Reconfiguration of cortical network connectivity with increasing cognitive complexity

Kimberly Nestor
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IMAGINE YOUR DAILY DRIVE TO WORK/ SCHOOL

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INITIALLY AT 9:00 AM
IT IS HABITUAL

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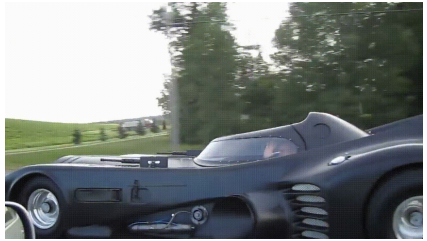

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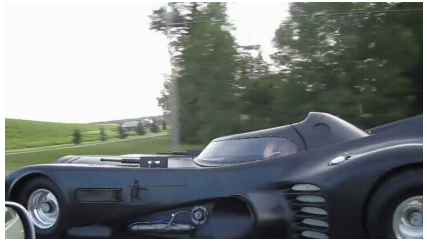

SUDDENLY AT 9:05 AM
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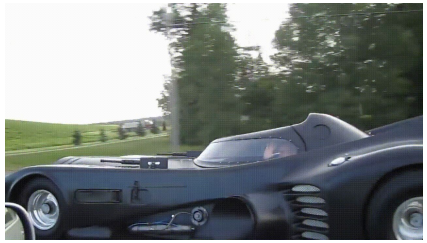

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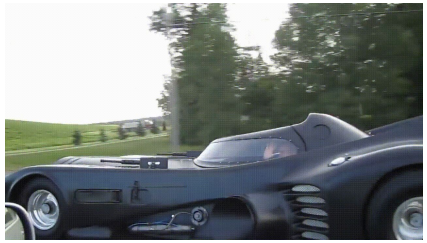

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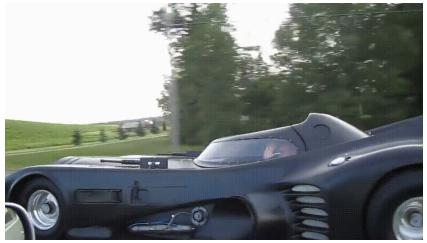

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OPTION 2: SWERVE

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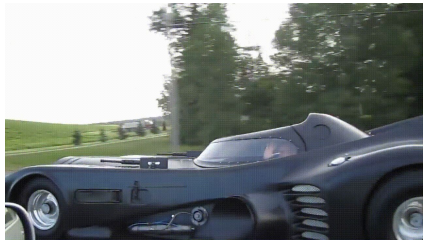

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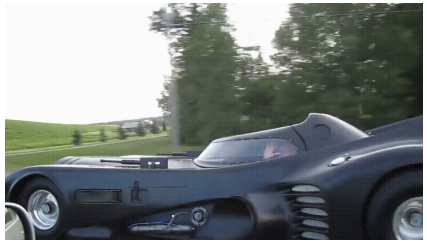

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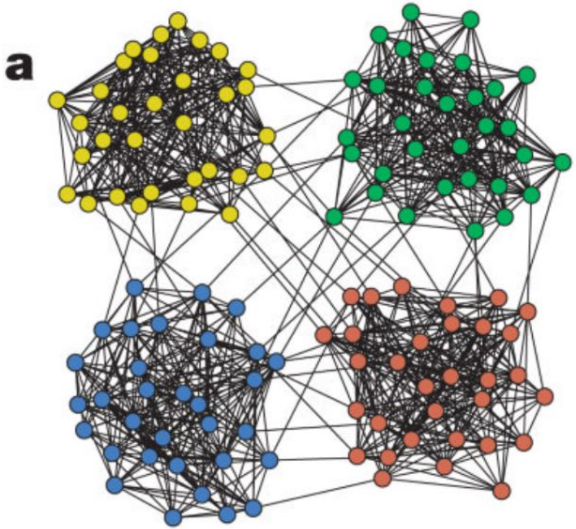
OPTION 2: SWERVE


Network connectivity is mutable and can change from modular to integrated



MODULAR

9:00 AM

Guimerà & Nunes Amaral, 2005

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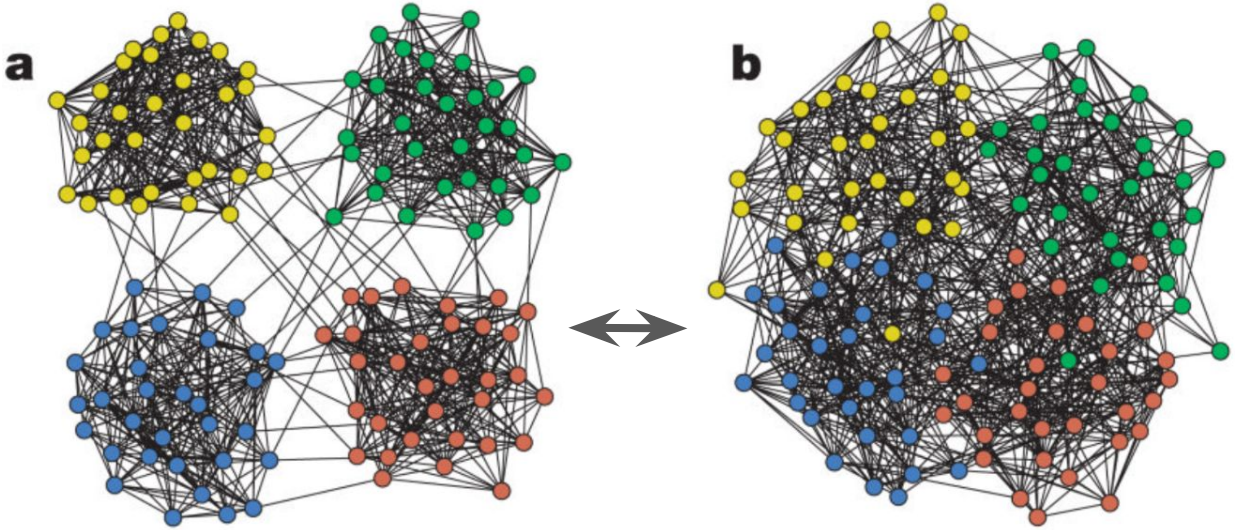

MODULAR
9:00 AM

TRANSITION

Guimerà & Nunes Amaral, 2005

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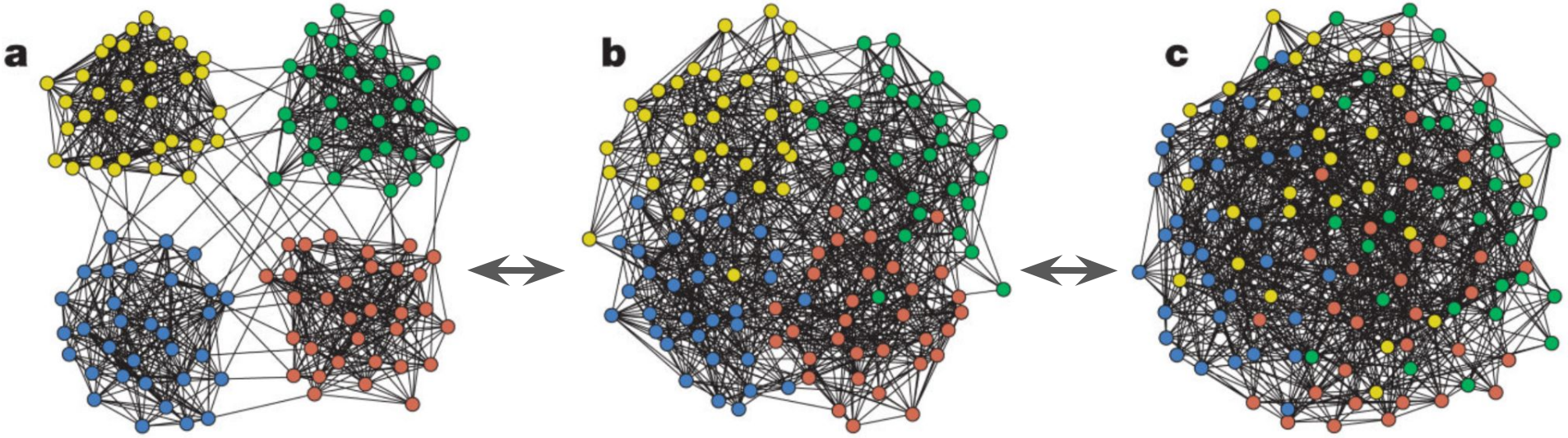
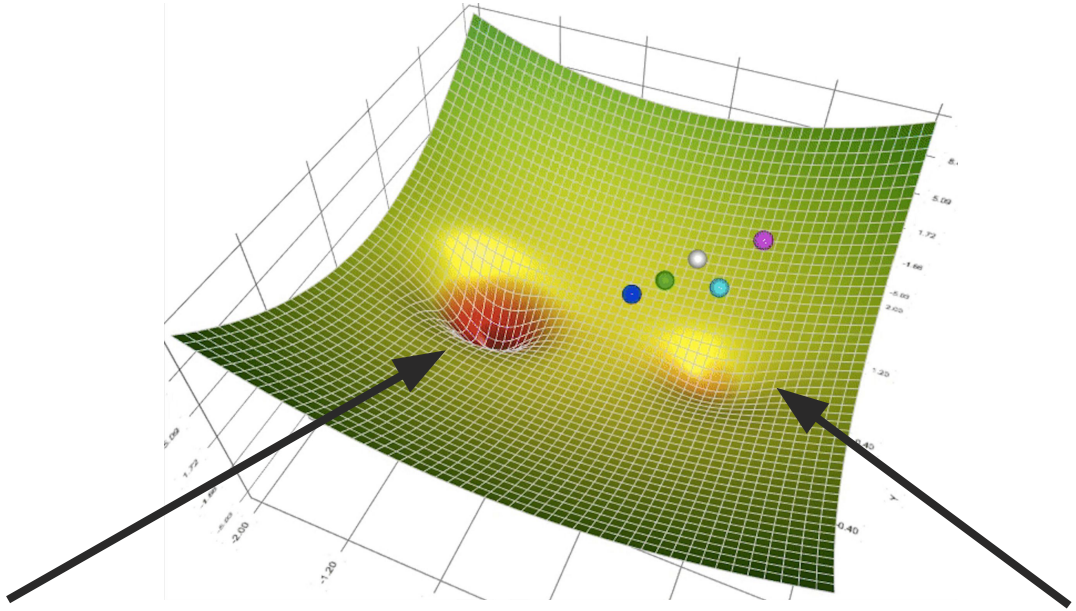


Guimerà & Nunes Amaral, 2005

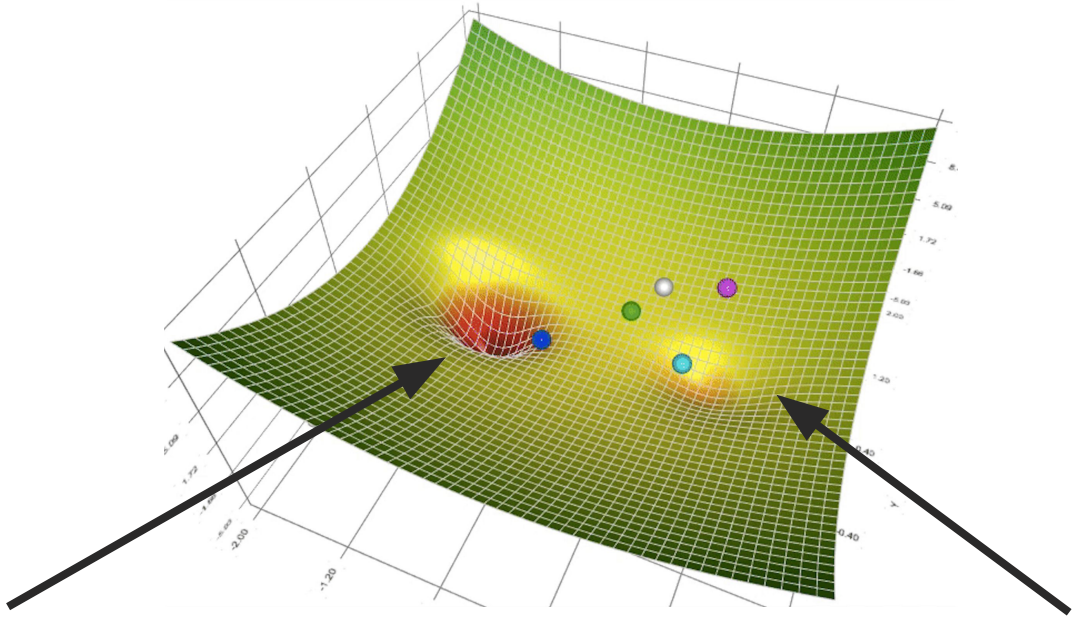
The attractor landscape facilitates energy entrapment in minima and maxima



DEEP WELL
MODULAR

SHALLOW WELL
INTEGRATED

The attractor landscape facilitates energy entrapment in minima and maxima



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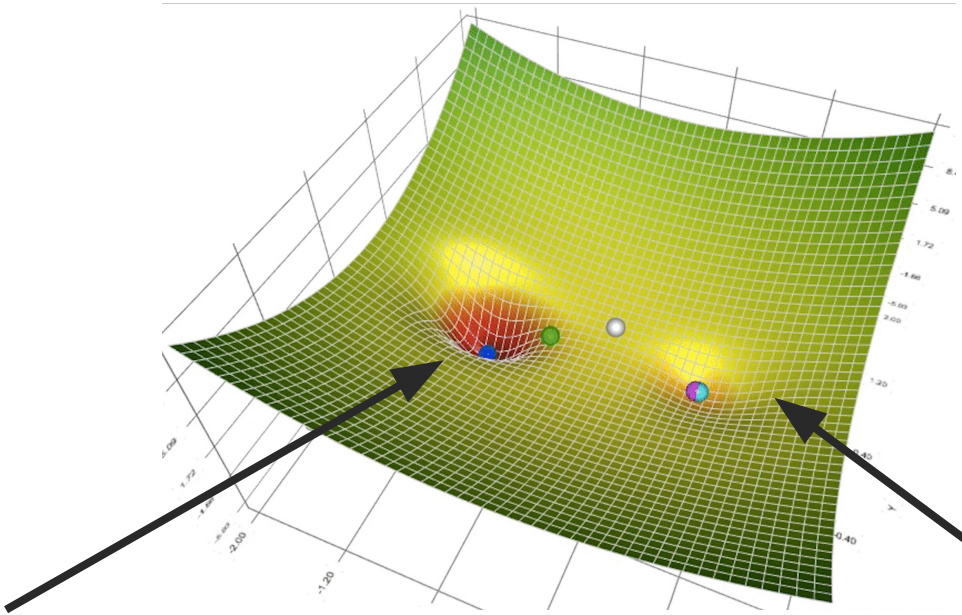


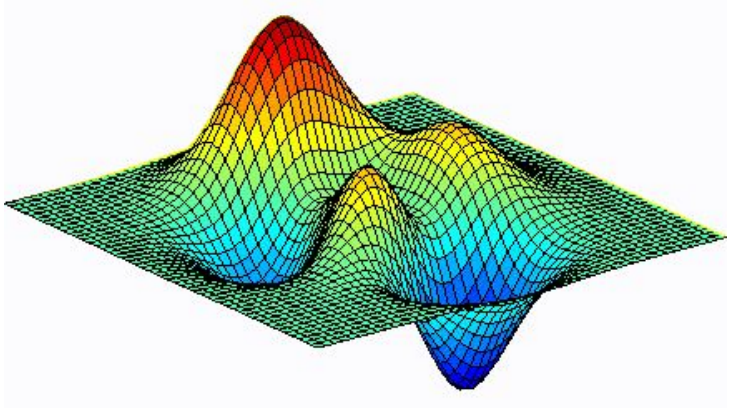
DEEP WELL
MODULAR

SHALLOW WELL
INTEGRATED

How does the brain adapt to an ever changing landscape?

Learning is possible in a fast and slow timescale (Zhou et al., 2019)

- Fast neural reorganization allows adaptation to new tasks
- Slow neural reorganization allows for task precision



Cortical activation patterns are linked to task cognitive complexity (Owen et al., 2021)

- Complex cortical activation in sequential story listening task
- Less complex network dynamics in a randomly scrambled story

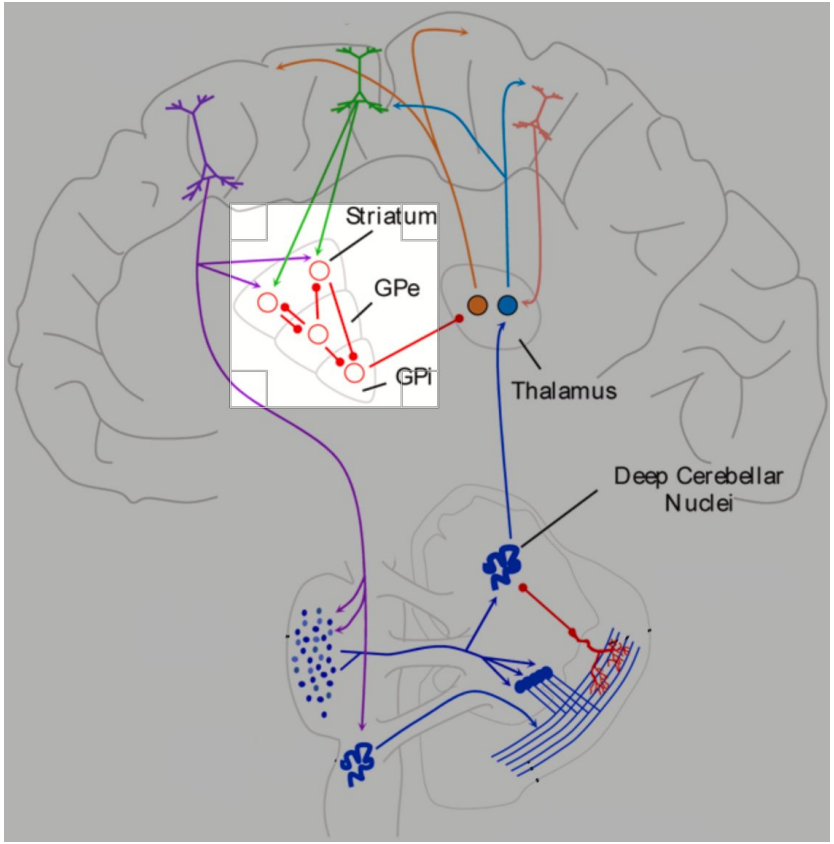
Cortical activation patterns can indicate richness of memory recall (Geib et al., 2017)

- High cortical connectivity shown to allow for vivid visual memory recall
- Low cortical connectivity led to dim visual memory recall

PROJECT AIM 1

DETERMINE WHETHER CORTICAL ACTIVATION PATTERNS ARE IN **MODULAR** CONNECTIVITY DURING EASIER **(CONGRUENT)** TASKS AND IN **INTEGRATED** CONNECTIVITY DURING HARDER **(INCONGRUENT)** TASKS

Subcortical regions are highly connected with cortical regions

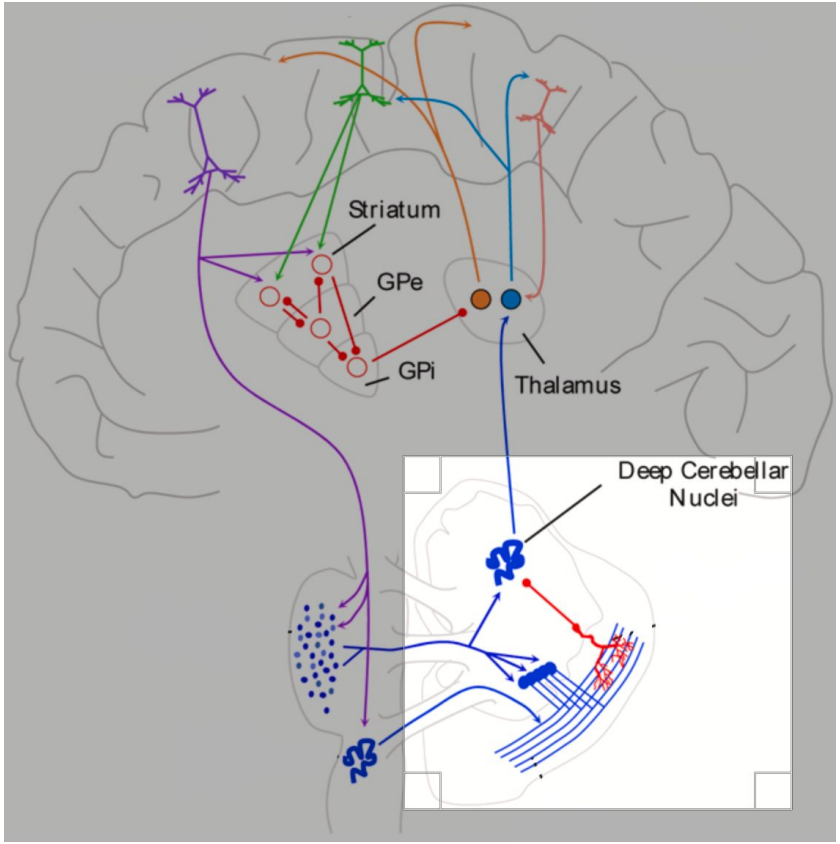


Integration

- Basal ganglia projects to matrix thalamus from globus pallidus interna (GPi).
  - Matrix thalamus projects diffusely to cortical regions

Shine, 2021

Subcortical regions are highly connected with cortical regions

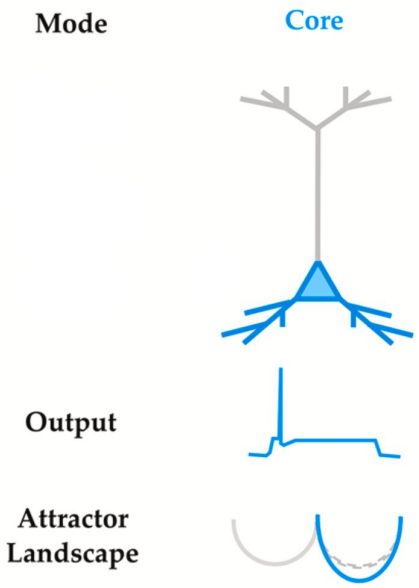


Segregation

- Cerebellum projects to core thalamus from the deep cerebellar nuclei
  - Core thalamus projects focally to cortical hubs

Shine, 2021

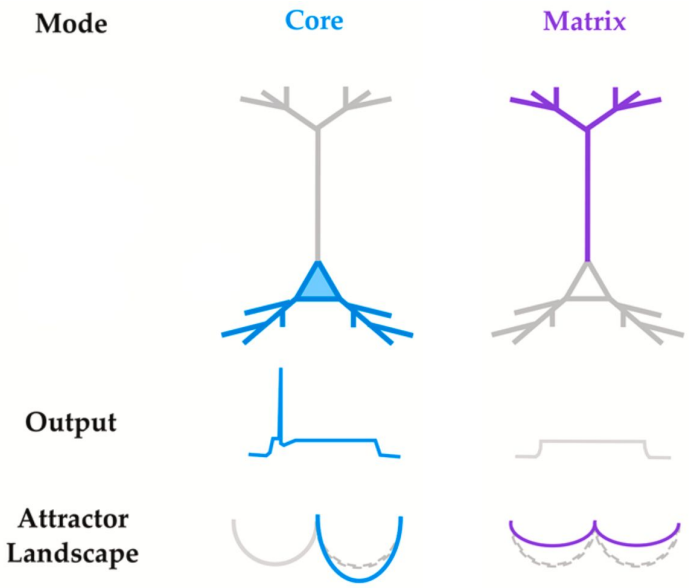
Cellular activation input to the thalamus drive changes in the attractor landscape



- Segregation leads to deepening of the wells
  - Greater stores of energy to select regions
  - Excitatory, glutamatergic input from the deep cerebellar nuclei to core thalamus (Shine, 2021).

Shine, 2021

Cellular activation input to the thalamus drive changes in the attractor landscape



- Segregation leads to deepening of the wells
  - Greater stores of energy to select regions
  - Excitatory, glutamatergic input from the deep cerebellar nuclei to core thalamus (Shine, 2021).

- Shallowing of wells and global integration
  - Less energy stored in regions, but spread across landscape
  - Inhibitory GABAergic cells of the GPi to matrix thalamus cause tonic inhibition causing cortical activation (Shine, 2021).

Shine, 2021

PROJECT AIM 2

DETERMINE WHETHER CEREBELLUM DRIVES **MODULAR** STATES AND BASAL GANGLIA DRIVES **INTEGRATED** STATES

PROJECT HYPOTHESES

AIM 1

We will observe modular cortical activity during congruent or easy tasks, due to minimal computational complexity required and thereby requiring less coordinated activity in the brain between networks.

AIM 2

More specifically, heightened activation of the cerebellum with modular cortical activation patterns during congruent tasks.

Conversely, activation of the basal ganglia with integrated cortical activation patterns during incongruent tasks.

METHODS

Participants - total n=242, sample n=181

Female=119, Male=123

Mean age=40 ± 6 years, min=30, max=51

Scanner - Siemens 3T Trio

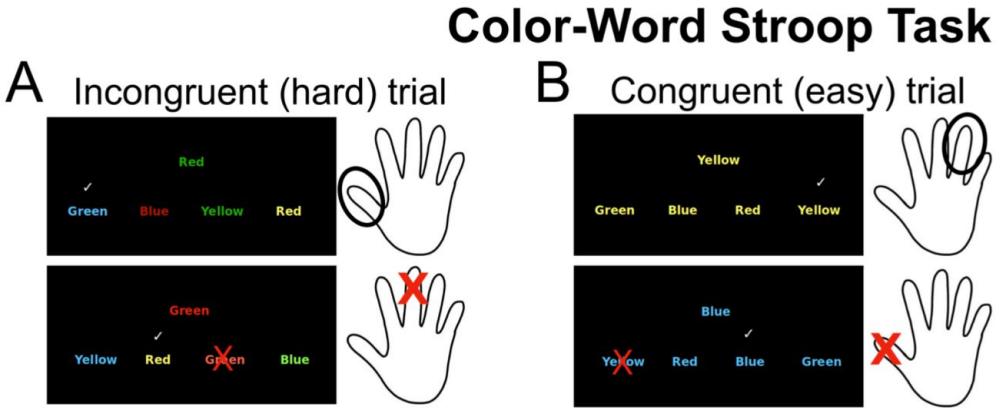
12-channel head coil

fMRI = T2*weighted; 3mm isotropic; RT = 2s; ET = 28ms; Flip = 90°

Task Acquisition - Multi-Source Interference Task (MSIT) and Stroop Task

Adaptive dependent on participant accuracy only in incongruent blocks

Interleaved, four congruent and four incongruent blocks (60s), rest (10s)



Rasero et al., 2021

METHODS

Data analysis

Shen functional atlas parcellation - determinines clusters of brain areas, where k=268

Edge functional connectivity - fMRI analysis method, allows examination of network across entire timescale

Participation coefficient - estimate value for integration across a network

Modularity index

Estimate value Q, for modularity across a network

Instantiated with pre-segmented communities

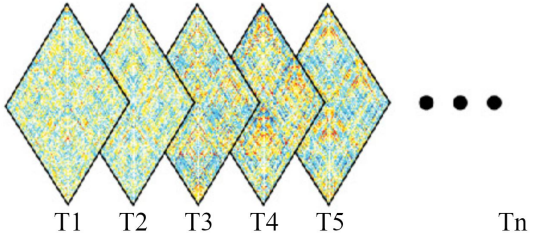
Modularity maximization

Greedy method to determine highest Q by grouping nodes into communities

Segments modularized brain networks based on functional connectivity

Shen, 2021
Zamani Esfahlani et al., 2021
Shine et al., 2016

PREDICTIONS



Zamani Esfahlani et al., 2021

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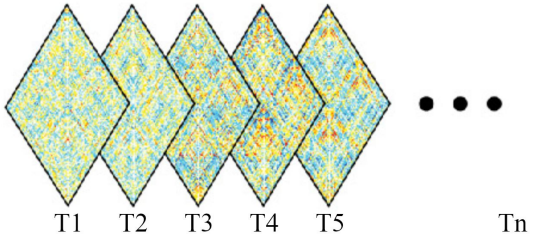

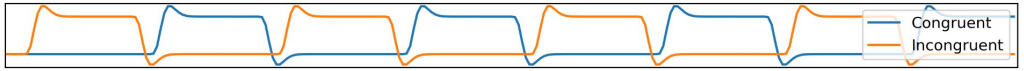

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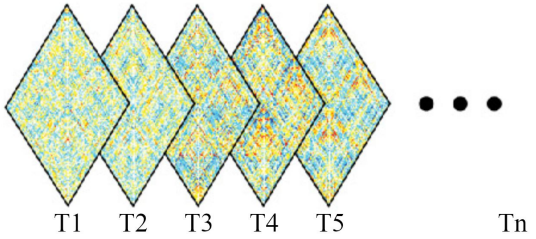

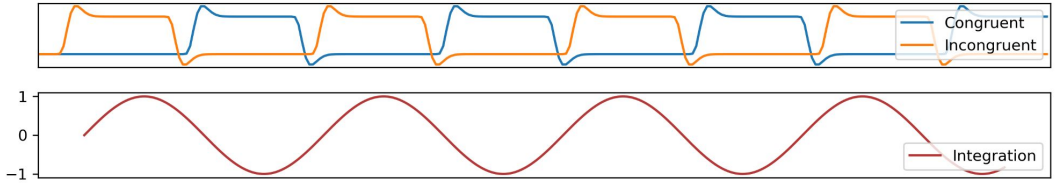

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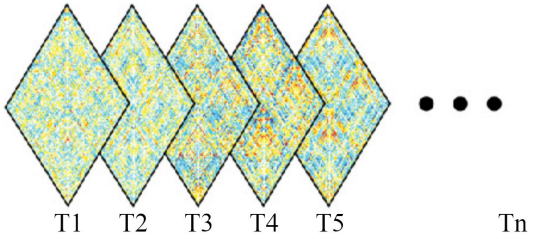

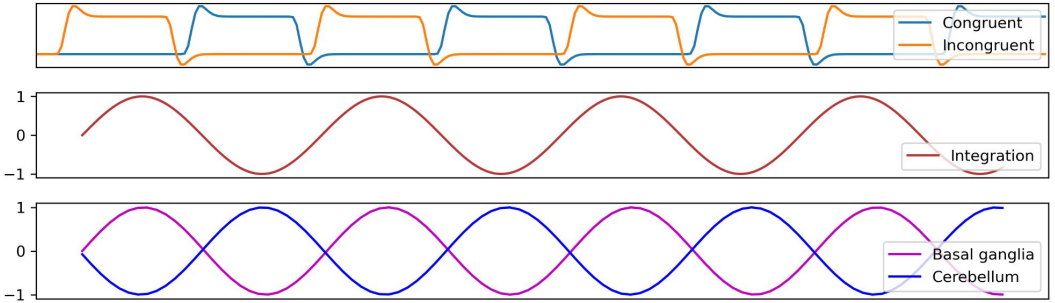

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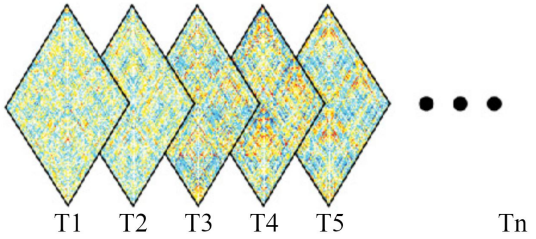

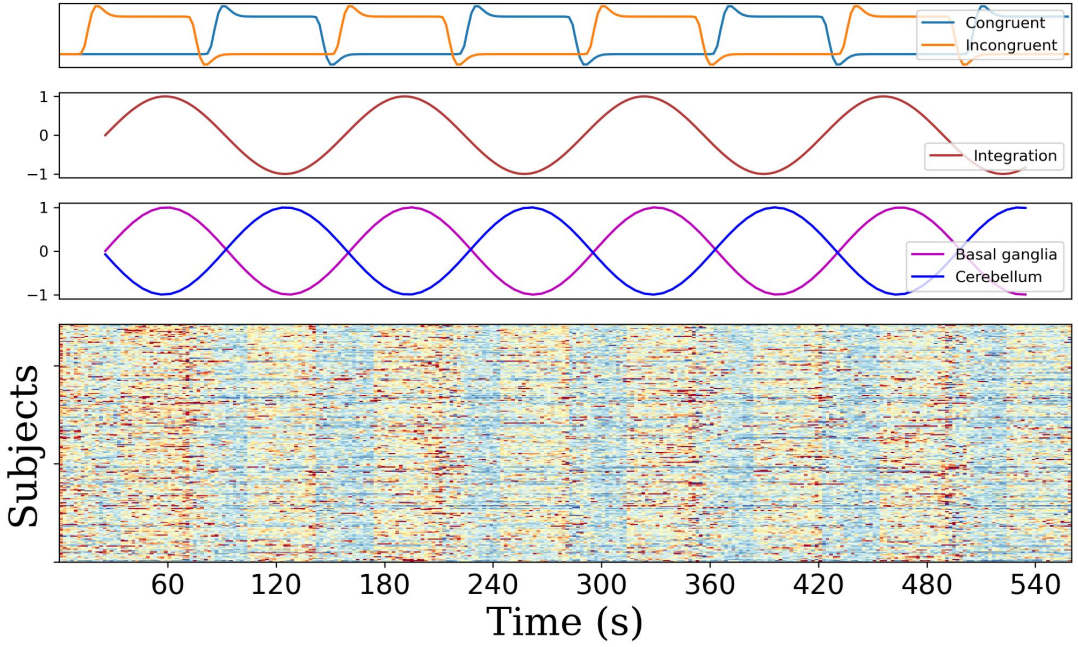

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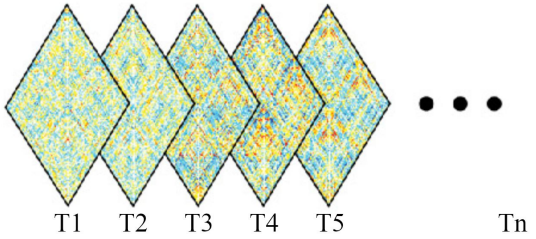
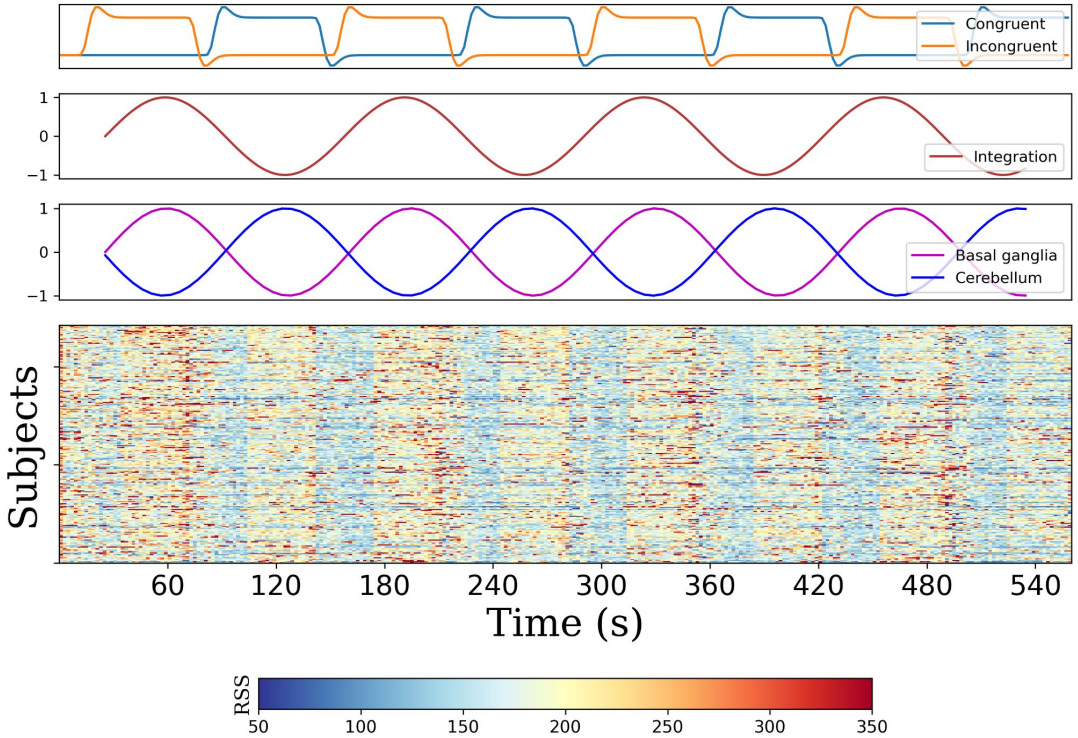
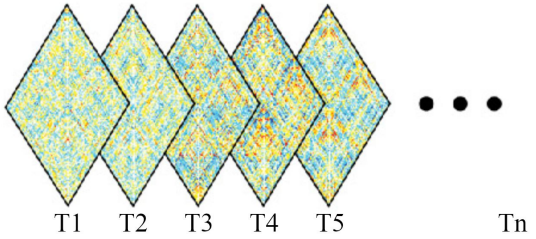
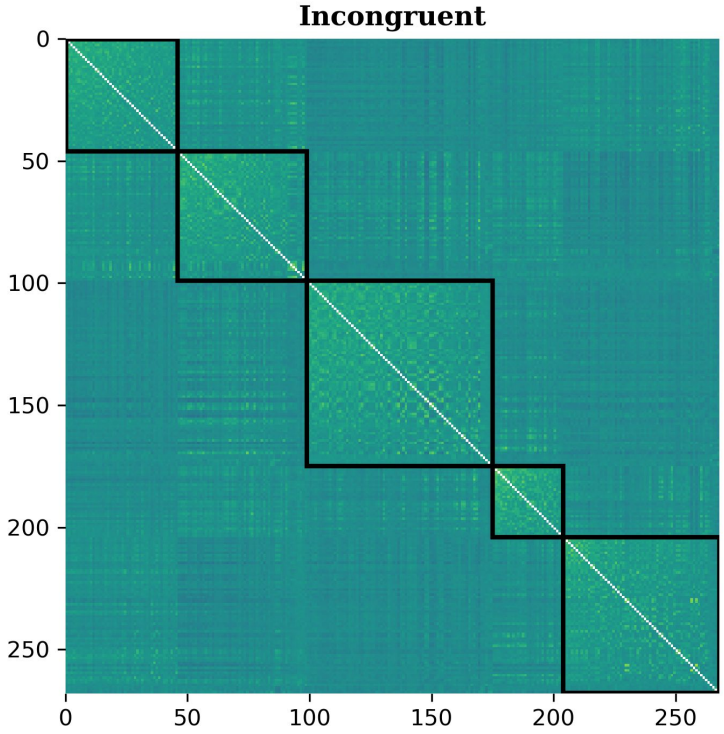




RESULTS: AIM 1

Correlation Heatmap





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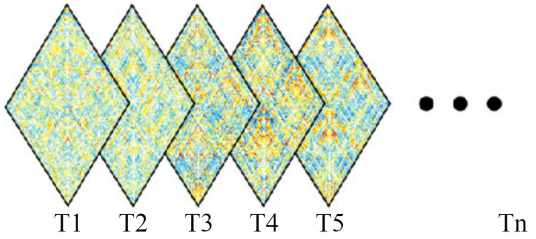

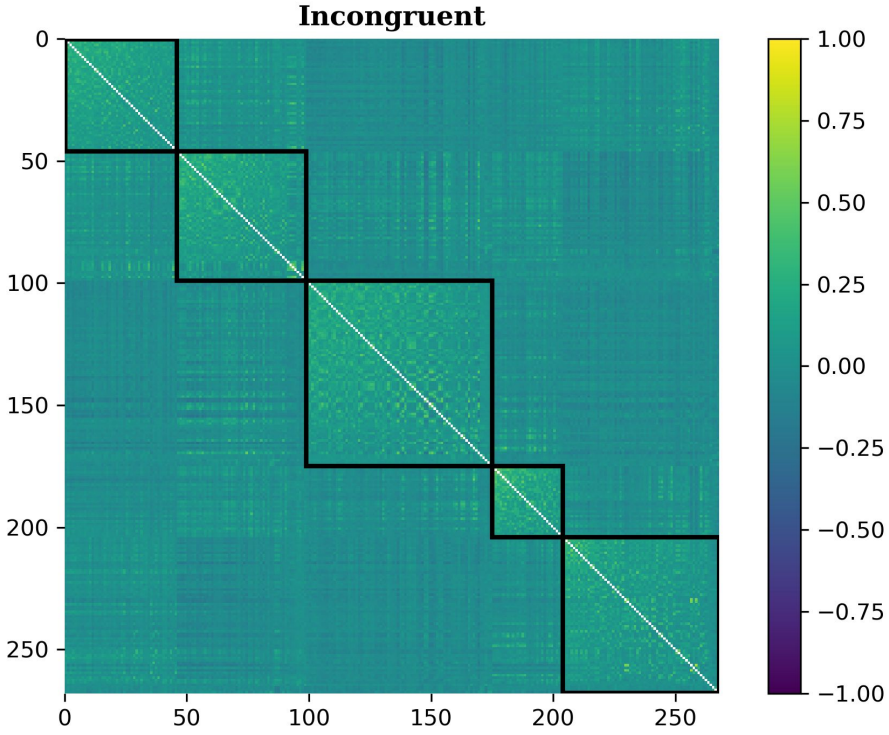

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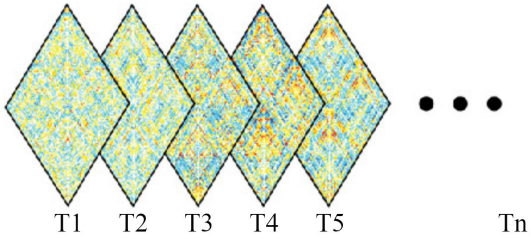

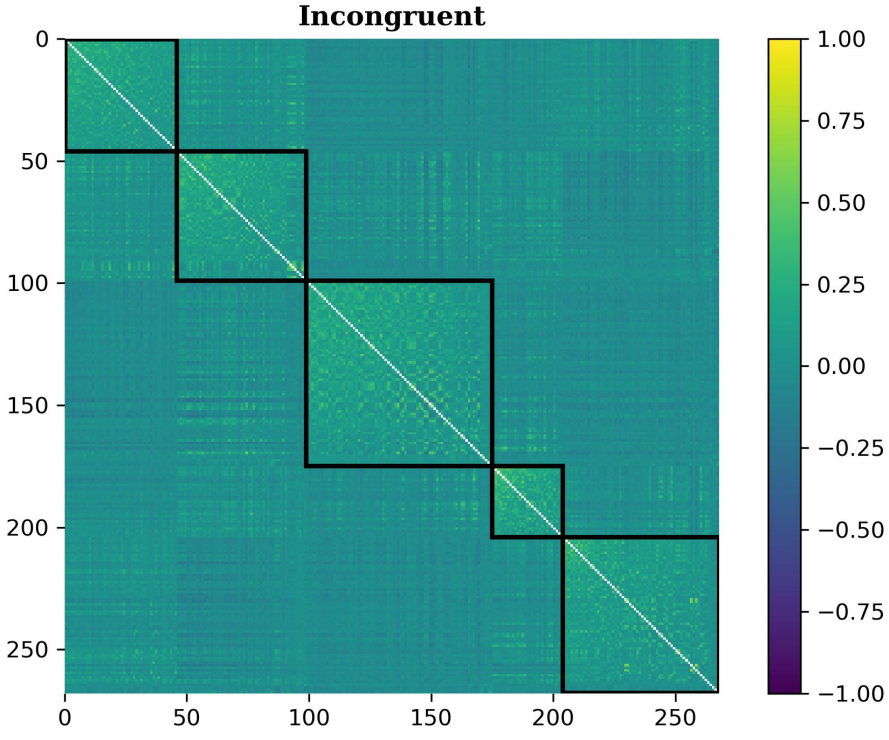

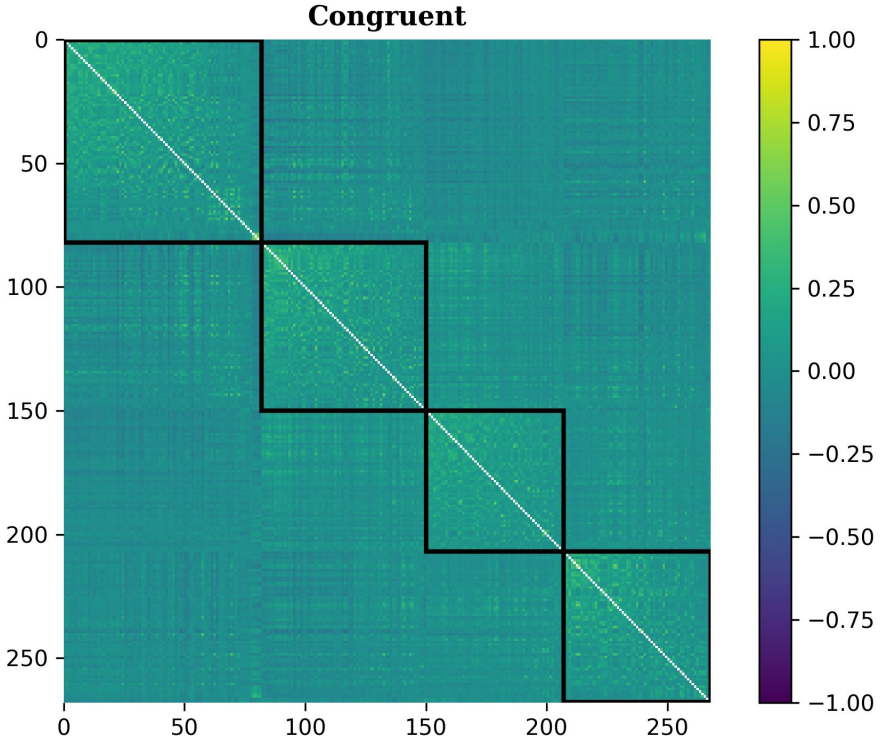

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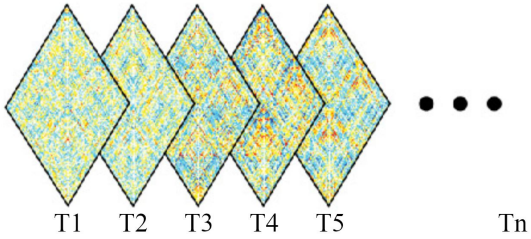

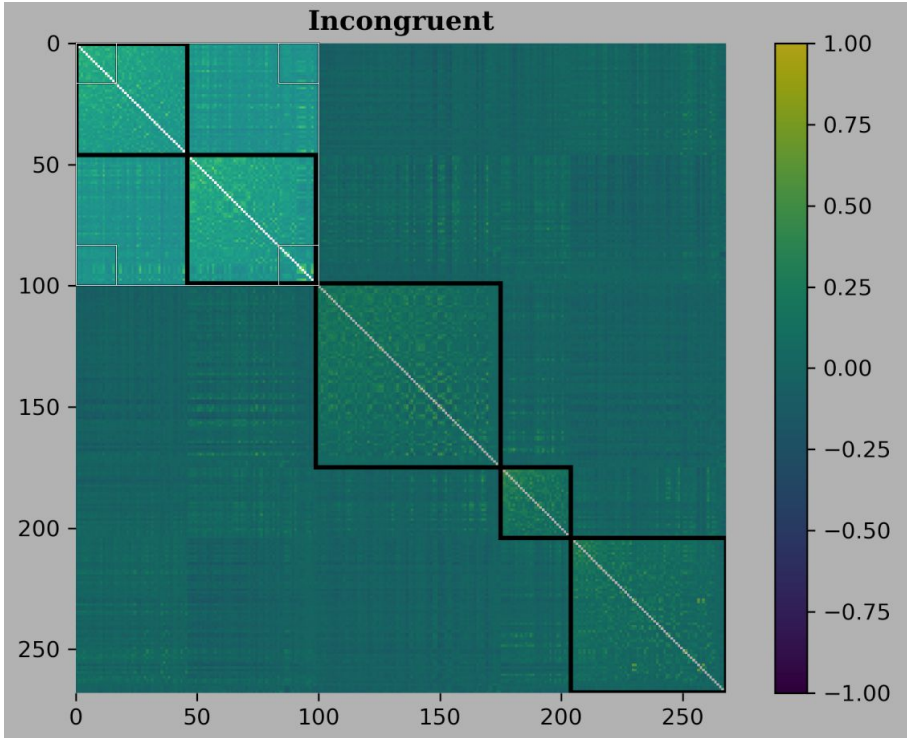

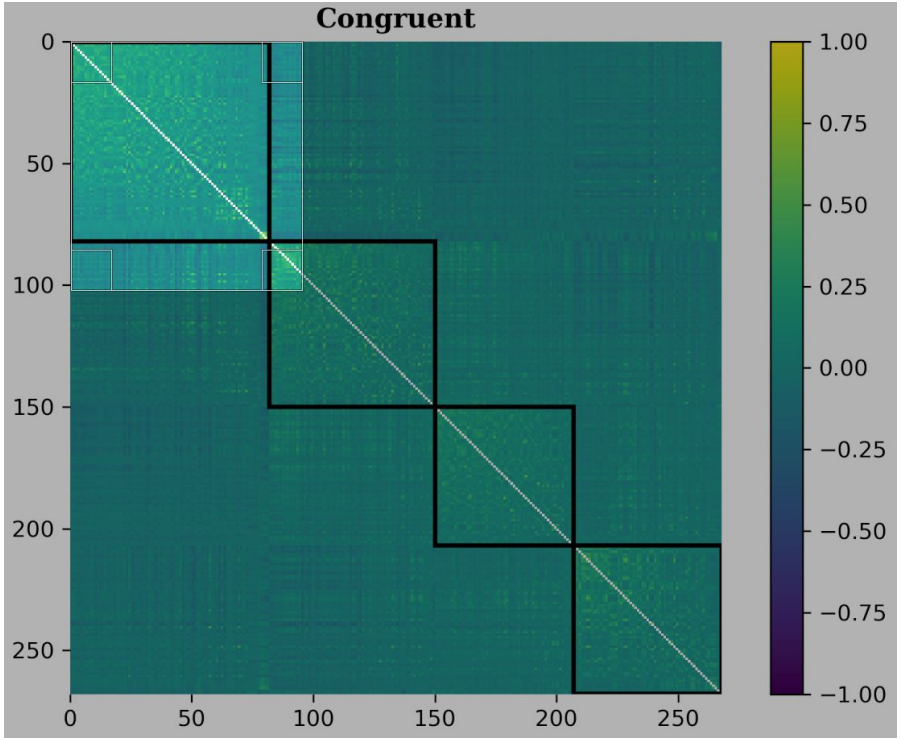

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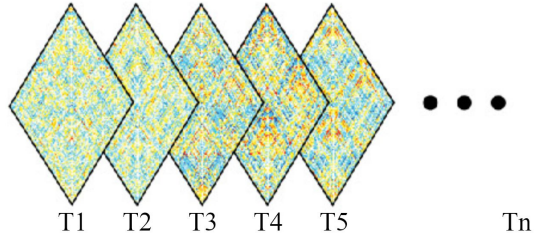

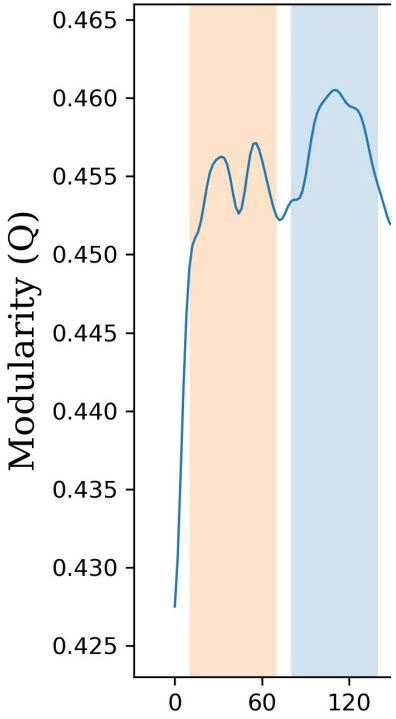

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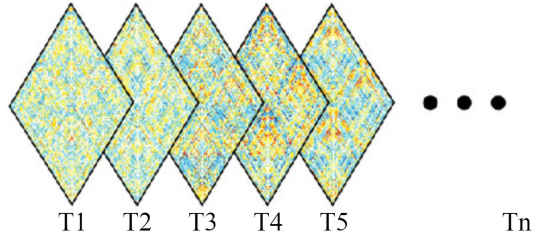

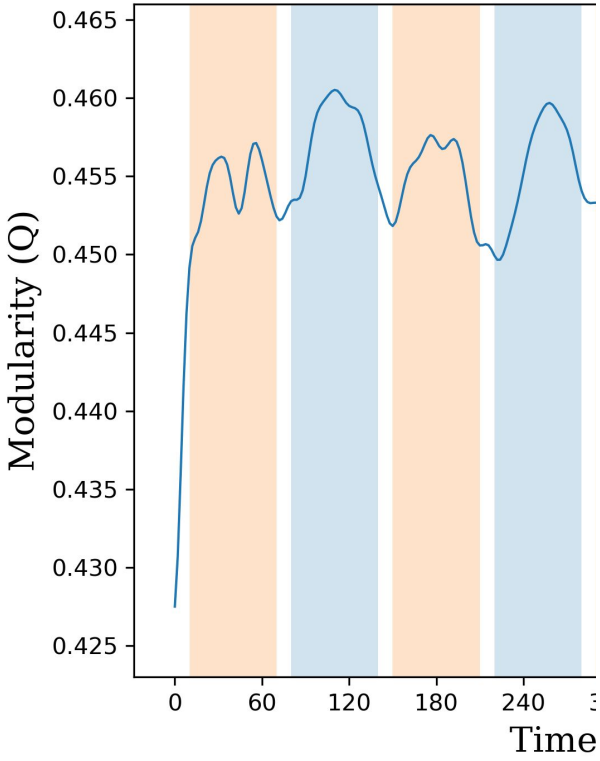

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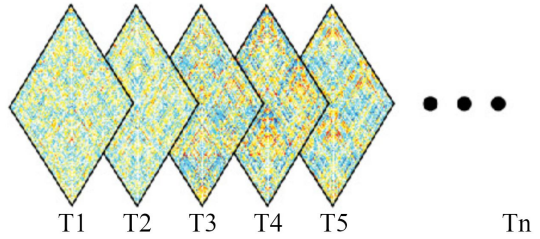

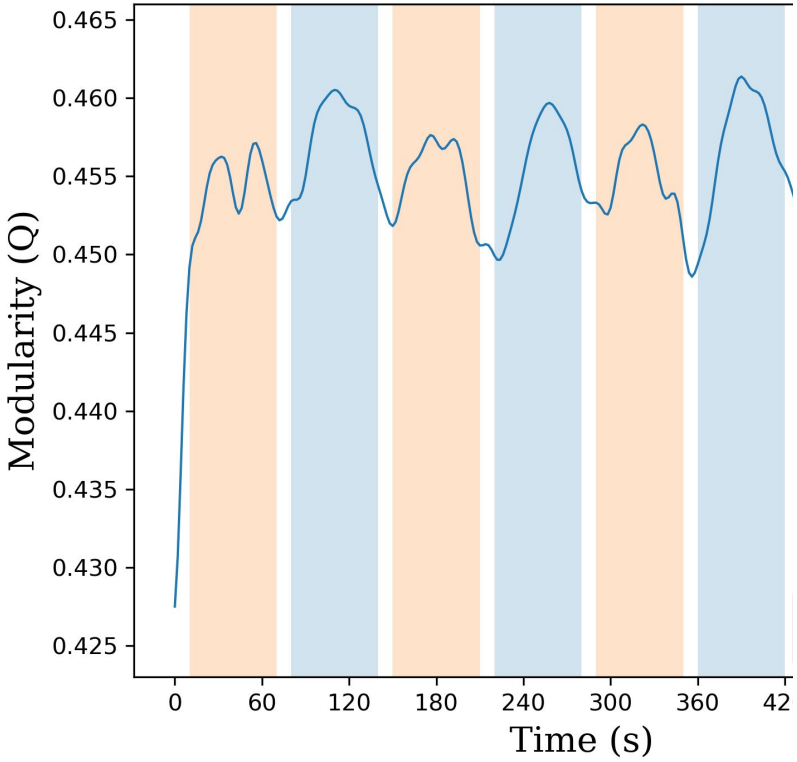

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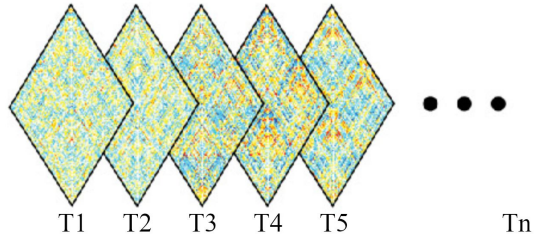

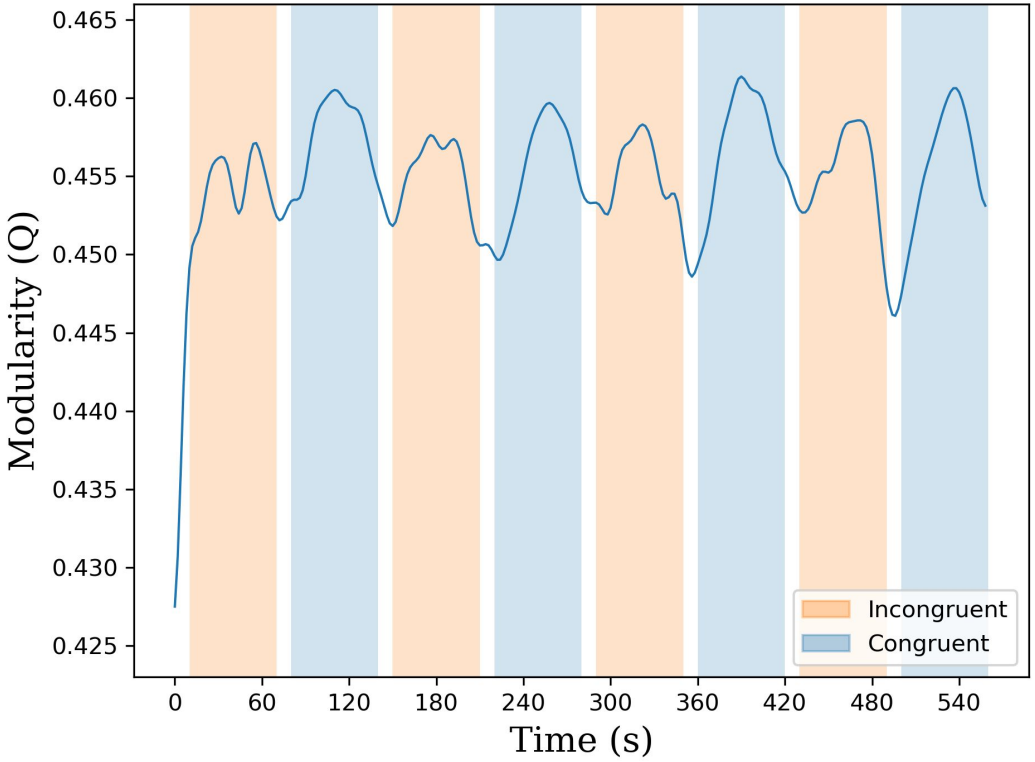

- Low modularity during incongruent task
- High modularity during congruent task
- Very low modularity at rest
  - Rest differs from prediction

FUTURE: AIM 1

- Determine quantitative values for incongruent and congruent blocks
- Perform modularity maximization
- Determine Participation coefficient values

PROPOSED PLAN: AIM 2

- Get Shen atlas precursor nodes
- Identify basal ganglia and cerebellar regions
- Determine Modularity index and Participation coefficient values
    - Is basal ganglia is highly integrated during high cortical network integration ?
    - Is cerebellum highly modular during high cortical network modularization ?

CONCLUSION

- Cortical connectivity patterns have **lower modularity** (i.e. higher integration) during **incongruent** task blocks
- Cortical connectivity patterns have **higher modularity** during **congruent** task blocks
- Short 10s rest between tasks have very low modularity (i.e. high integration)
- We are excited to see whether our hypotheses also hold for Aim 2
    - Basal ganglia leads to integration
    - Cerebellum leads to modularization

THANK YOU !

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QUESTIONS ?