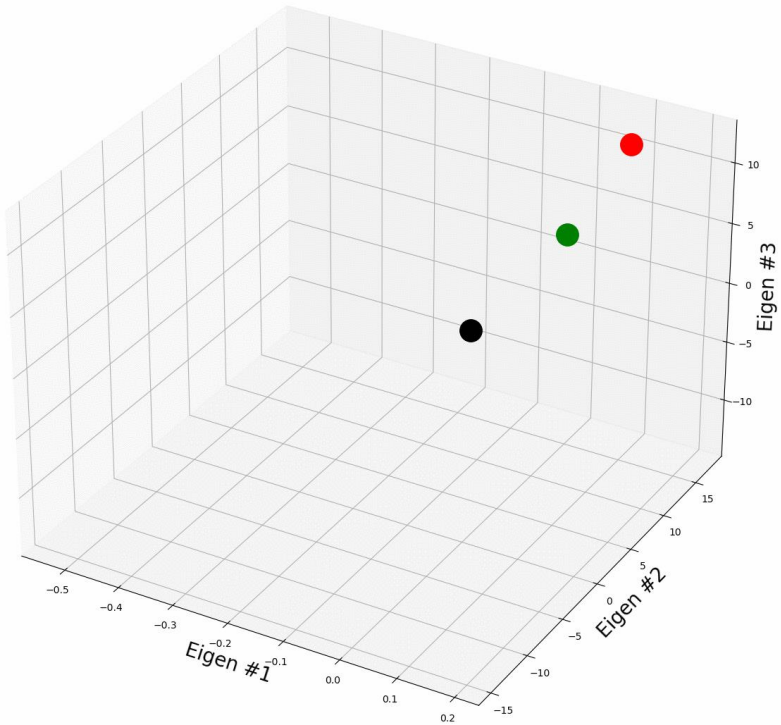
Improved Patient



NOT Improved Patient

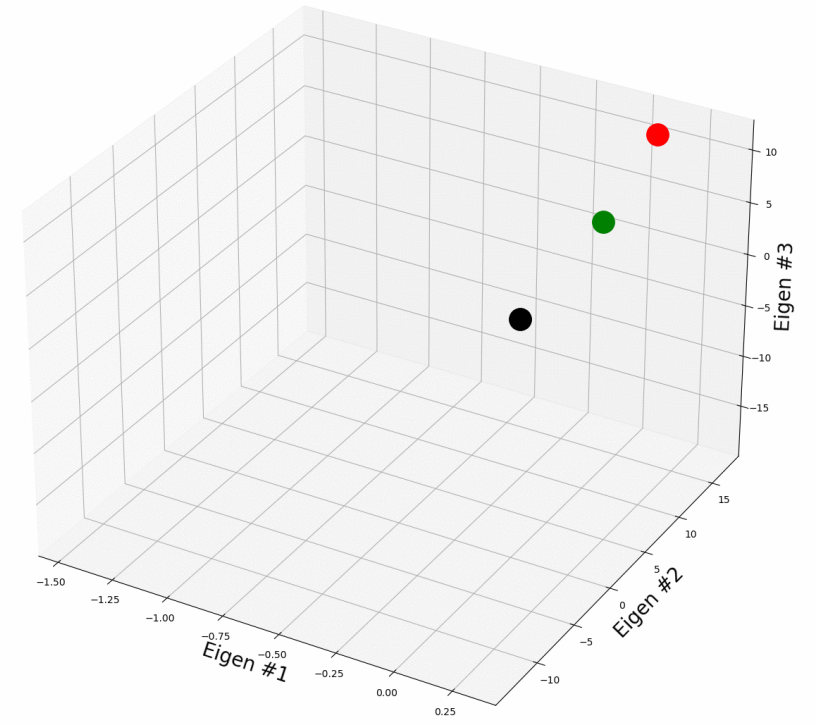
- Pre
- Post

time=-100ms



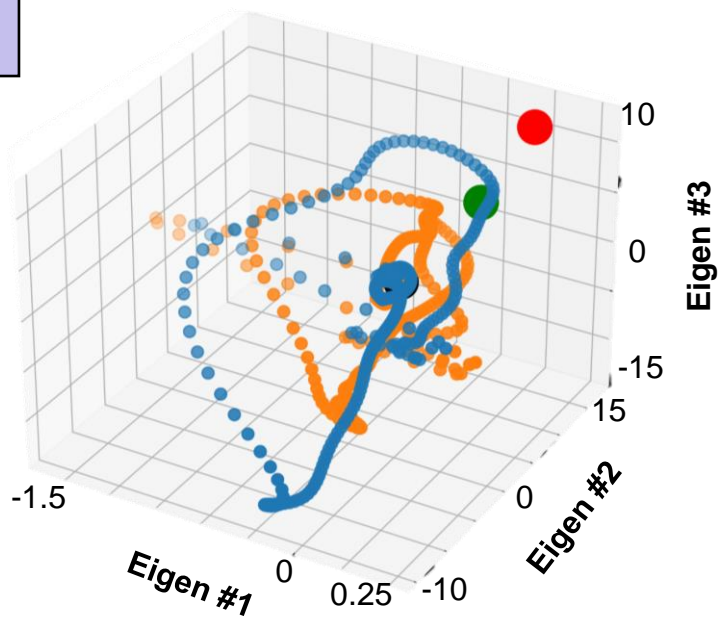
- Pre
- Post

time=-100ms

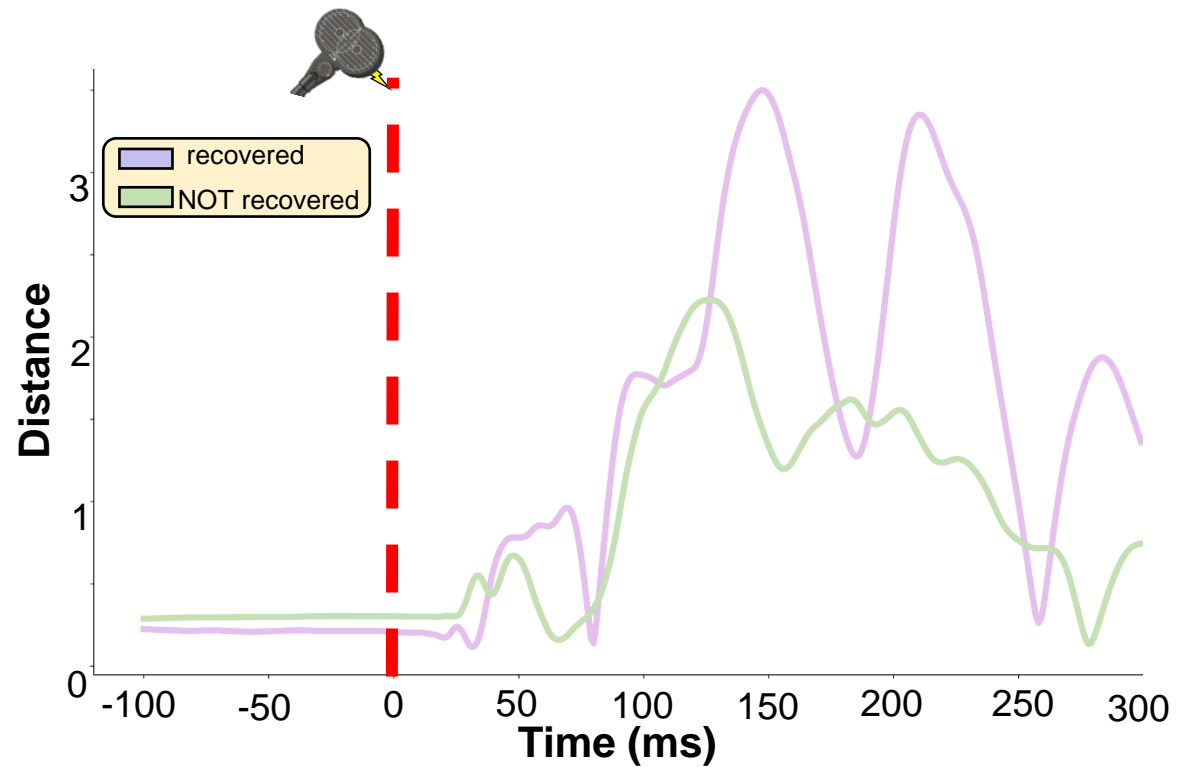
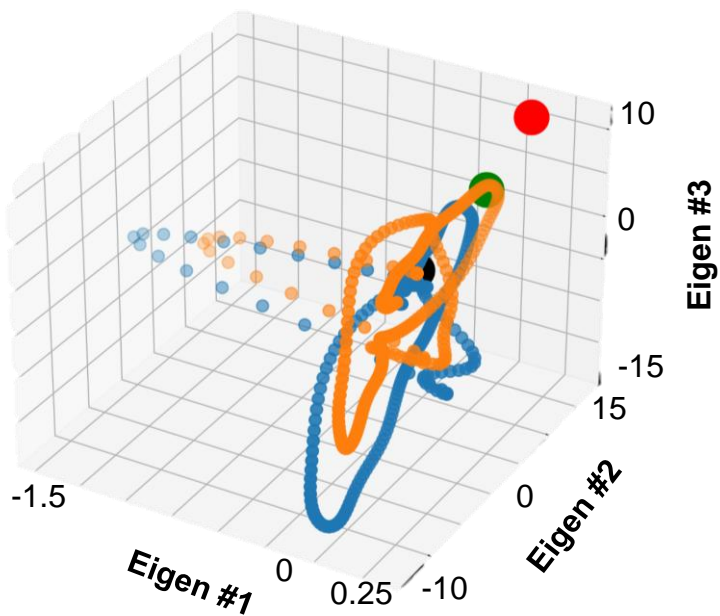
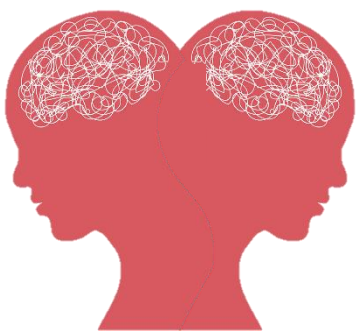


Manifold predicts clinical outcome

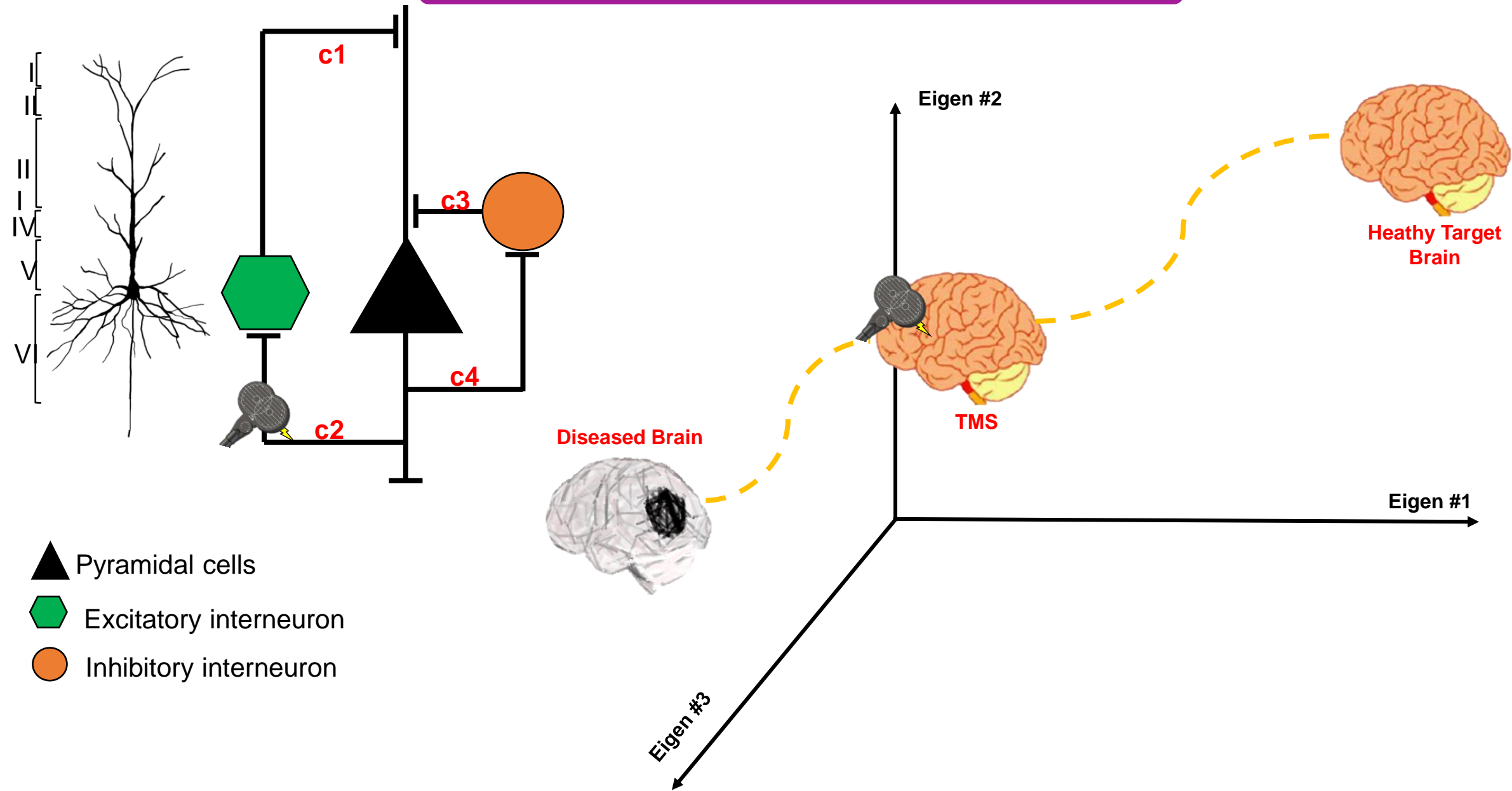
Improved Patient



NOT Improved Patient

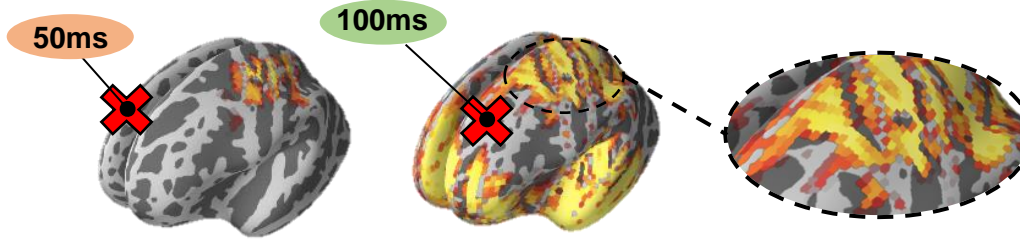
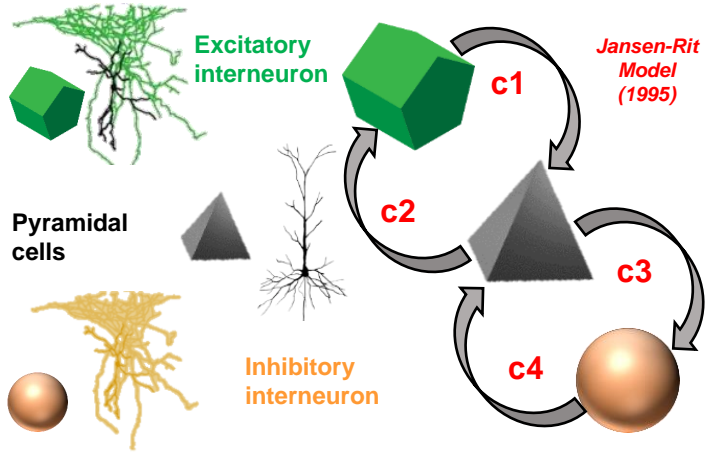


Future Directions



Recap

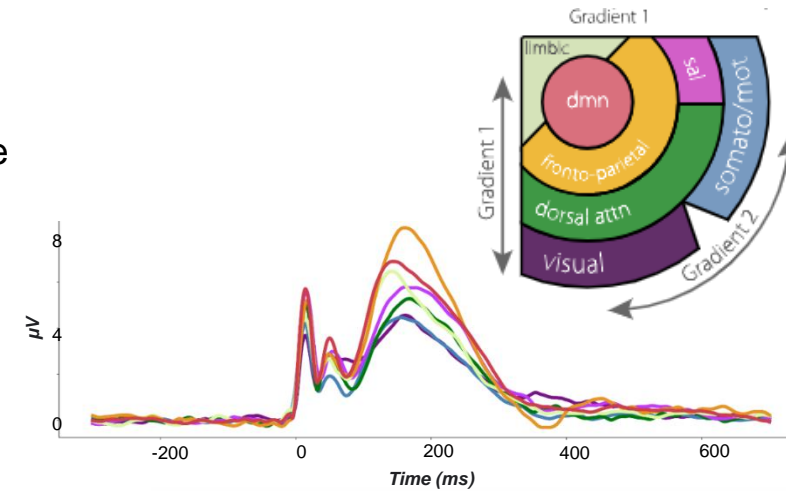
Robust recovery of individual subjects' empirical evoked propagation patterns



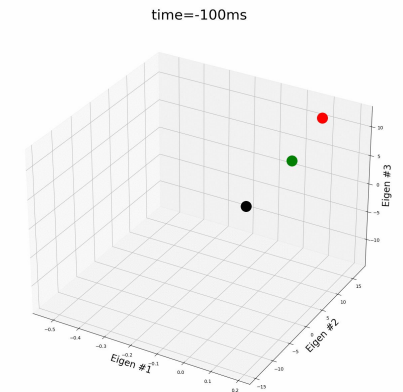
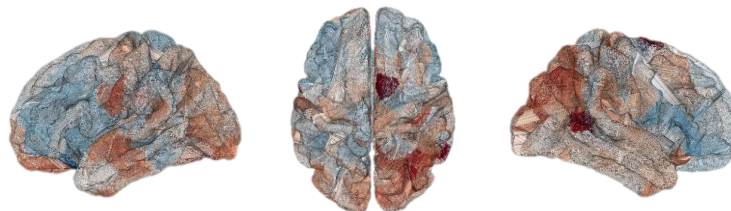
Time and Space are both important for shaping the TMS-induced signal propagation

Recurrent activity is either a local echo or a network reverberation

Differences in propagation pattern between network

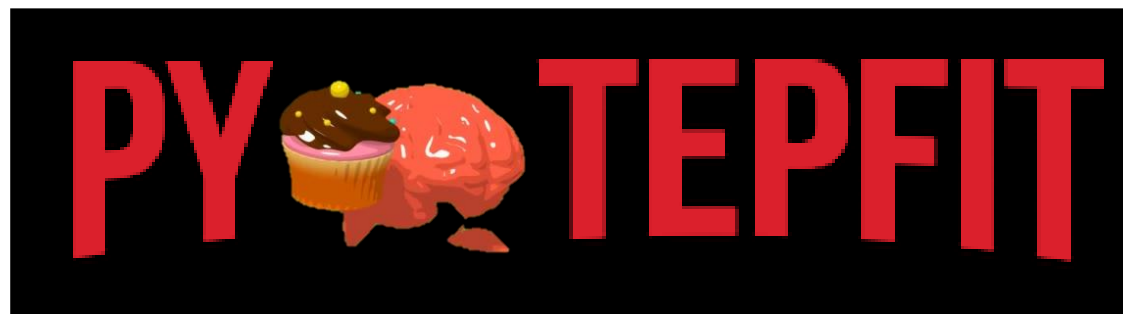


Model structural and dynamic features can be useful in clinical settings





https://github.com/GriffithsLab/PyTepFit



GriffithsLab / PyTepFit Public

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tepfit	first commit	7 days ago
.gitignore	Add files via upload	7 days ago
README.md	Update README.md	17 hours ago

README.md

Modelling large-scale brain network dynamics underlying the TMS-EEG evoked response

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Whole Brain Modelling



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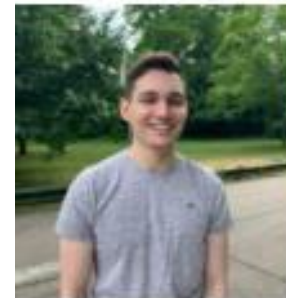
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