Investigating neural effects of musical training using the dynamic, model-free naturalistic paradigm

Dr. Vinoo Alluri
Assistant Professor
Cognitive Science Lab

INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY
HYDERABAD

Kohli Center on Intelligent Systems

Investigating neural effects of musical training using the **dynamic, model-free naturalistic paradigm**

Dr. Vinoo Alluri
Assistant Professor
Cognitive Science Lab

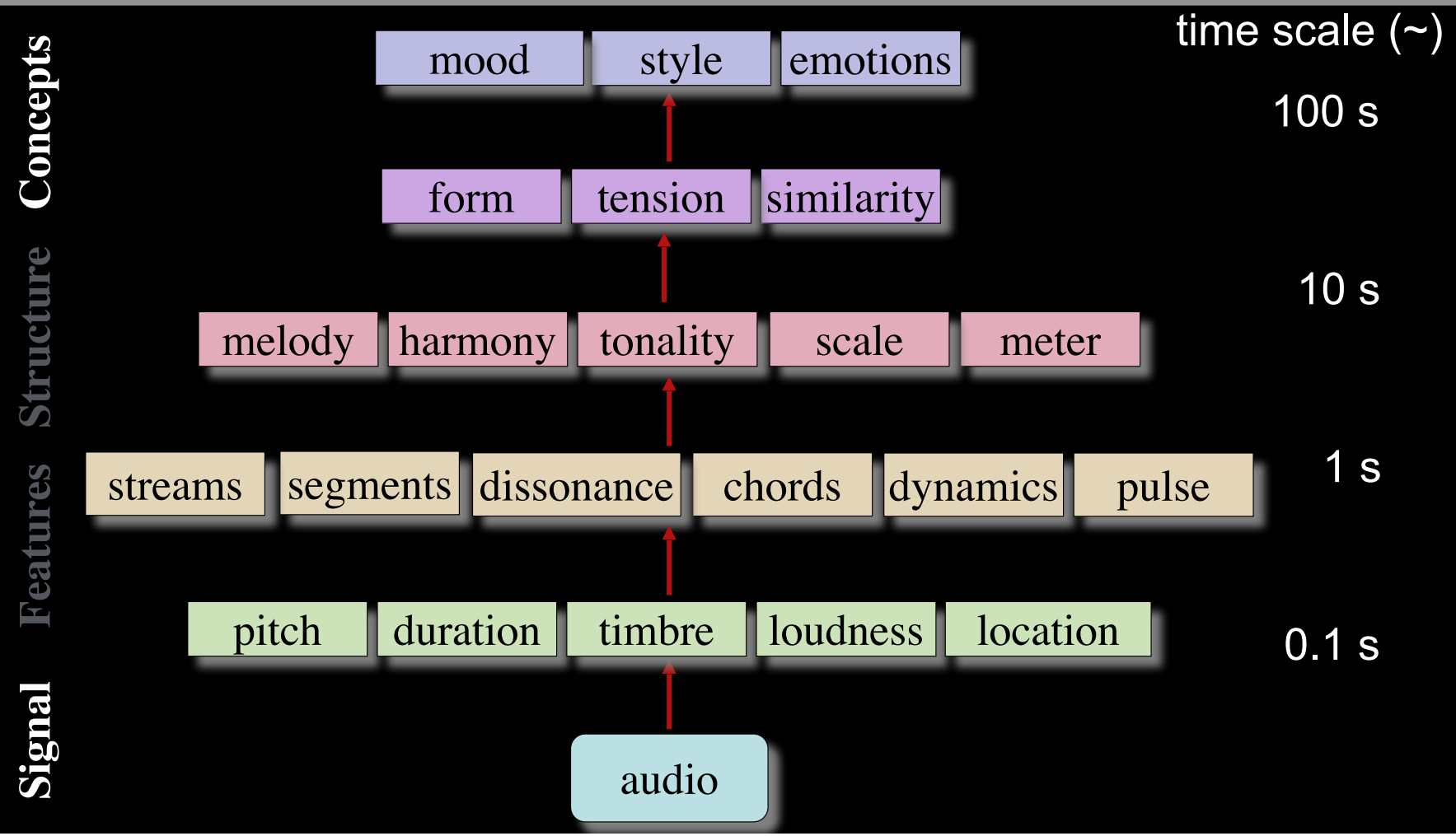
INTERNATIONAL INSTITUTE OF INFORMATION TECHNOLOGY
HYDERABAD

Kohli Center on Intelligent Systems

Outline

- music processing as a **dynamic** process (predictive coding)
- traditional vs **naturalistic** paradigm
- model-based vs **model-free**
- effects of **musical training** using the **naturalistic paradigm**
- summary of studies

music processing is **dynamic**



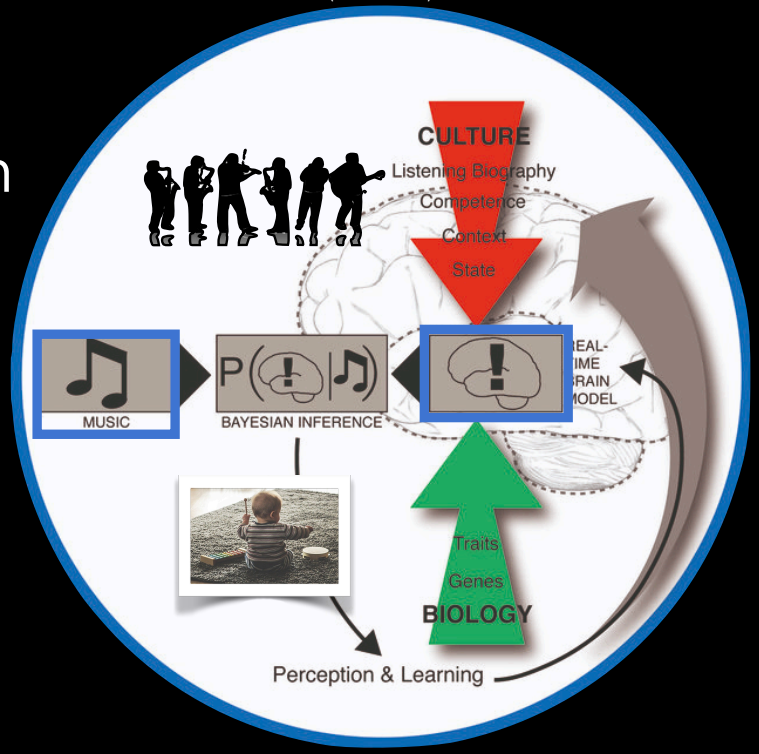
music processing is **dynamic**

predictive coding framework

- an interplay between anticipatory structures in music and predictive brain processes at varying temporal scales
- hierarchical predictions
- internal models modulated by
  - nurture (e.g.culture,musical training)
  - nature (musical aptitude)

predictive coding

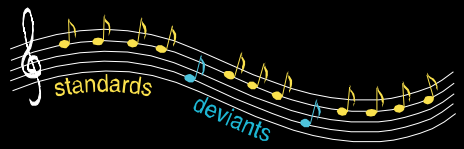
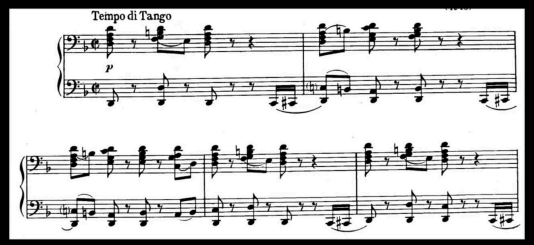
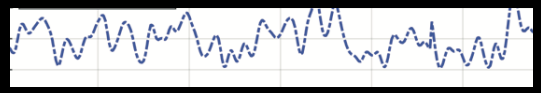
(Friston 2008)



Gebauer, Kringelbach & Vuust 2012

Koelsch, Vuust & Friston 2019

traditional vs **naturalistic** paradigm

	stimuli	**presentation**
traditional		
naturalistic		

model-based vs model-free

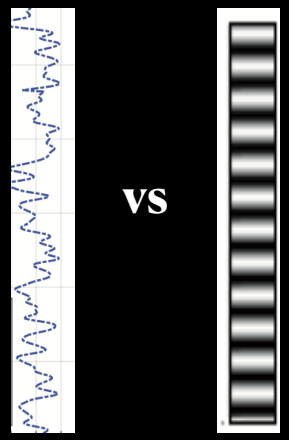
	phenomenon	**assumptions**	**methods**
model-based	external regressor		
model-free	no external regressor		

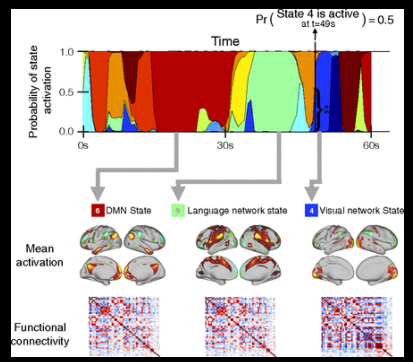
naturalistic + model-based/free

naturalistic vs traditional

- model-based
  - dynamically varying continuous regressor vs boxcar function
- model-free
  - continuous changes in brain states at different time-scales vs block-based changes

–> naturalistic - more flexible





Vidaurre et al. 2017, PNAS

model-based vs model-free

	phenomenon	assumptions	methods
model-based	external regressor	more confirmatory & hypothesis-driven	SPM (GLM) PPI
model-free	no external regressor	more exploratory & data-driven	ISC, ISPS, ICA Unsupervised clustering, HMM, graph-based

effects of musical background

naturalistic paradigm

continuous music listening

resting state

classification

regression

mus vs nonmus

musical aptitude

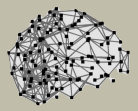
outline

mus vs nonmus

model-based

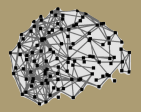
study 1: brain responses to acoustic features

- **study 2**: cerebello-hippocampal connectivity
- **study 3**: processing pulse clarity/beat salience

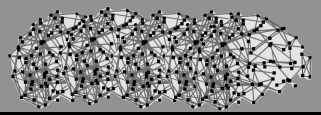


model-free

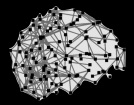
- **study 4**: functional symmetry in brain responses
- **study 5**: limbic region connectivity
- **study 6**: full-brain connectivity: a graph-theoretical approach



- **study 7**: dynamic brain states

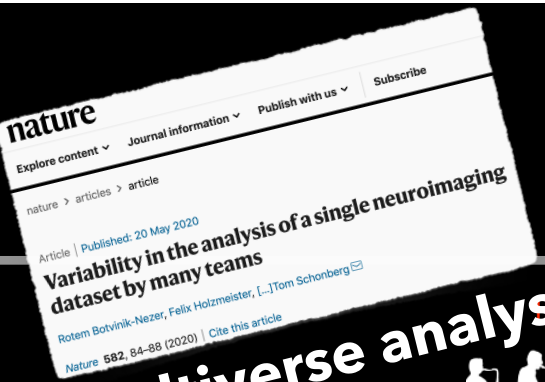


segregated

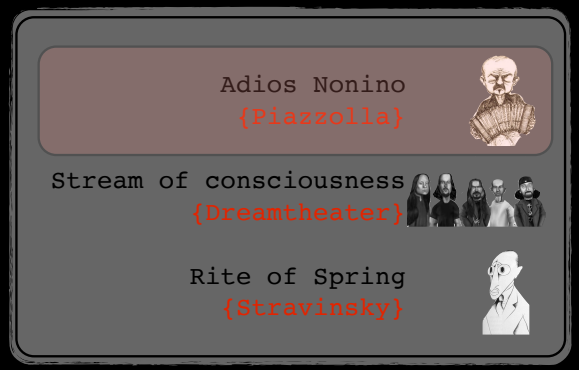


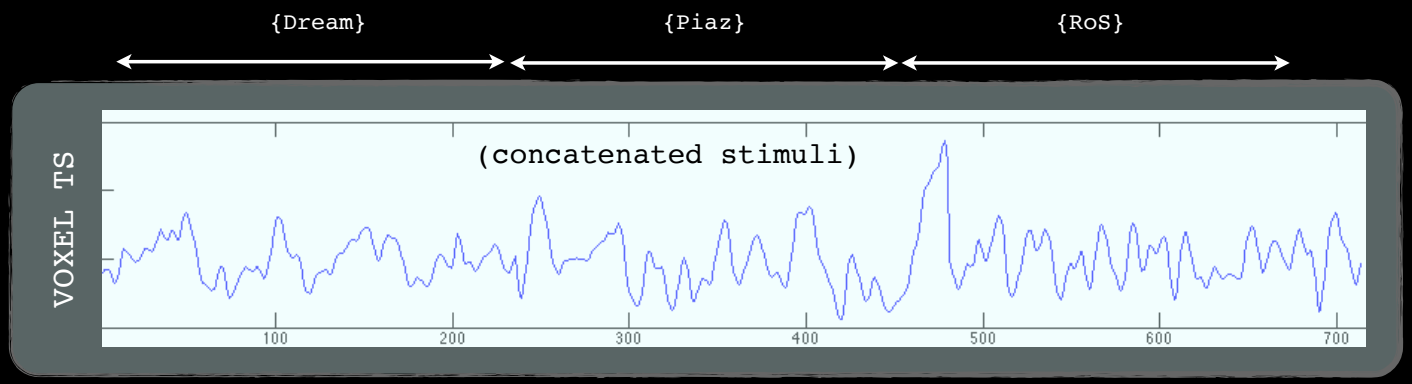
integration

dataset

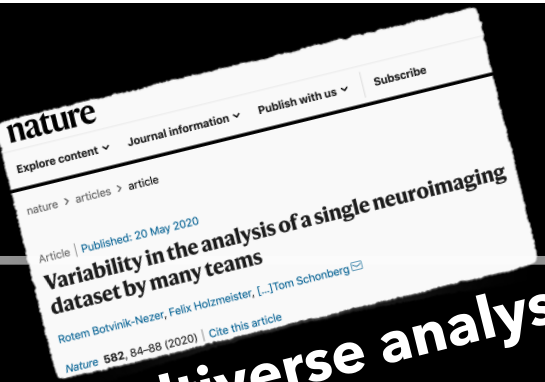


multiverse analysis





one-to(o)-many



multiverse analysis

- 108 individuals performed decision making under risk
- 9 hypotheses to test by 70 teams
- **result**
  - non-identical data analysis workflows
  - disagreement across teams for most of the tested hypotheses and variations in results
- **solution**:
  - validating and sharing complex analysis workflows
  - performing and reporting multiple analyses of the same data

outline

mus vs nonmus

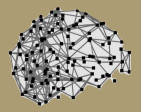
model-based

study 1: brain responses to acoustic features

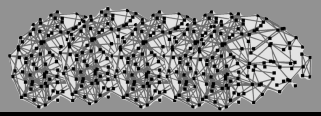
- **study 2**: cerebello-hippocampal connectivity
- **study 3**: processing pulse clarity/beat salience

model-free

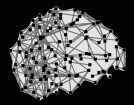
- **study 4**: functional symmetry in brain responses
- **study 5**: limbic region connectivity
- **study 6**: full-brain connectivity: a graph-theoretical approach



- **study 7**: dynamic brain states



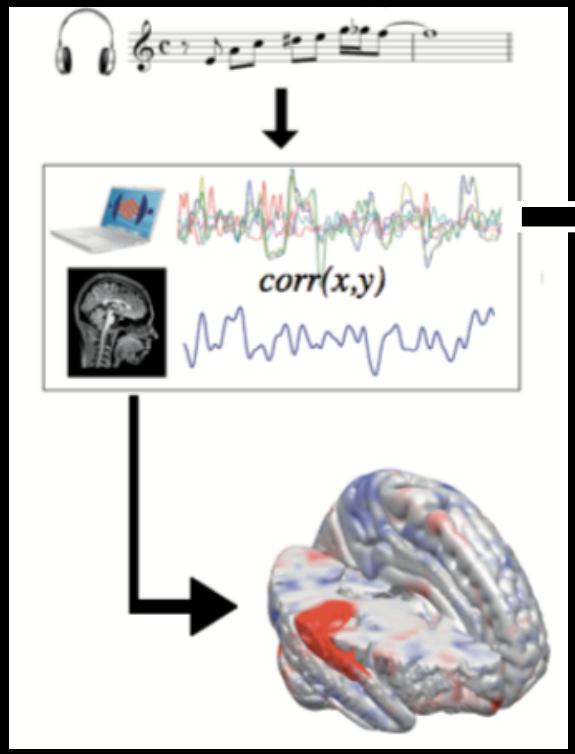
segregated



integration

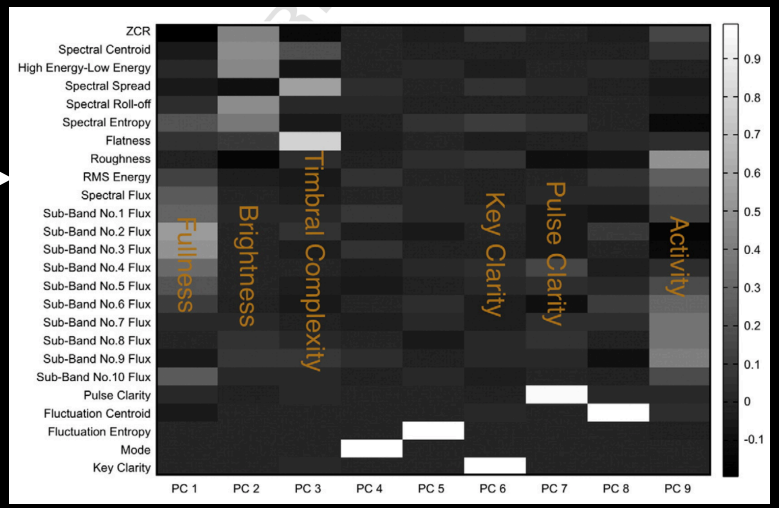
model-based

brain responses to acoustic features



Loudness
Root Mean Square Energy
Timbre
Zero Crossing Rate
Spectral Centroid
High Energy – Low Energy Ratio
Spectral Spread
Spectral Entropy
Spectral Roll-off
Spectral Flux
Spectral Flatness
Roughness
Sub-band Flux (10)

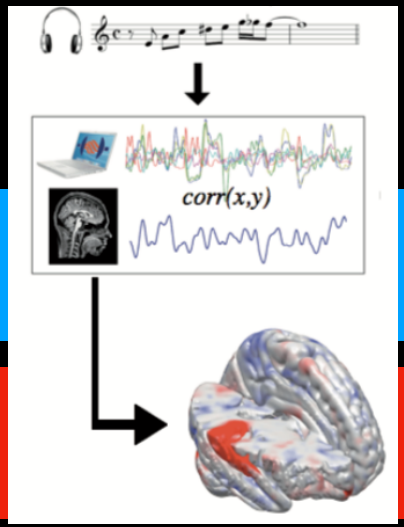
Tonality
Mode
Key Clarity
Rhythm
Fluctuation Centroid
Fluctuation Entropy
Pulse Clarity



Niranjan,D., Burunat, I., Toiviainen, P., Brattico, E., and Alluri, V. (2019) Influence of Musical Expertise on the processing of Musical Features in a Naturalistic Setting. Conference on Cognitive Computational Neuroscience 2019. Berlin

model-based

brain responses to acoustic features



- less group-level consistencies
- greater group-level consistencies in DMN-related regions

- greater limbic activations during low beat salience/pulse clarity
- greater auditory activations to high beat salience/pulse clarity

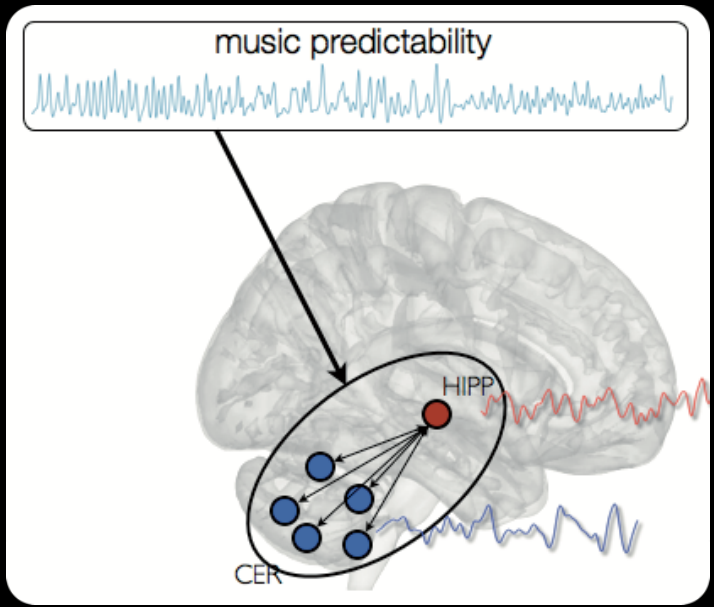
- very low group-level consistencies
- greater limbic activations to high tonal clarity

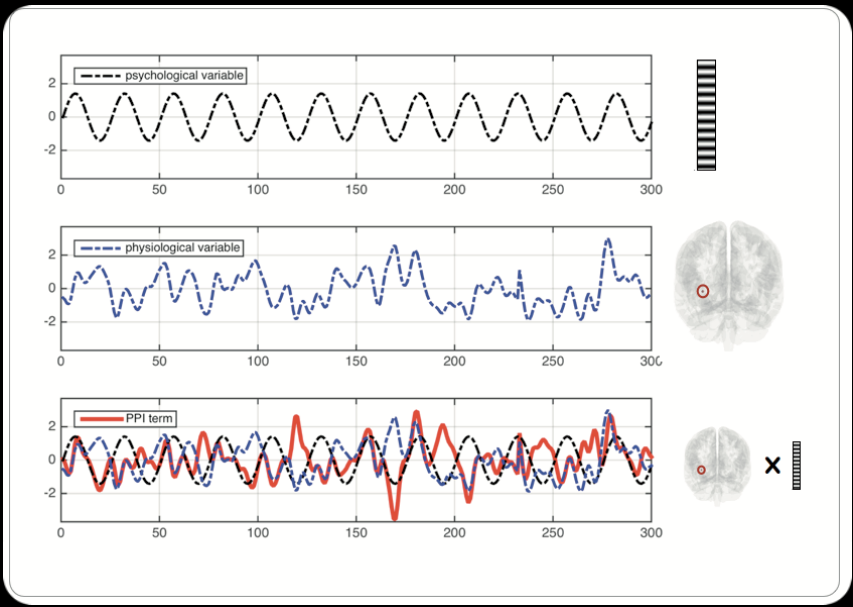
Timbral **Tonal** **Rhythmic**

Niranjan,D., Burunat, I., Toiviainen, P., Brattico, E., and Alluri, V. (2019) Influence of Musical Expertise on the processing of Musical Features in a Naturalistic Setting. Conference on Cognitive Computational Neuroscience 2019. Berlin

model-based
cerebello-hippocampal connectivity

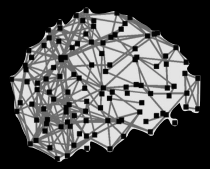
new regressor via perceptual test





CER-HIPP coupling -> a marker of predictive accuracy, spatiotemporal movements & prediction of movements

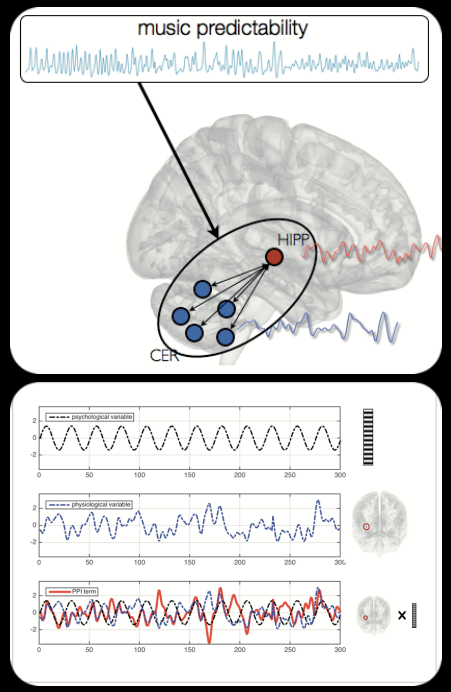
Burunat, I., Brattico, E., Martín Hartmann,. M, Peter Vuust, P., Teppo Särkämö, Toiviainen, P., (2018) Musical training predicts cerebello-hippocampal coupling during music listening. *Psychomusicology: Music, Mind, and Brain*, 28 (3), 152



model-based
cerebello-hippocampal connectivity

- increased CER-HIPP connectivity during low musical predictability especially with cognitive CER regions

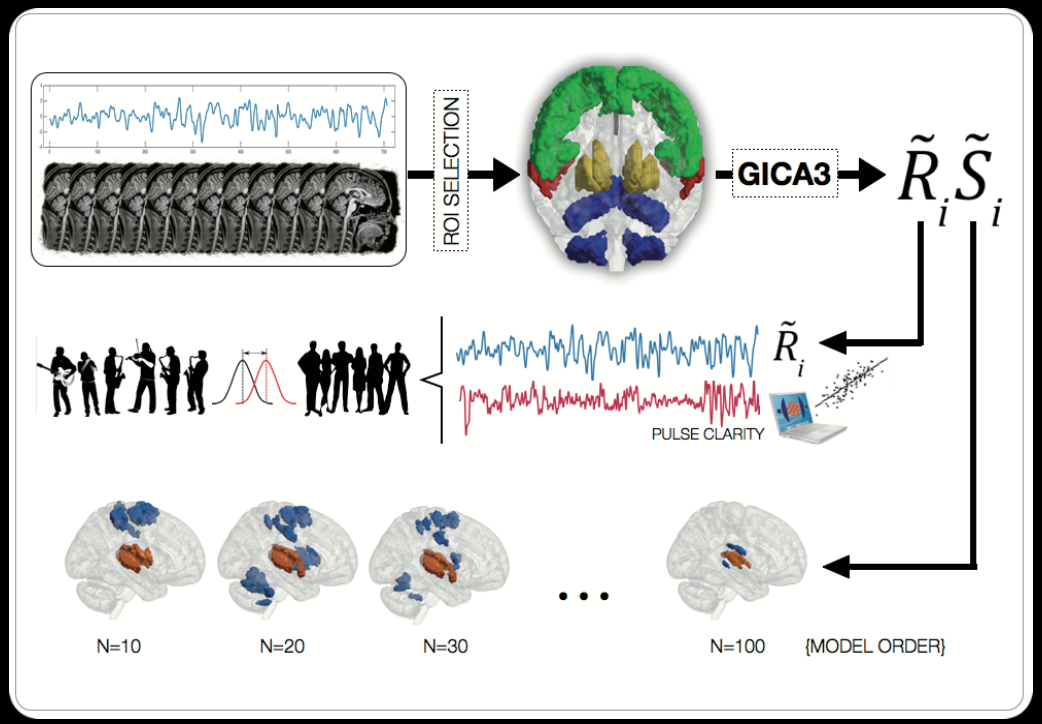
- increased predictability-driven connectivity was positively correlated with the length of their musical training



Burunat, I., Brattico, E., Martín Hartmann,. M, Peter Vuust, P., Teppo Särkämö, Toiviainen, P., (2018) Musical training predicts cerebello-hippocampal coupling during music listening. *Psychomusicology: Music, Mind, and Brain*, 28 (3), 152

model-free + model-based

processing beat salience/pulse clarity



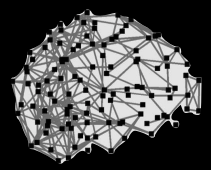
identifying into spatially independent but functionally connected brain networks

Model-free

identify independent network that correlates with beat salience

Model-Based

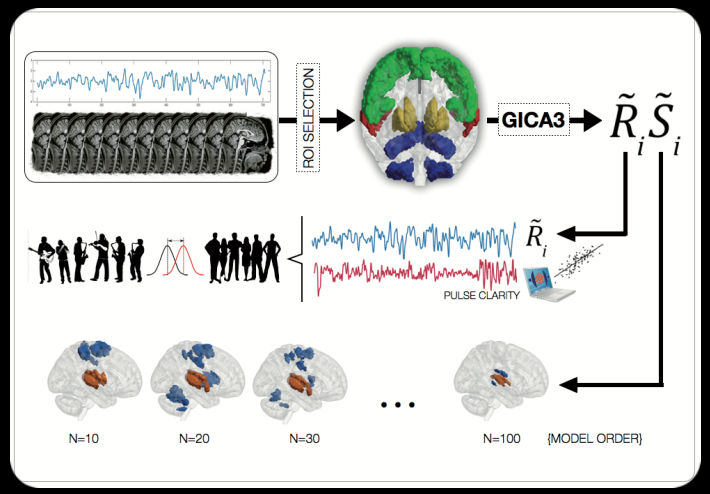
Burunat, I., Tsatsishvili, V., Brattico, E., Toiviainen, P. (2017) Coupling of Action-Perception Brain Networks during Musical Pulse Processing: Evidence from Region-of-Interest-Based Independent Component Analysis. *Frontiers in Human Neuroscience*, 11, 230



model-free + model-based
processing beat salience/pulse clarity

- possess models of pulse clarity which do not fit the model of pulse clarity derived from the acoustic stimulus

Model-free



Model-Based

- brain activity was overall significantly better predicted by the stimulus' beat salience/pulse clarity

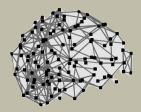
Burunat, I., Tsatsishvili, V., Brattico, E., Toiviainen, P. (2017) Coupling of Action-Perception Brain Networks during Musical Pulse Processing: Evidence from Region-of-Interest-Based Independent Component Analysis. *Frontiers in Human Neuroscience*, 11, 230

outline

model-based

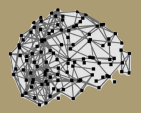
study 1: brain responses to acoustic features

- **study 2**: cerebello-hippocampal connectivity
- **study 3**: processing pulse clarity/beat salience

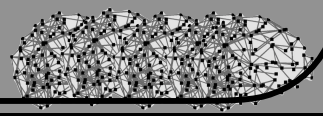


model-free

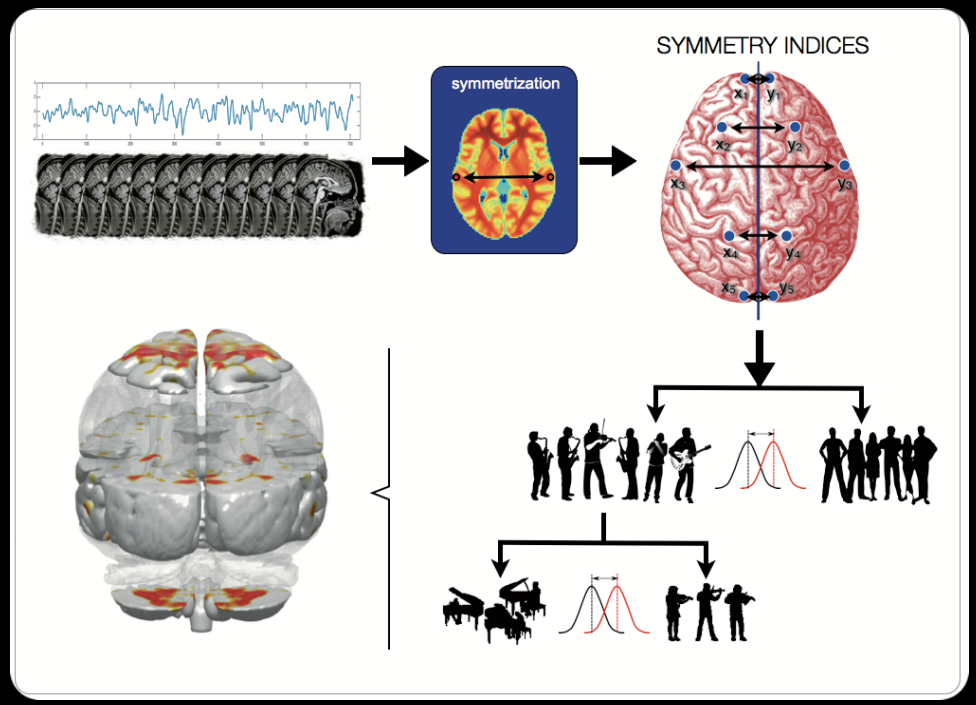
- **study 4**: functional symmetry in brain responses
- **study 5**: limbic region connectivity
- **study 6**: full-brain connectivity: a graph-theoretical approach



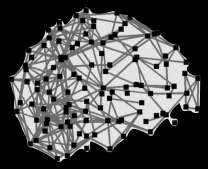
- **study 7**: dynamic brain states



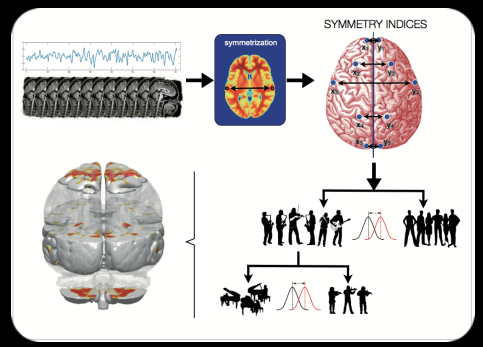
model-free
whole-brain functional symmetry



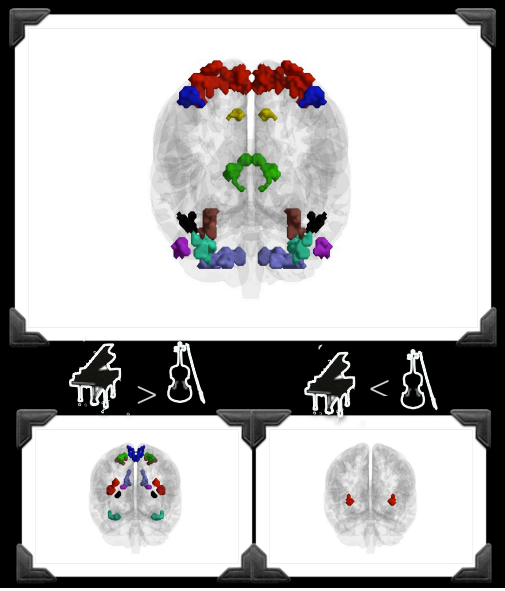
Burunat, I., Brattico, E., Puoliväli, T., Ristaniemi, T., Sams, M., & Toiviainen, P. (2015). Action in perception: Prominent visuo-motor functional symmetry in musicians during music listening. PLOS ONE 10(9).



model-free
whole-brain functional symmetry



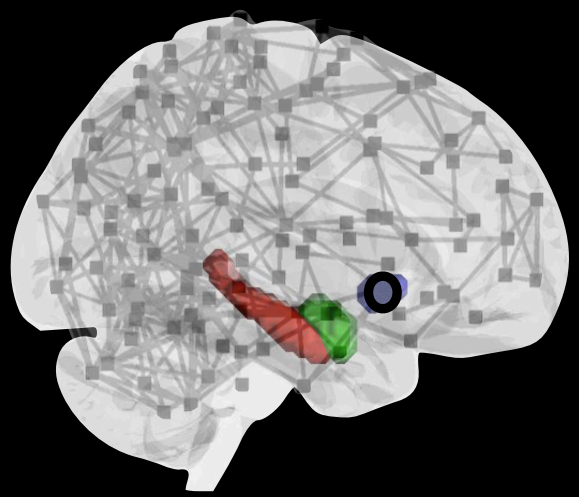
- greater symmetry in responses
- KEY > STR {determined by postural and kinematic symmetry of instrument playing}
- cross-modal transfer effect: motor training affects music perception



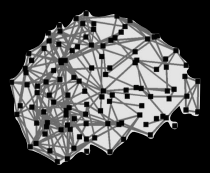
Burunat, I., Brattico, E., Puoliväli, T., Ristaniemi, T., Sams, M., & Toiviainen, P. (2015). Action in perception: Prominent visuo-motor functional symmetry in musicians during music listening. PLOS ONE 10(9).

model-free

limbic seed-based brain connectivity

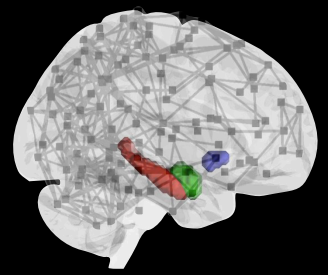


Alluri, V., Brattico, E., Toiviainen, P., Burunat, I., Bogert, B., Numminen, J., Kliuchko, M (2016). Musical expertise modulates functional connectivity of limbic regions during continuous music listening. Psychomusicology: Music, Mind and Brain. Vol 25(4), 443-454. http://dx.doi.org/10.1037/pmu0000124



model-free

limbic seed-based brain connectivity

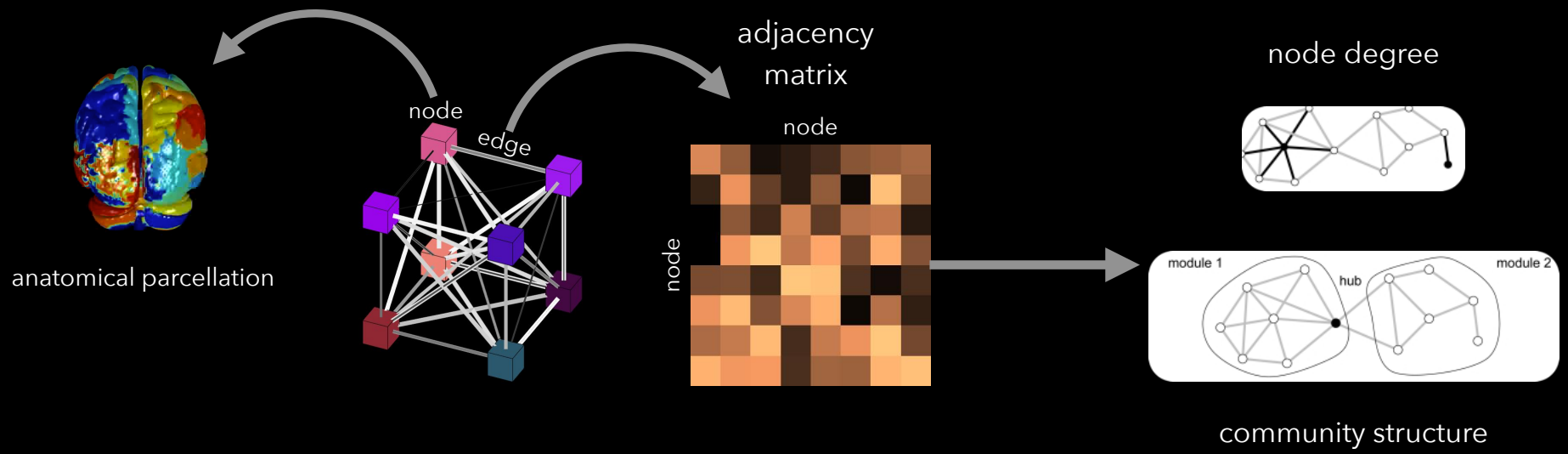


- greater & wider connectivity
- increased coupling between areas that process musical emotions with areas that process motor commands

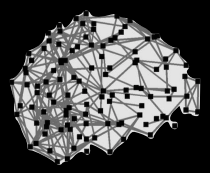
NAc -> right NAc connectivity
unaffected by musical expertise
(universal structure for pleasure)

Alluri, V., Brattico, E., Toiviainen, P., Burunat, I., Bogert, B., Numminen, J., Kliuchko, M (2016). Musical expertise modulates functional connectivity of limbic regions during continuous music listening. Psychomusicology: Music, Mind and Brain. Vol 25(4), 443-454. http://dx.doi.org/10.1037/pmu0000124

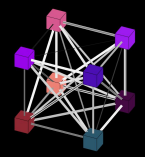
model-free
whole-brain connectivity



Alluri, V., Toiviainen, P., Burunat, I., Kliuchko, M., Vuust, P., Brattico, E. (2017). Connectivity patterns during music listening: Evidence for action-based processing in musicians. Human Brain Mapping, Vol 38 (6), pp. 2955–2970.

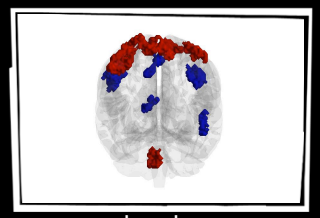


model-free
whole-brain connectivity



mus > nonmus **nonmus > mus**

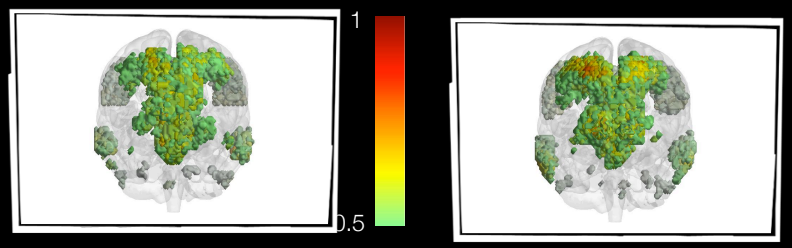
- cerebro-cerebellar sensorimotor hubs



node degree

- DMN-related hubs

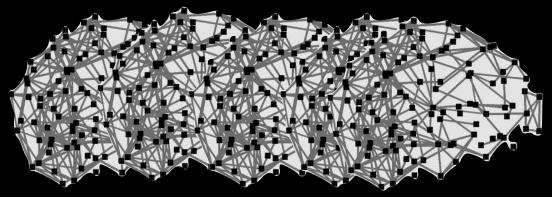
- more consistent community structure in somatomotor regions



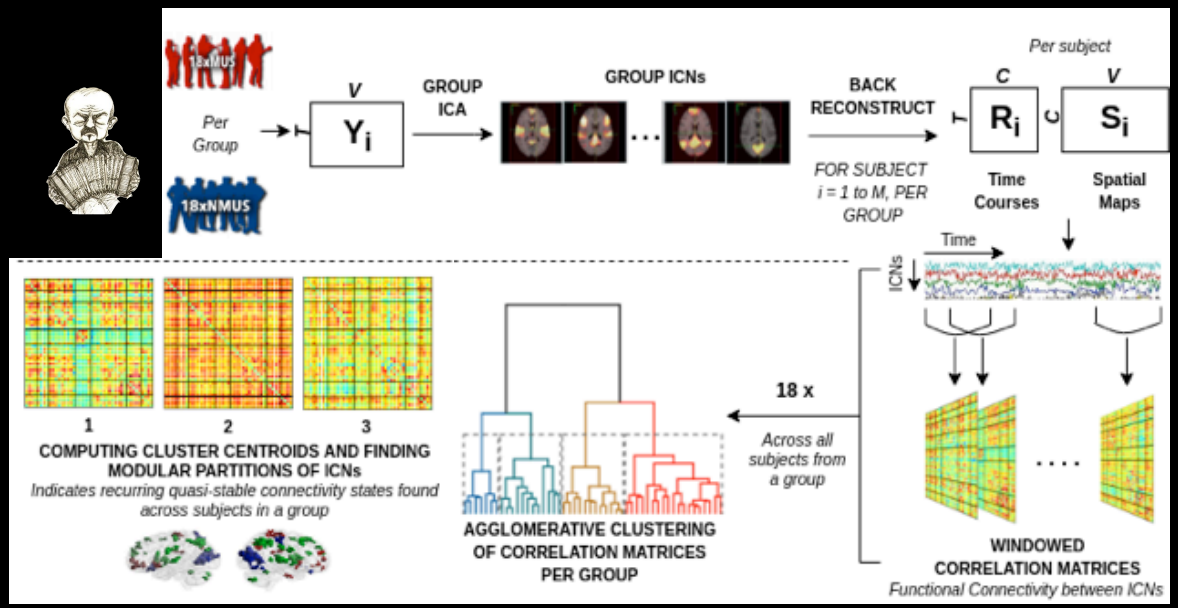
community structure

- more consistent community structure in DMN

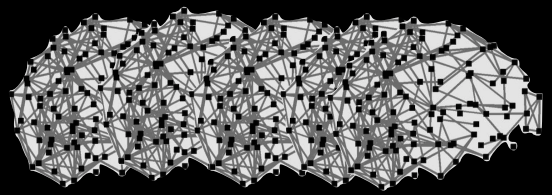
Alluri, V., Toiviainen, P., Burunat, I., Kliuchko, M., Vuust, P., Brattico, E. (2017). Connectivity patterns during music listening: Evidence for action-based processing in musicians. Human Brain Mapping, Vol 38 (6), pp. 2955–2970.



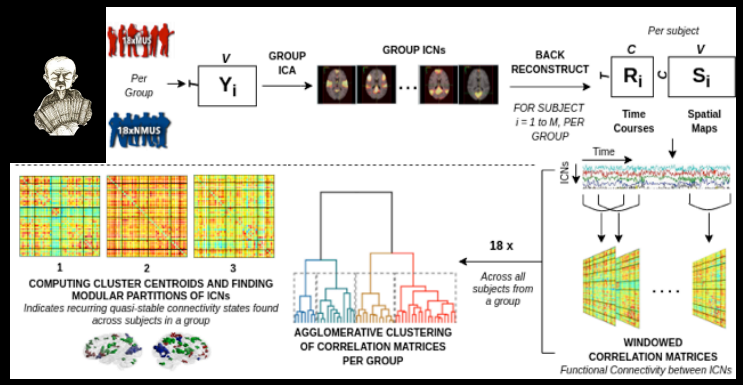
model-free
dynamic brain states



Niranjan,D., Toiviainen, P., Brattico, B., and Alluri, V. (2019) Dynamic Functional Connectivity in the Musical Brain. In The 12th International Conference on Brain Informatics, Hainan, China.



model-free
dynamic brain states



- greater variability (more number) in states
- most common state -> visuo-sensorimotor integration
- lesser state-variability (similar listening strategies)
- presence of DMN states for larger periods of time (greater mind wandering)

Niranjan,D., Toiviainen, P., Brattico, B., and Alluri, V. (2019) Dynamic Functional Connectivity in the Musical Brain. In The 12th International Conference on Brain Informatics, Hainan, China.

what did we learn?

model-based	- less consistent responses in DMN-regions - greater limbic responses to decreased beat salience	- more consistent responses in DMN-regions - internal model of beat salience relies on acoustical content and more predictable
model-free	- altered DMN connectivity - somatomotor regions central in global connectivity - **action-oriented predictive processing model (AOPP*)**	- more consistent DMN connectivity - DMN-related region central in global connectivity - perception-based model*

*minimize the prediction error by actively engaging the motor system internally to generate the motor commands needed to fulfill the predictions

*attempt to match incoming sensory information based on modification of top down predictions

what can’t we learn?

	Limitations
model-based	- limited no. of regressors - collinearity
model-free	- every method adapted gives a result - actual experiences needed

what can’t we learn?

	Limitations
model-based	- limited no. of regressors - collinearity
model-free	- every method adapted gives a result - actual experiences needed

naturalistic paradigm

blasphemy !!!

2011

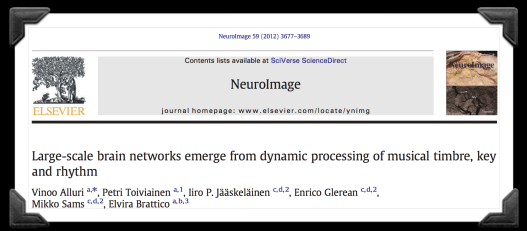
2012

2020

2021

2024

Symposium naturalistic paradigm



NeuroImage 59 (2012) 3677–3689

Contents lists available at SciVerse ScienceDirect

NeuroImage

journal homepage: www.elsevier.com/locate/ynimg

Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm

Vinoo Alluri [a,*], Petri Toiviainen [a,1], Iiro P. Jääskeläinen [c,d,2], Enrico Glerean [c,d,2], Mikko Sams [c,d,2], Elvira Brattico [a,b,3]

Special Issue naturalistic imaging

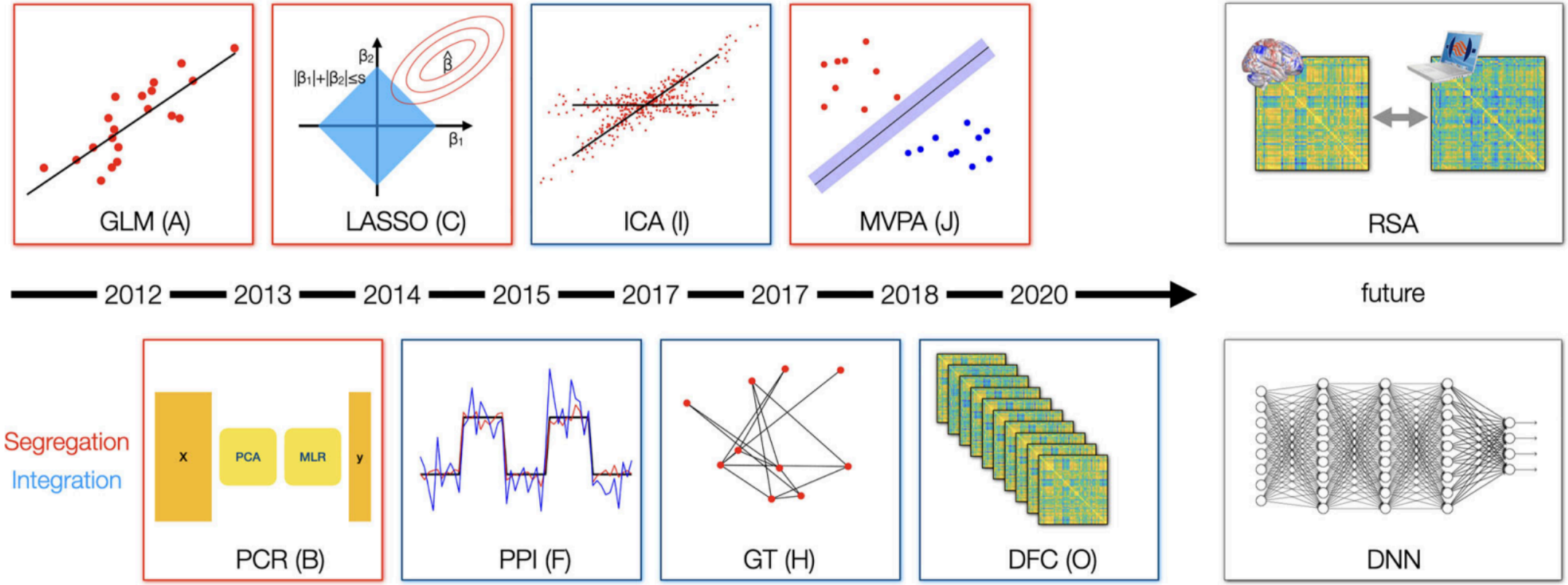
ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

PERSPECTIVE

The naturalistic paradigm: An approach to studying individual variability in neural underpinnings of music perception

Vinoo Alluri, Petri Toiviainen

First published: 17 October 2023 | https://doi.org/10.1111/nyas.15075 | Citations: 1



ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

PERSPECTIVE

The naturalistic paradigm: An approach to studying individual variability in neural underpinnings of music perception

Vinoo Alluri, Petri Toiviainen

First published: 17 October 2023 | https://doi.org/10.1111/nyas.15075 | Citations: 1

The End