Harnack-Haus, Berlin | 5 December, 2024

Cognition Academies, Max Planck School of Cognition

Music, Brain, and Emotions: a practical workshop

Seung-Goo ("Sng-Gu") Kim

Research Group Neurocognition of Music and Language, Max Planck Institute for Empirical Aesthetics, Frankfurt am Main

🤔: Who is this?

Seung-Goo Kim

- Originally from Seoul, South Korea, been in Germany for 8+ years without learning German😜
- First name: Seung-Goo 승구[/sɯŋgu/](勝九)
    - You can always call me “SG” [Es-Gee] if you feel [ɯ] is too difficult. 🤗
- Family name: Kim 김[/gim/](金)
- And very into 🧠🎶🤖

2016, Leipzig

2019, Jeju


SCORE<1> HI-SCORE SCORE<2>
0990 0000
3
CREDIT 05

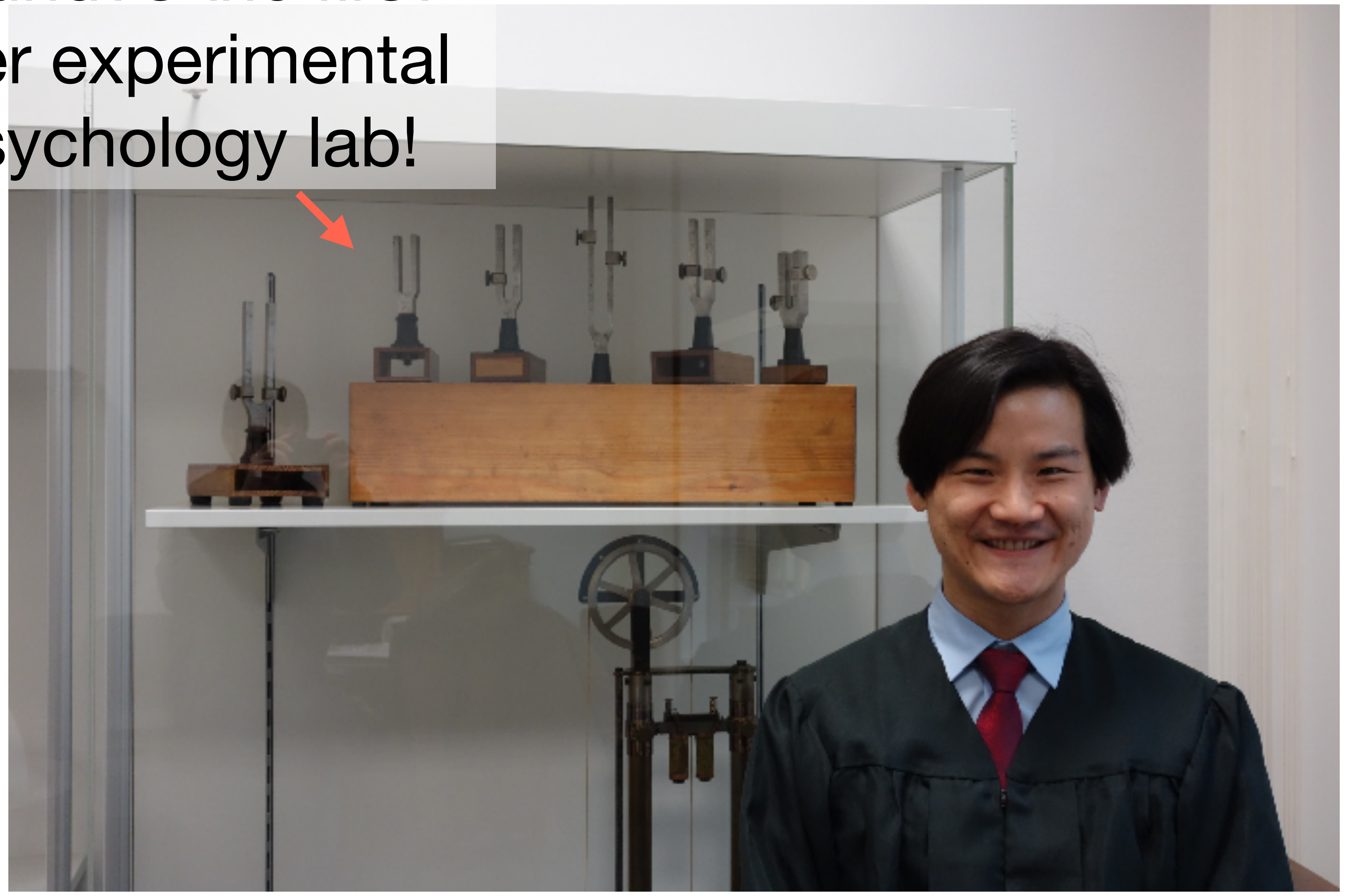

Scream Tracker V3.21
Copyright (C) 1993,1994 Sami Tammilehto
Song Armani Showers
Instrument 01: (C) Edge / EMF 1994
Order 000/010
Pattern 00
Row 00
Channel 01
File armani.s3m (S3M)
Chord none
C.Tempo 7D
C.Speed 06
Baseoctave 3
FreeMem: 281K
FreeEMS: 31280K
FreeGUS: 1018K
ESC ...... Main Menu
F10 ...... Quick-Help
CTRL-Q .. Quit to DOS
F1..F4 .. Edit Screen
CTRL-L .. Load Module
F5/F8 ... Play / Stop
Pattern Editor (F2)
01: L1
02: R1
03: L2
04: R2
05: L3
00 E-3 01 01 S85 | ^^. .. .. .00 | ^^. .. .. .00 | ^^. .. .. S8B | ^^. .. .. .00
01 A-3 .. 01 GAF | ... . .00 | ... . .00 | ... . .00 | 00
02 B-3 .. 02 G00 | ... . .00 | ... . .00 | E-3 01 01 .00 | 00
03 E-3 .. 02 G00 | ... . .00 | ... . .00 | A-3 .. .. GAF | 00
04 B-3 .. 03 G00 | ... . .00 | ... . .00 | B-3 .. .. G00 | 00
05 C-4 .. 03 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
06 E-3 .. 04 G00 | ... . .00 | ... . .00 | B-3 .. .. G00 | 00
07 D-4 .. 05 G00 | ... . .00 | ... . .00 | C-4 .. .. G00 | 00
08 E-3 .. 05 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
09 A-3 .. 06 G00 | ... . .00 | ... . .00 | D-4 .. .. G00 | 00
10 B-3 .. 06 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
11 E-3 .. 07 G00 | ... . .00 | ... . .00 | A-3 .. .. G00 | 00
12 B-3 .. 07 G00 | ... . .00 | ... . .00 | B-3 .. .. G00 | 00
13 C-4 .. 08 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
14 E-3 .. 09 G00 | ... . .00 | ... . .00 | B-3 .. .. G00 | 00
15 E-4 .. 09 G00 | ... . .00 | ... . .00 | C-4 .. 02 G00 | 00
16 E-3 .. 10 G00 | E-4 01 00 S8F | ... . .00 | E-3 .. .. G00 | 00
17 A-3 .. 10 G00 | ... . .00 | ... . .00 | E-4 .. .. G00 | 00
18 B-3 .. 11 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
19 E-3 .. 11 G00 | ... .. 01 .00 | ... . .00 | A-3 .. .. G00 | 00
20 B-3 .. 12 G00 | ... . .00 | ... . .00 | B-3 .. 03 G00 | 00
21 C-4 .. 13 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
22 E-3 .. 13 G00 | ... .. 02 .00 | ... . .00 | B-3 .. .. G00 | 00
23 D-4 .. 14 G00 | ... . .00 | ... . .00 | C-4 .. .. G00 | 00
24 E-3 .. 14 G00 | ... .. 03 .00 | ... . .00 | E-3 .. .. G00 | 00
25 A-3 .. 15 G00 | ... . .00 | ... . .00 | D-4 .. .. G00 | 00
26 B-3 .. 15 G00 | ... . .00 | ... . .00 | E-3 .. .. G00 | 00
27 E-3 .. 16 G00 | ... .. 04 .00 | ... . .00 | A-3 .. .. G00 | 00
28 B-3 .. 17 G00 | ... . .00 | ... . .00 | B-3 .. .. G00 | 00

https://pixabay.com/illustrations/brain-mind-psychology-idea-drawing-2062057/

Education & Training (1)

- 1996–1999, Musical composition at *Sunwha* Arts High School, South Korea
- 2000–2004, dual BAs in Economics & Psychology, *Yonsei* University, South Korea
- 2008–2010, MS in Cognitive Sciences, Seoul National University, South Korea (MEG for music)
- 2010–2012, Graduate researcher, Seoul National University, South Korea (sMRI for stat)
- 2012–2017, Ph.D. (Dr. rer. nat.) in Psychology, IMPRS for Neuro-Comm, MPI for CBS, Leipzig (s/fMRI for music)

From Wilhelm Wundt's the first ever experimental psychology lab!

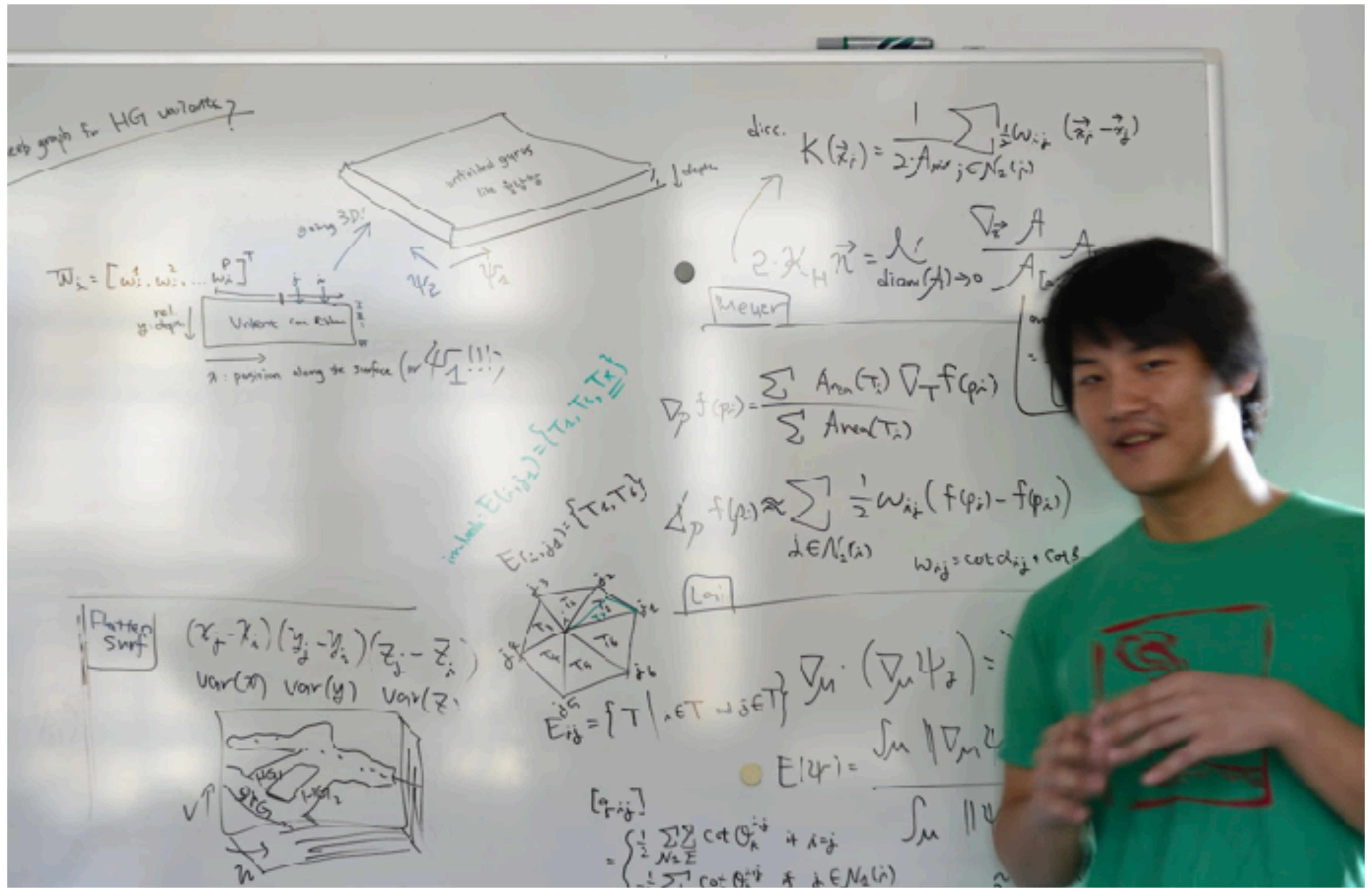


2017, Leipzig

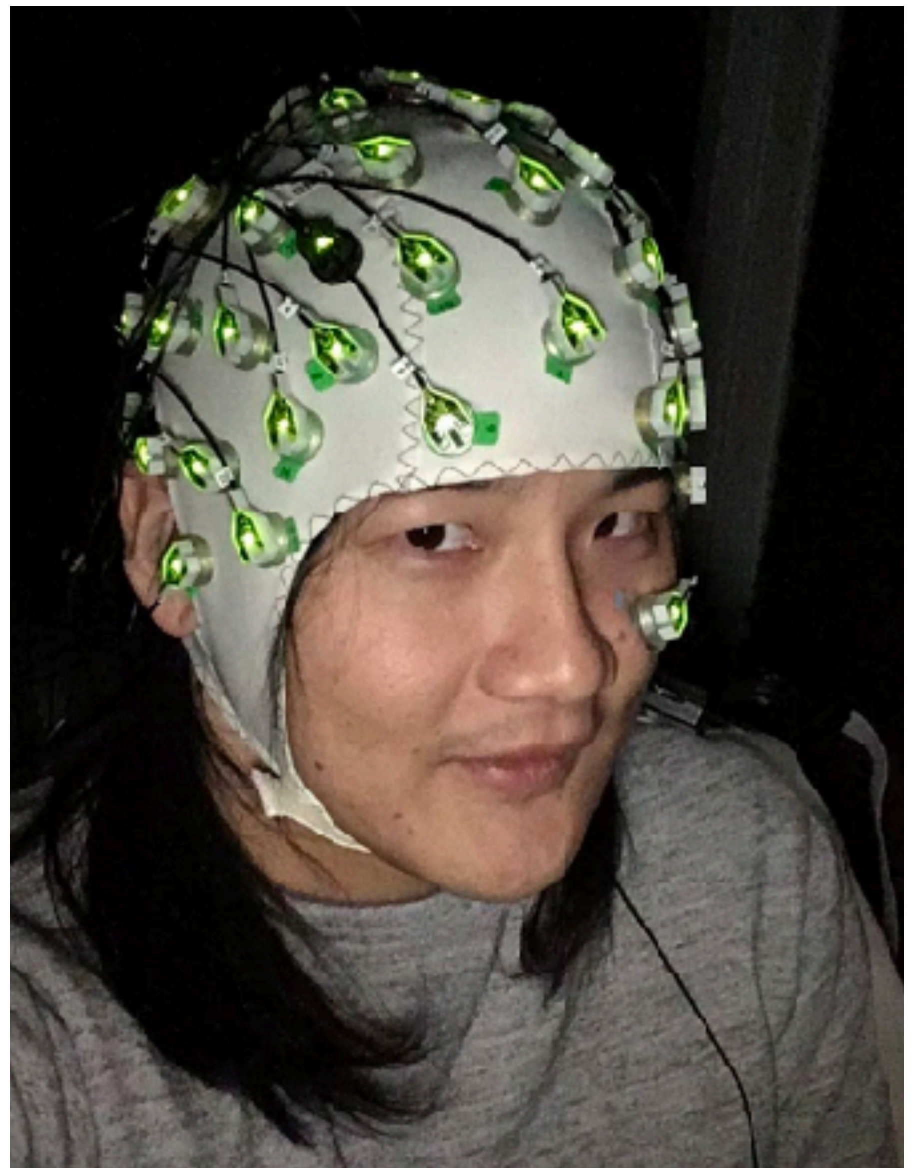
2017, Leipzig

Education & Training (2)

- 2017–2018, Postdoc, Cambridge University, UK (s/fMRI for psychiatry; PI: Dr. Valerie Voon)
- 2018–2021, Postdoc, Duke University, NC, USA (M/EEG, fMRI for speech; PI: Dr. Toibas Overath)
- 2021–, **Research Scientist, Max Planck Institute for Empirical Aesthetics, Frankfurt am Main** (fMRI for music; PI: Dr. Daniela Sammler)



2013, Leipzig



2018, Durham, NC


MAX PLANCK INSTITUTE
FOR EMPIRICAL AESTHETICS


Harmony in the pianist's brain
Playing without sound
Listening
L R
z=26
z=41
z=56
z=-3
z=12
T


SCHÖN

🤔: What do we do this morning?

Session plan

Music, Brain, and Emotions

From	To	Contents	Dur
09:30	10:15	**Introduction**: Music, Brain, Emotions	45m
10:15	10:45	**Live Experiment**: Music & Emotions	30m
10:45	11:00	Coffee break	15m
11:00	11:20	**Theories**: How to analyze naturalistic experiments	20m
11:20	11:50	**Hands-on**: Analysis	30m
11:50	12:00	Summary & discussion	10m
		SUM	*2h 15m*

What's['re] your language[s]?

scripting languages (Python, R, Matlab, Julia, Bash, Perl, Lisp)?
compiling languages (Java, C, C++, Rust)?
markup languages (md, tex, html, javascript)?

Excuse my language!

A few words on MATLAB and Open Science

- Why not Python? Have you heard about the Anaconda's Pricing Policy for Max Planck Institutes?
- Using MATLAB does not necessarily harm Open Science (Yes, it may grow dependency; but everyone needs to be **polylingual** anyways!)
- There are a couple of cloud platforms where you can run MATLAB without purchasing the license (e.g. code ocean, MATLAB online, …)
- Because of the liability, MATLAB is more rigorously maintained than many community codebases.
- Still many people understand MATLAB.
- (Real reason: Sorry, I have all my toys 🧸 in MATLAB until I rewrite them in Julia)

Music, Brain, and Emotions

Introduction

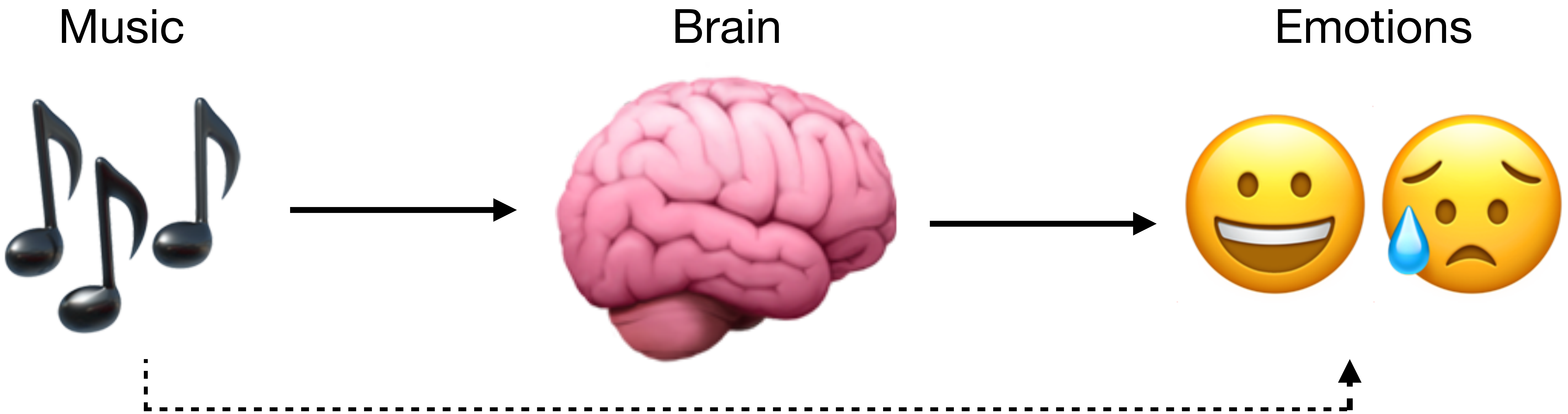
Go back to SESSION PLAN

SOUND DEMO: "Act I – Prelude", Tristan und Isolde, R. Wagner, Gewandhausorchester, Andris Nelson

https://voxpopulisphere.com/2015/11/01/audio-what-ancient-greek-music-actually-sounded-like/

How does music evoke emotions *via* the brain?

A very simplistic view

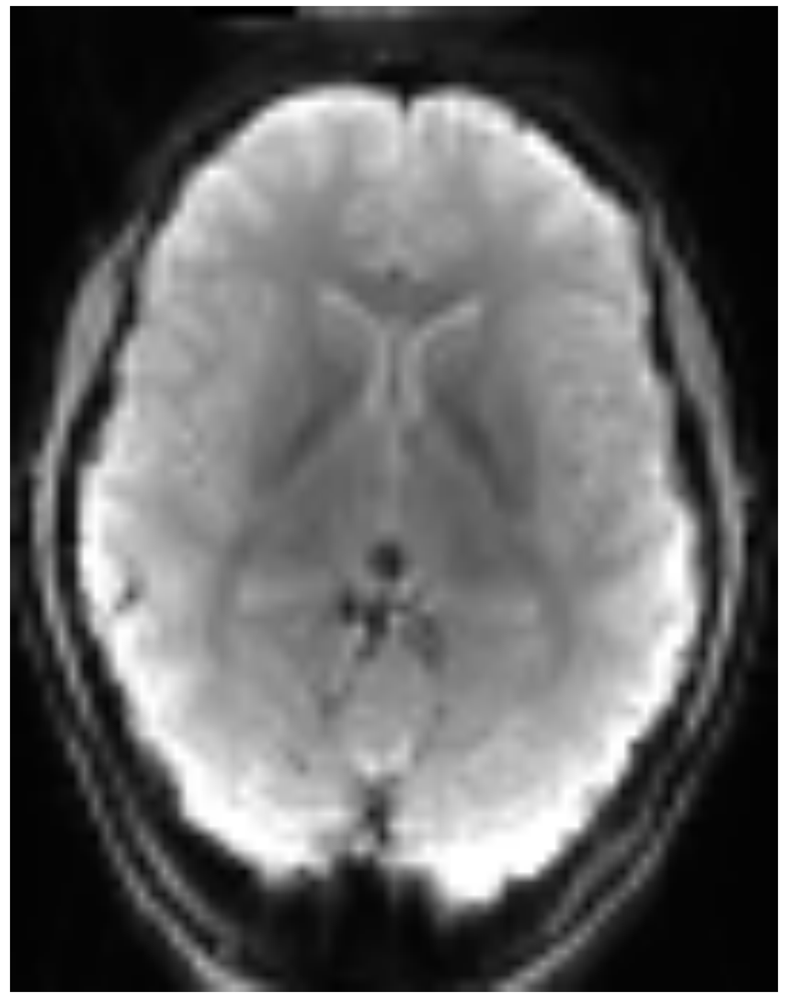


How does the brain transform the musical information?

Functional magnetic resonance imaging (fMRI)

Still, the state-of-the-art of non-invasive neuroimaging

T2* EPI image



- **Neurovascular coupling** {Somehow: probably by glial cells?}: neural activity → blood flow with oxygenated hemoglobin
- Oxygenation makes blood less paramagnetic, increasing the EPI image intensity ("**Blood-Oxygenation-Level-Dependent [BOLD] effect**" [1])
- Neural activity → BOLD response has been experimentally confirmed in animals (electrode-implanted monkeys [2]; optogenetic rodents [3]).
- It's **loud** (90+ dB; ANC: ~-30 dB), noisy (SNR = -2 dB), and expensive (€2M + a team led by an MR physicist). But it's still the SOTA (1 sec per volume & 3 x 3 x 3 mm^3 voxel).

[1] Ogawa et al., 1990, *PNAS*. [2] Logothetis et al., 2001, *Nature*. [3] Lee et al., 2010, *Nature*.

https://www.irasutoya.com/

Topics: Introduction

Music, Brain, Emotions

- Psychological models of emotions and musical emotions 🎶
- Cognitive accounts: Musical structures 🧐
- Affective accounts: Musical expressions 🥹
- Needs for “naturalistic" experiments 🦋

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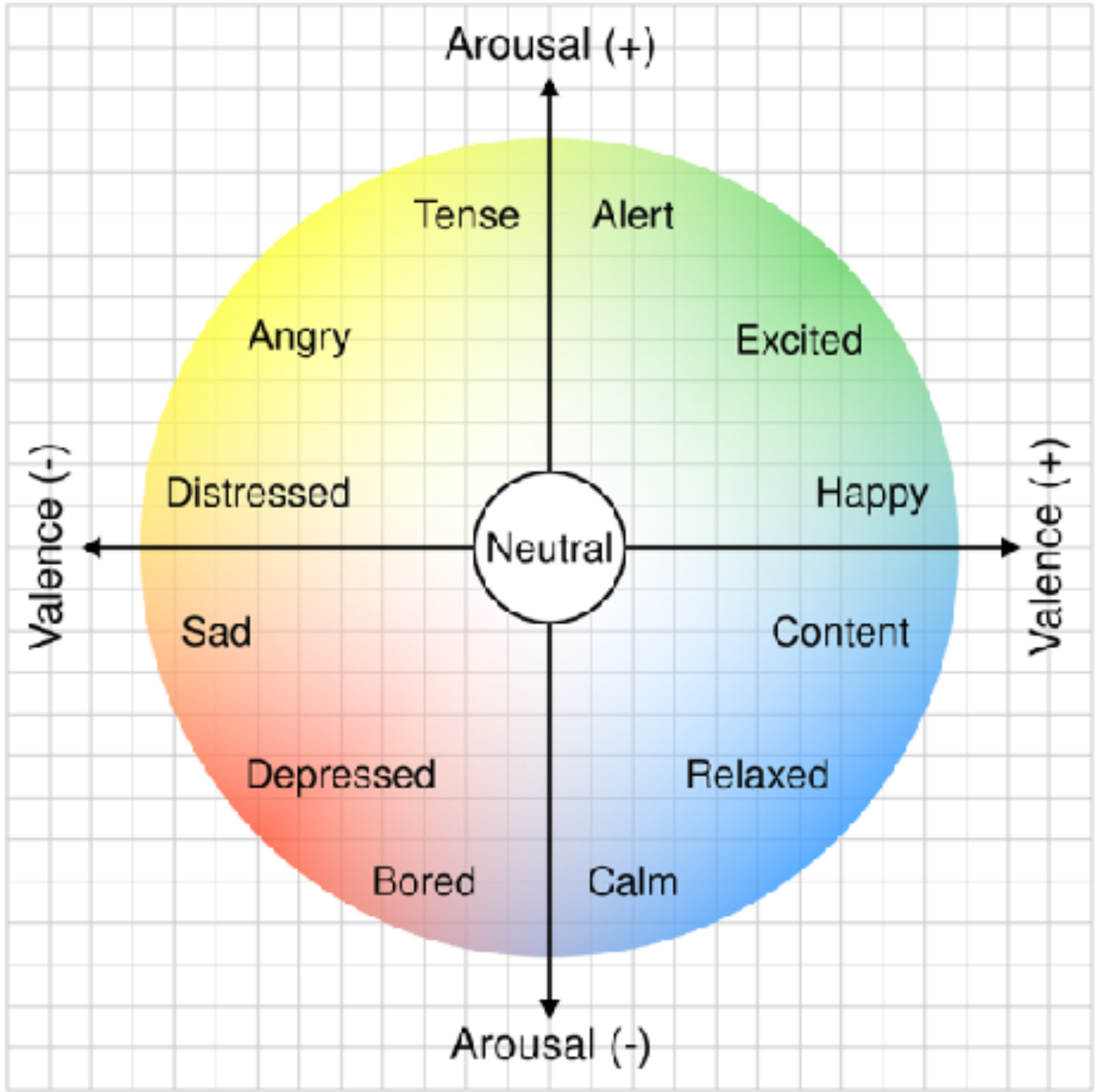
Fundamental emotion theories

A brief overview

- **Physiological** theories:
  - James-Lange (💦 → 😨), Cannon-Bard (💦&😨 = 😰)
  - Basic emotions: Ekman, K=6 (state = [🙂,😡,😥,🤢,😨,😯]), ..., currently Cowen & Keltner, K=27
- **Cognitive** (constructivist) theories:
  - Schachter-Singer (💦 → 🤔💭 → 😨)
  - Cognitive appraisal: e.g., Lazarus, Scherer: core affect (e.g., [Valence, Arousal]) → 🤔 [semantics, goals, relevance, ...] → 😨

Ekman's 6 basic emotions



James Russel's circumplex model

Objective measures of subjective emotions

Why is it different from the qualia of loudness?

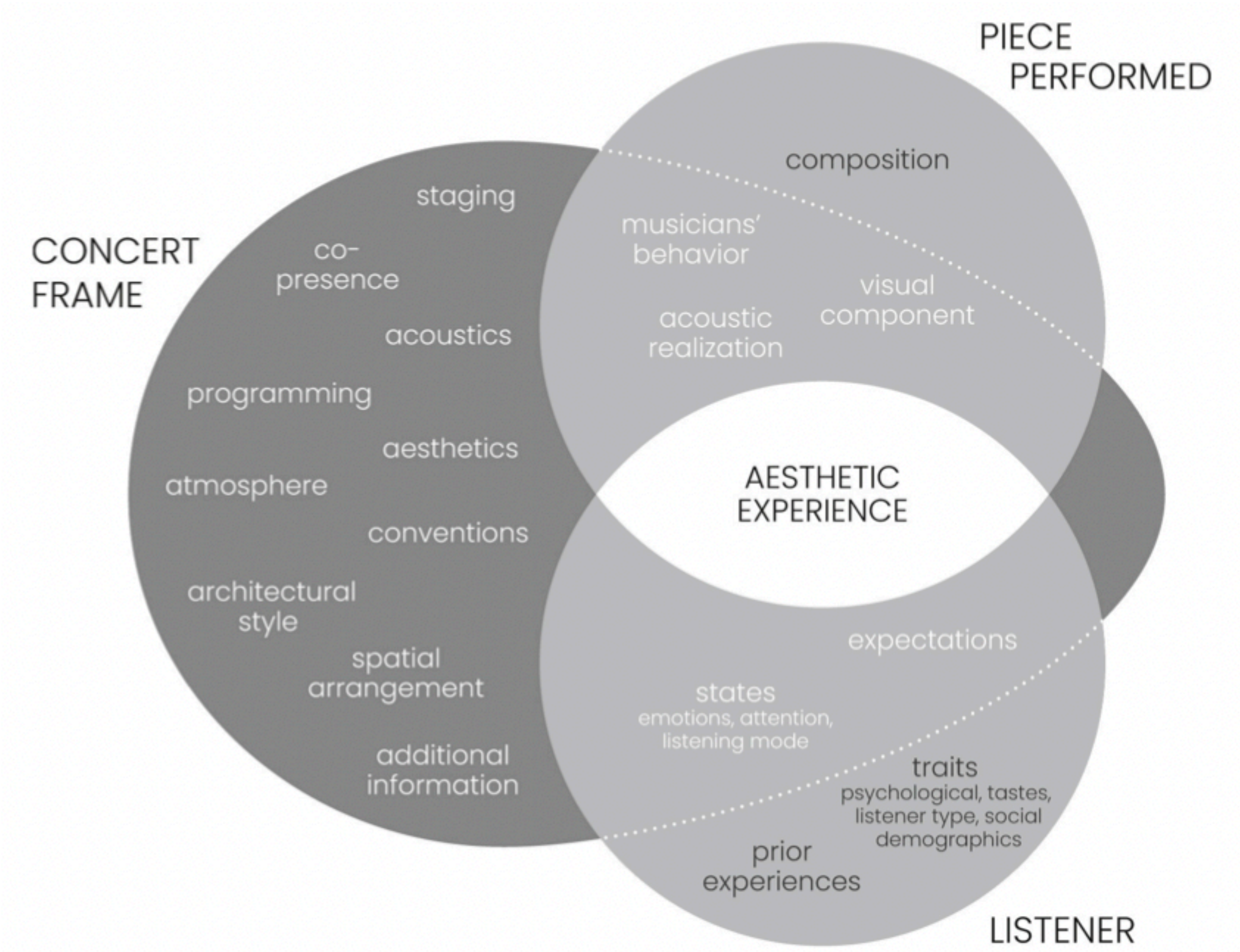
- **Why can't we just do psychophysics of emotions?** (e.g., 2AFC, odd-one-out, ...)
  - Because perceptual qualia is more consistent than emotions?
  - Because emotion is not a passive process? (constructivism)
  - (Bayesians: perception is not a passive process either!)
  - Or will the behavioral economics tell anything better about pleasure and values?
  - **What are your thoughts?** 🤔💭

Do "aesthetic emotions" exist?

Menninghaus et al., 2019, 2020; Skov & Nadal, 2020, Psychological Rev

- **Menninghaus**: Yes, because Kant said so ("disinterested pleasure"). Ambivalent emotions (e.g., bittersweet, pleasurable melancholy) are more common than everyday's emotions.
- **Skov**: No, because the affective states during aesthetic appreciation are not distinctive from other sensory valuations.
- **Menninghaus**: Still yes, because aesthetic emotions is essential for aesthetic evaluation. (hmm...🤔)

Theories on musical emotions



Wald-Fuhrmann et al., 2021, *Front. Psychol.*

Theories on musical emotions

"BRECVEMA", Juslin, 2013, *Physics of Life Rev*.

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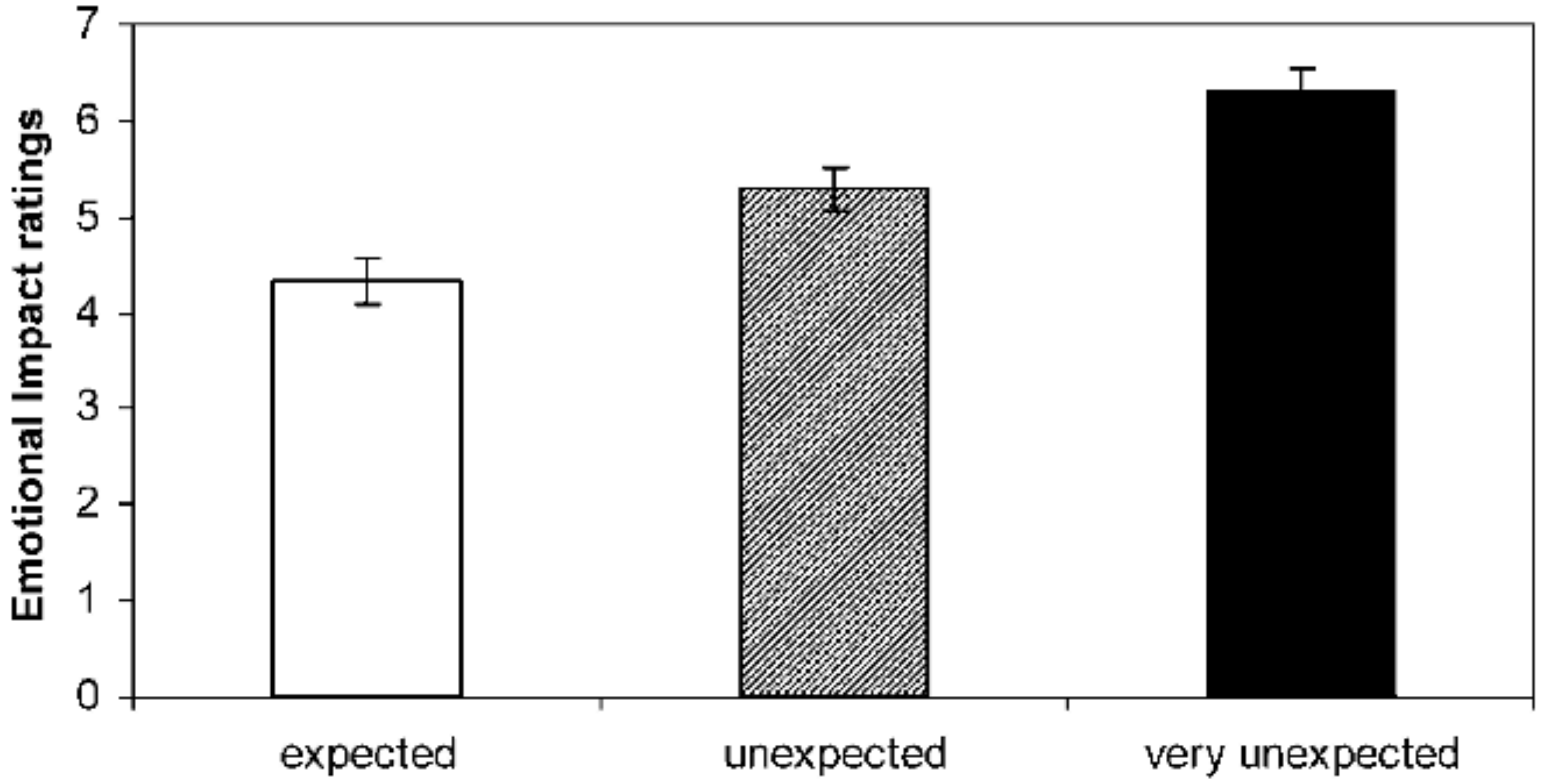
Cognitive accounts

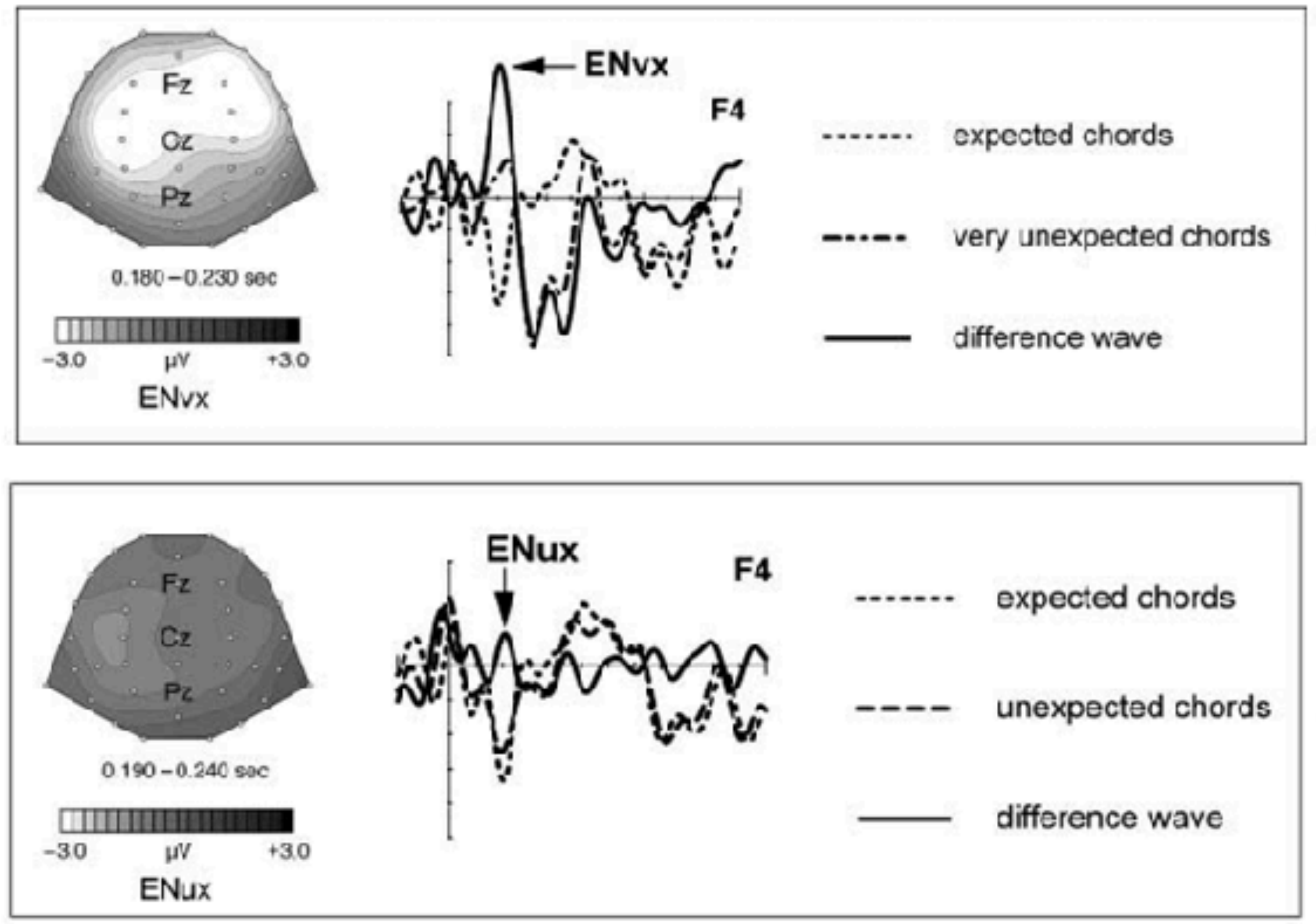
Listeners (even implicitly) perceives musical elements.

- **Spectral**: tonality (keys, scales, modes), pitch, intervals, chords, ...
- **Temporal**: meters, beats, rhythms, ...
- **Interplays** of **complexity** of patterns, forming and betraying **expectations**, leading to "Tension and Resolution" (Meyer, 1956)

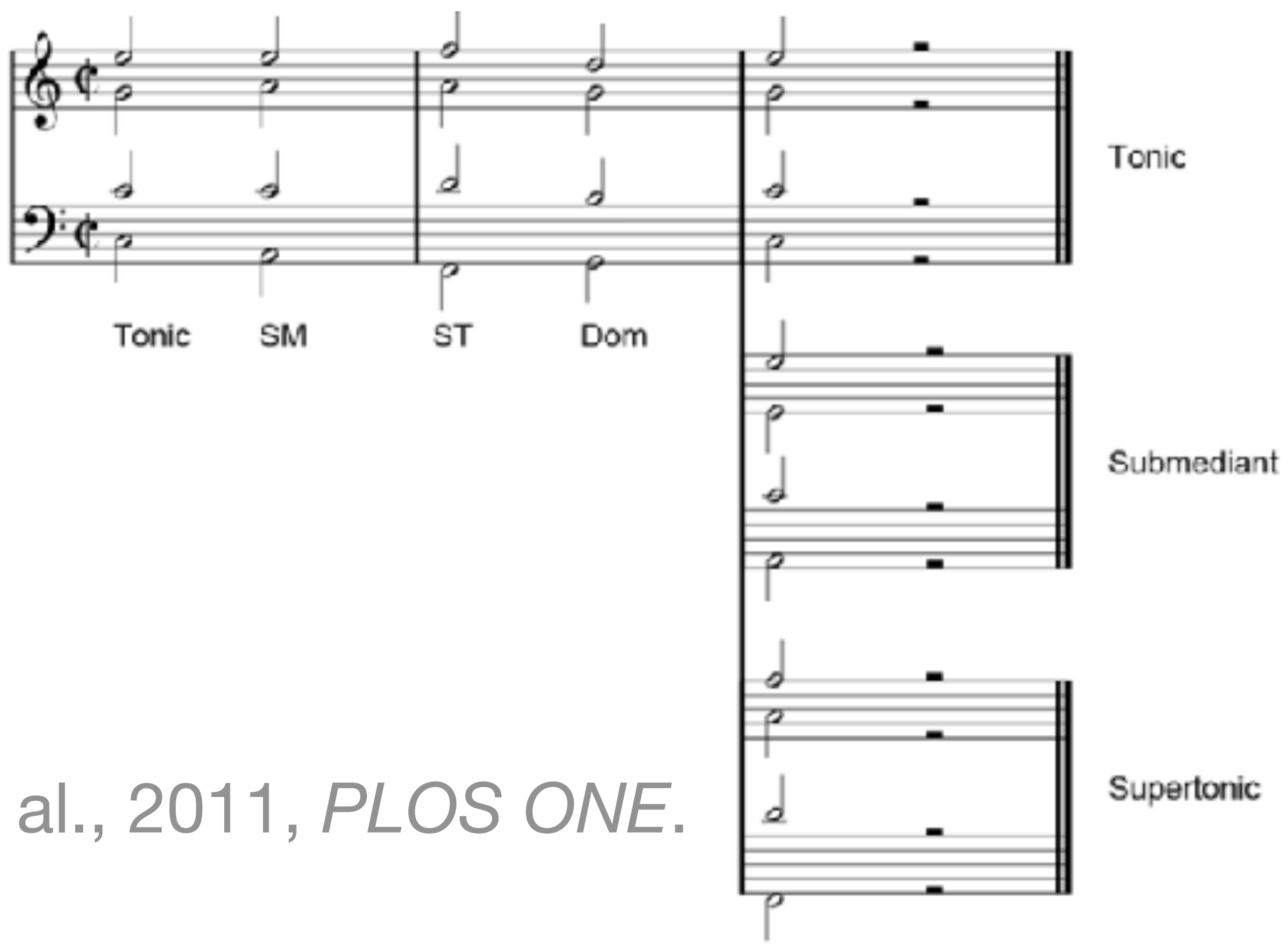
Cognitive processing of music

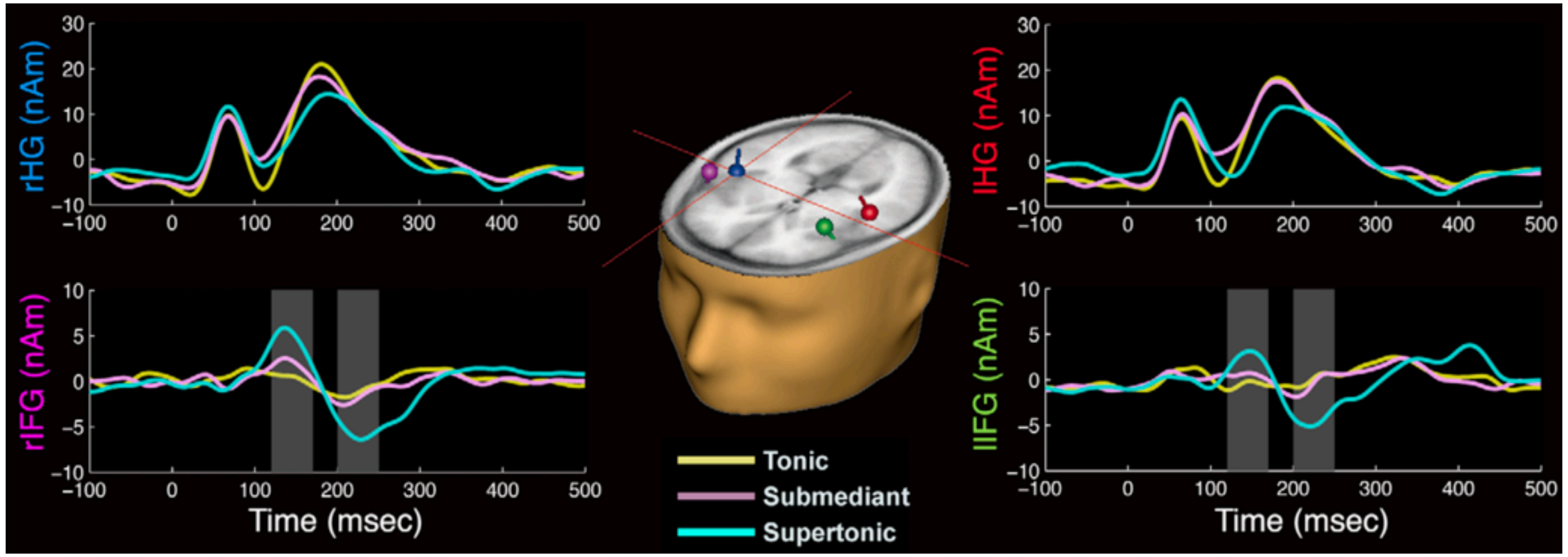
E.g., Tonal perception and expectations





Steinbeis, Sloboda, Koelsch, 2006, *J Cognitive Neuroscience*.



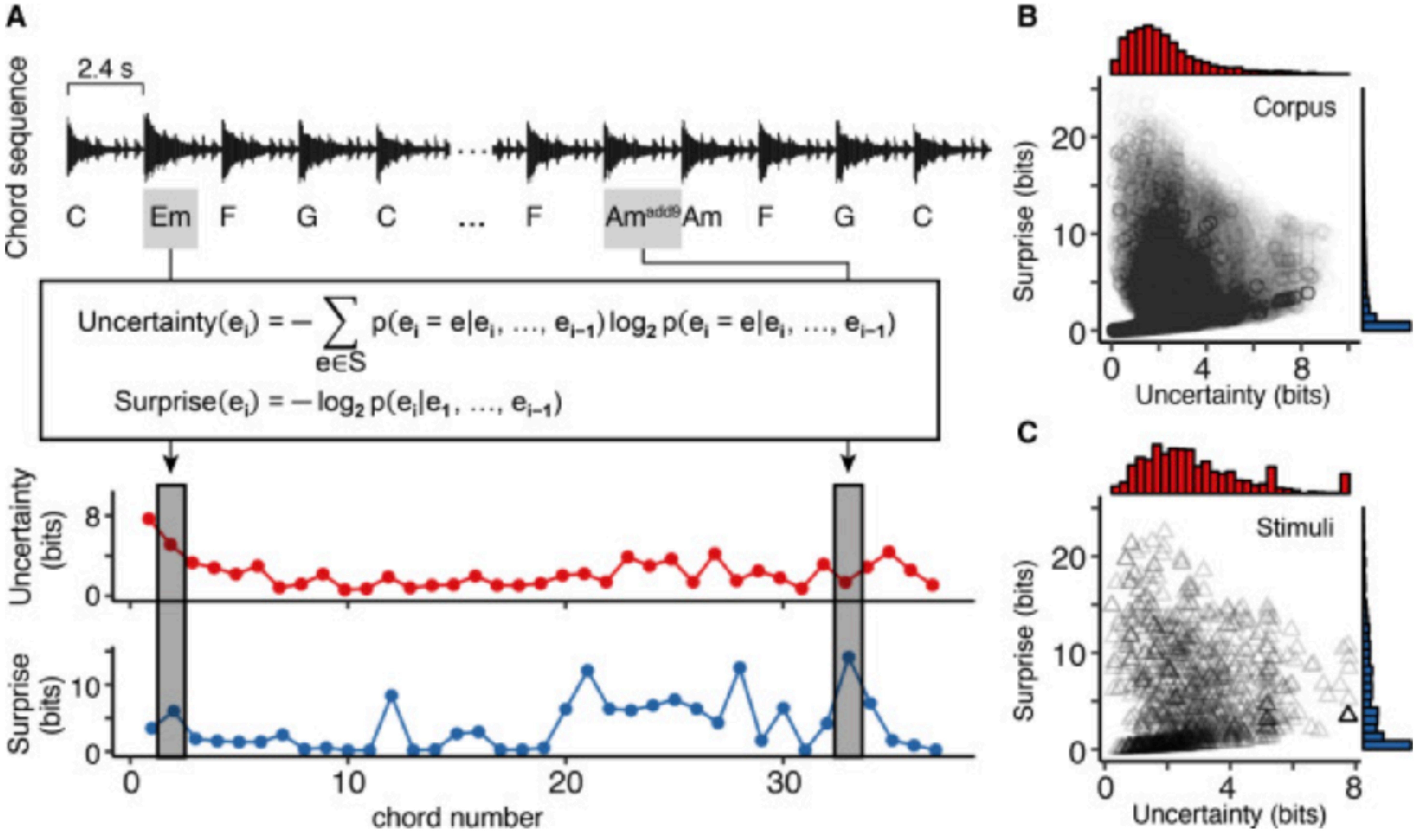


Kim et al., 2011, *PLOS ONE*.

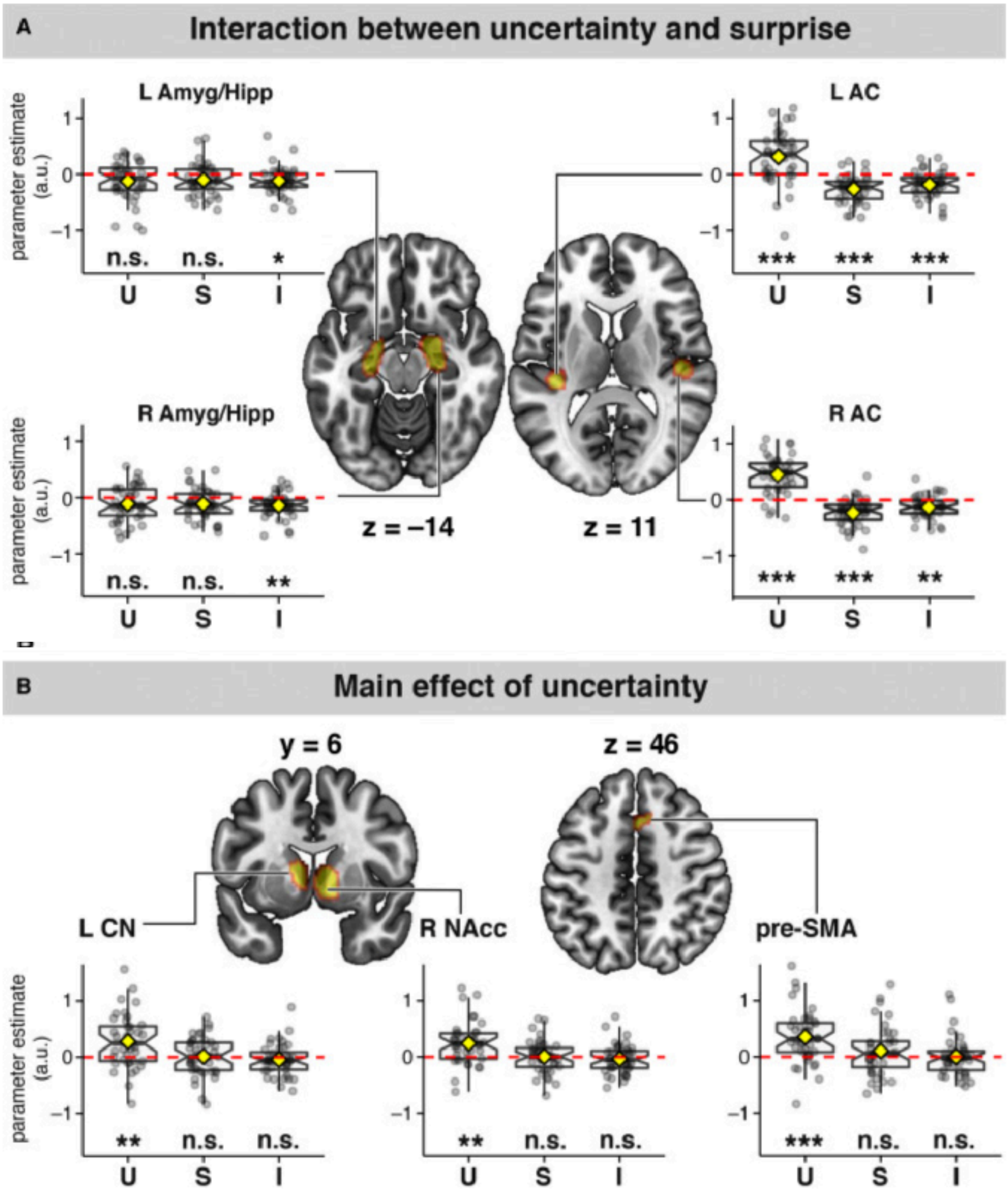
SOUND DEMO: Steinbeis+.2006; Cheung+.2019

Cognitive processing of music

E.g., Tonal perception and expectations



Cheung, ..., Koelsch, 2019, *Current Biology.*

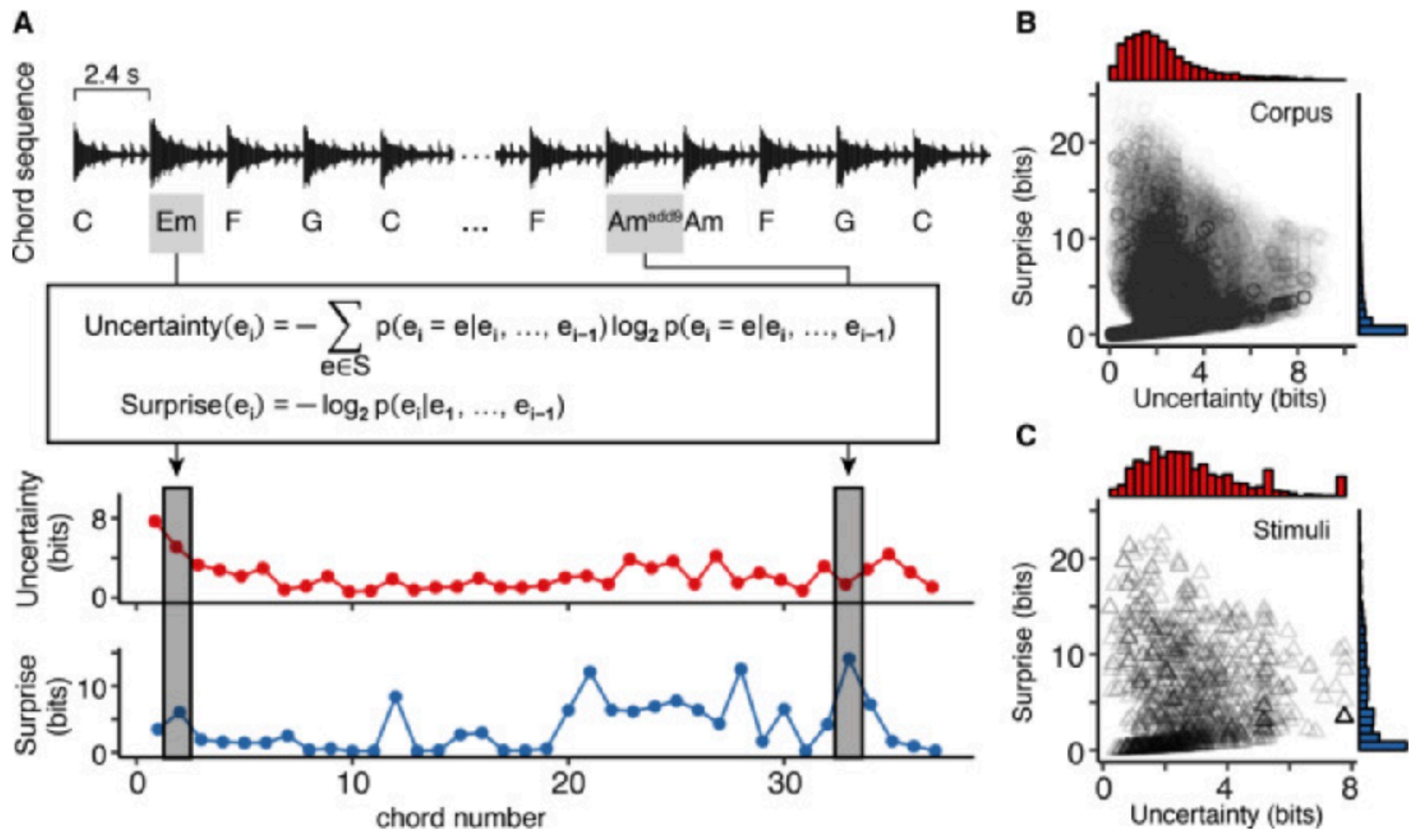


U = Uncertainty; **S** = Surprise; **I** = Uncertainty × Surprise

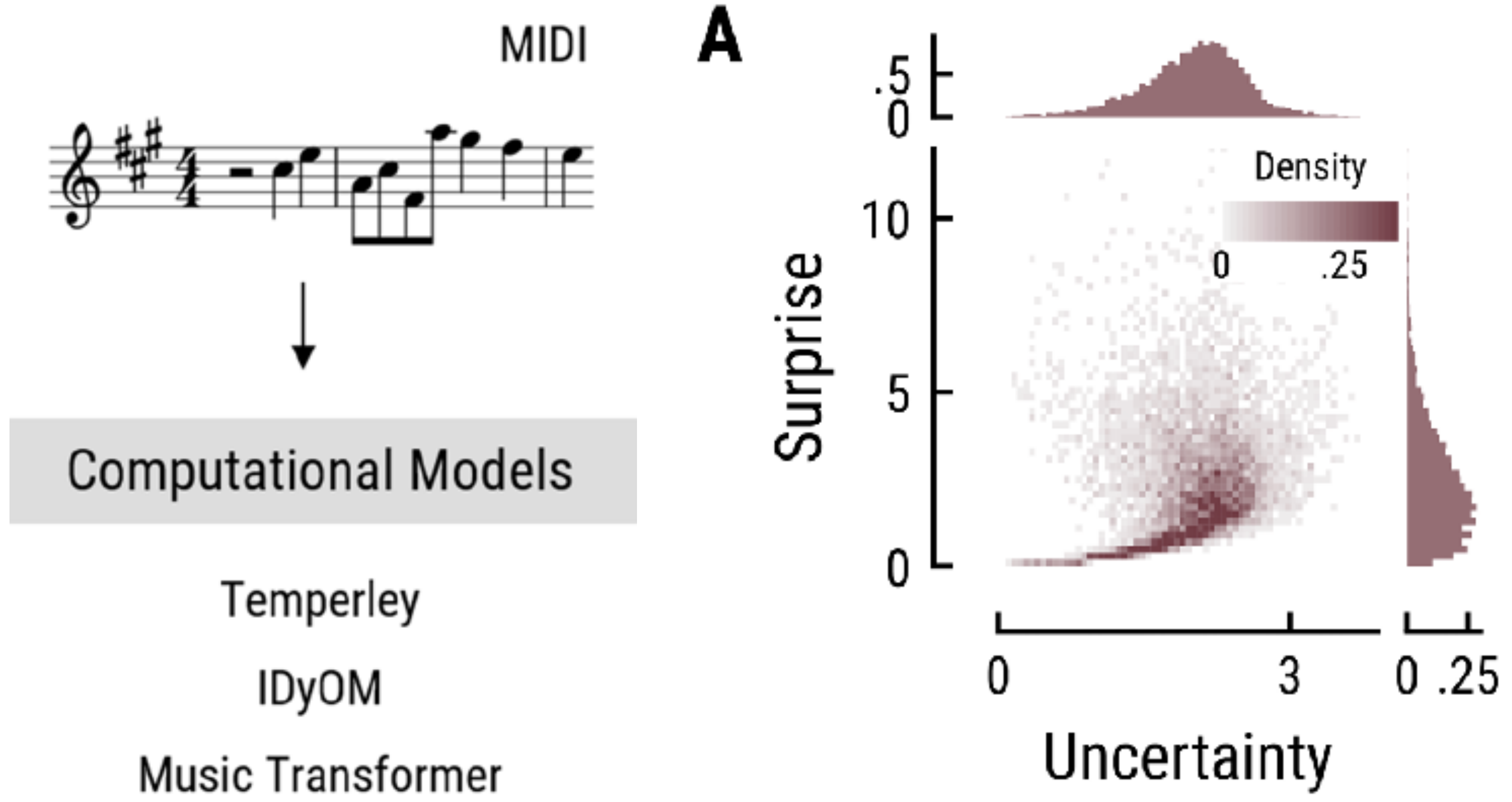
Symbol-domain models

Input: notes on the score

Modeling on MIDI notes: **n-gram modeling** (e.g., PPM, HMM),
deep neural networks (e.g., Melody RNN, MusicRNN, Music Transformer)



Cheung et al., 2019, *Current Biology.*



Kern et al., 2022, *eLife*.

But symbolic models often disregards expressions.

SOUND DEMO: "Unkempt Hair (쑥대머리)", Chun-hyang-ga (춘향가), Juri Kim (김주리), 2023

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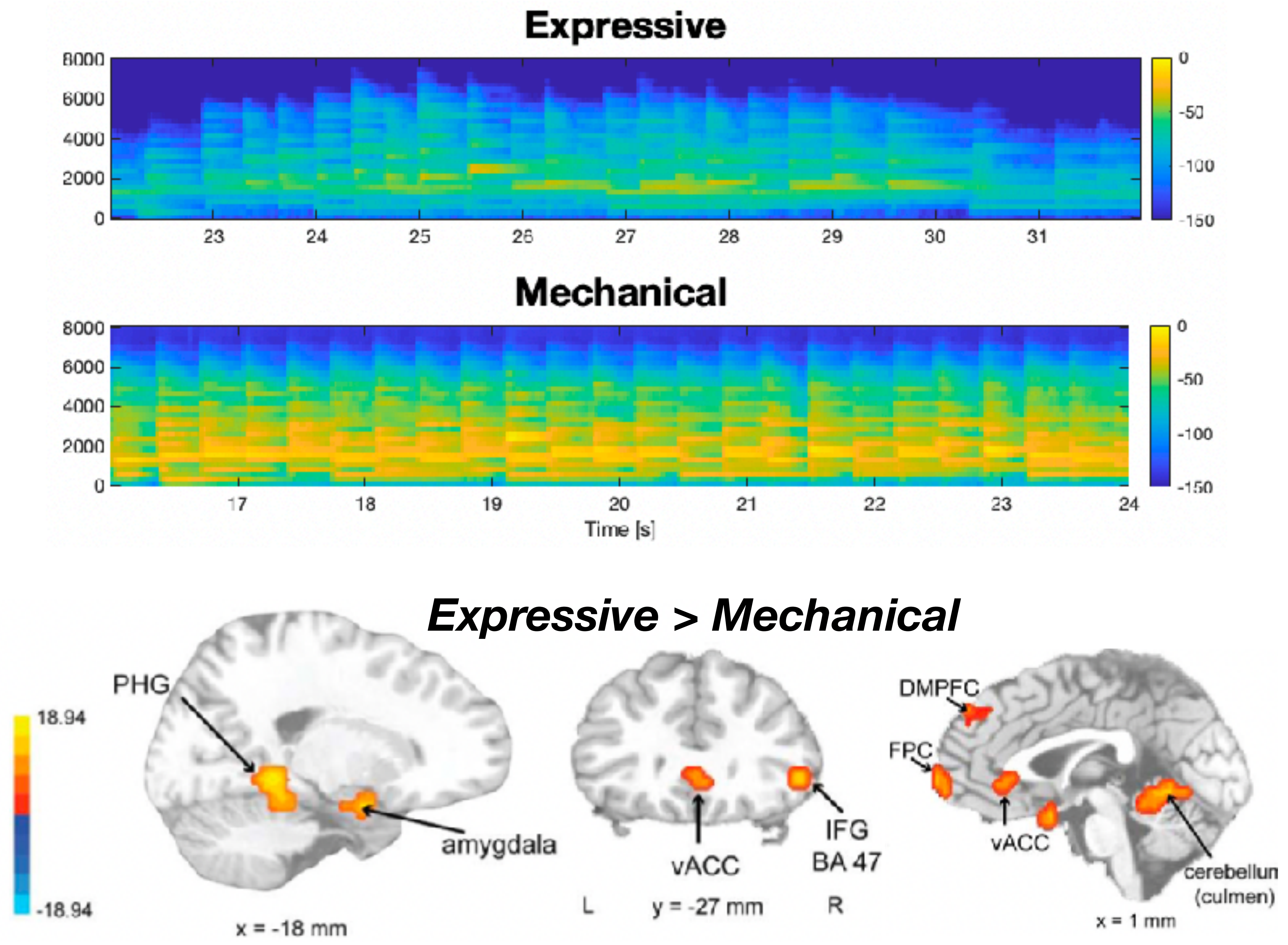
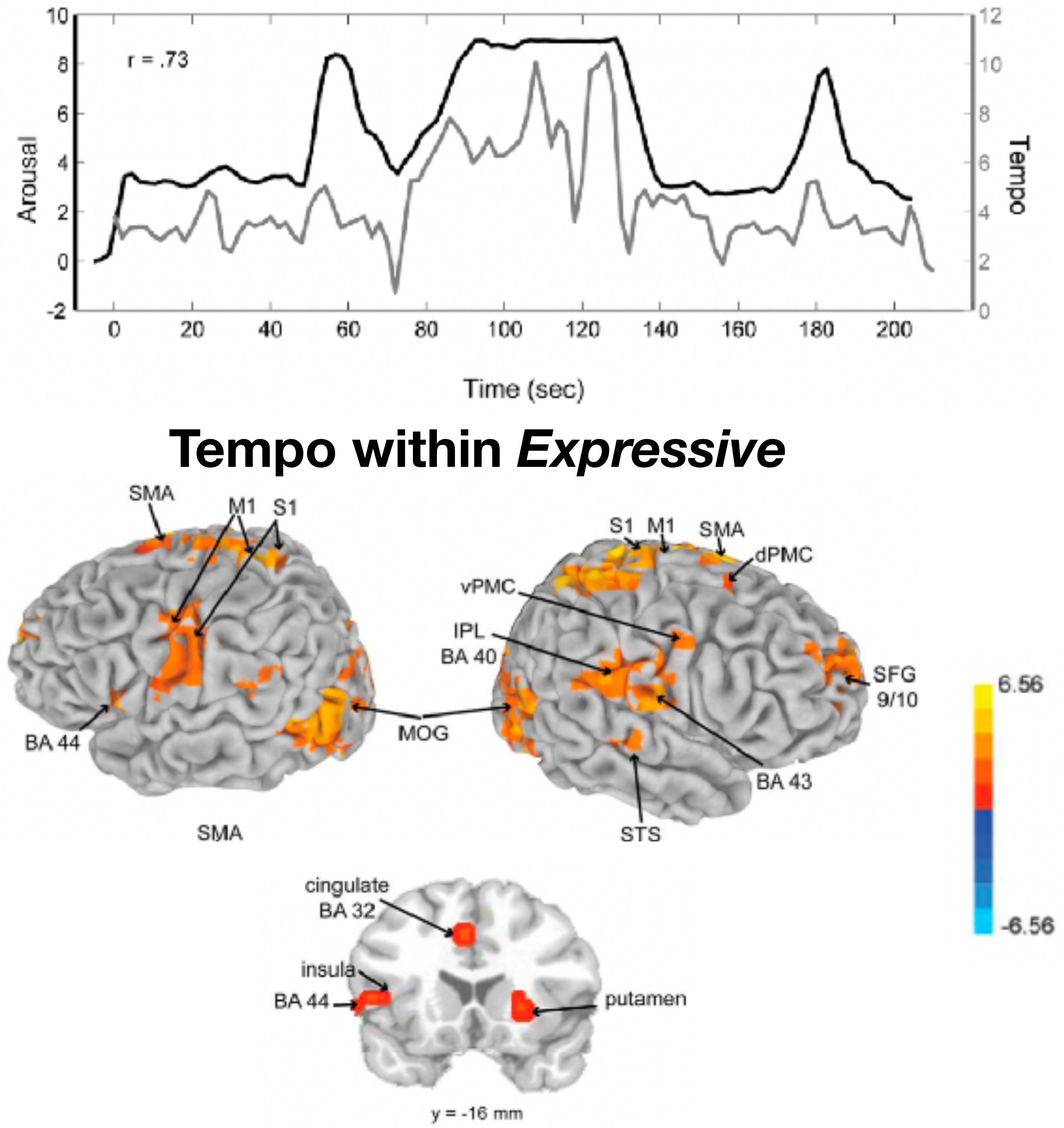
Cognitive processing of music

E.g., local dynamics and tempi perturbations



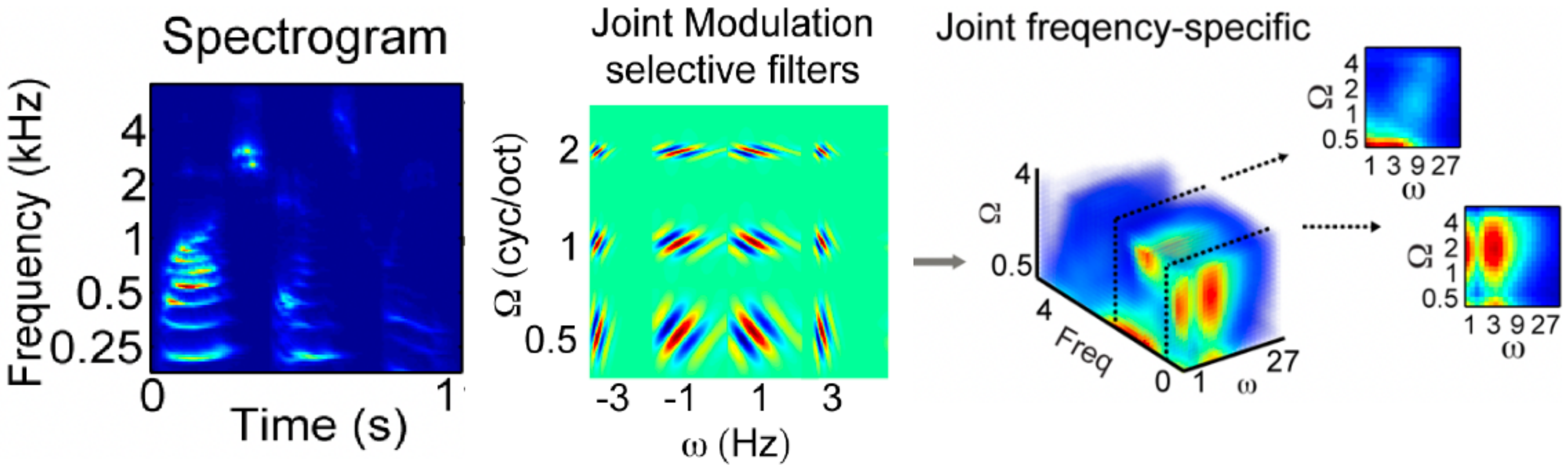
Chapin et al., 2010, *PLOS One*.



Audio-domain models

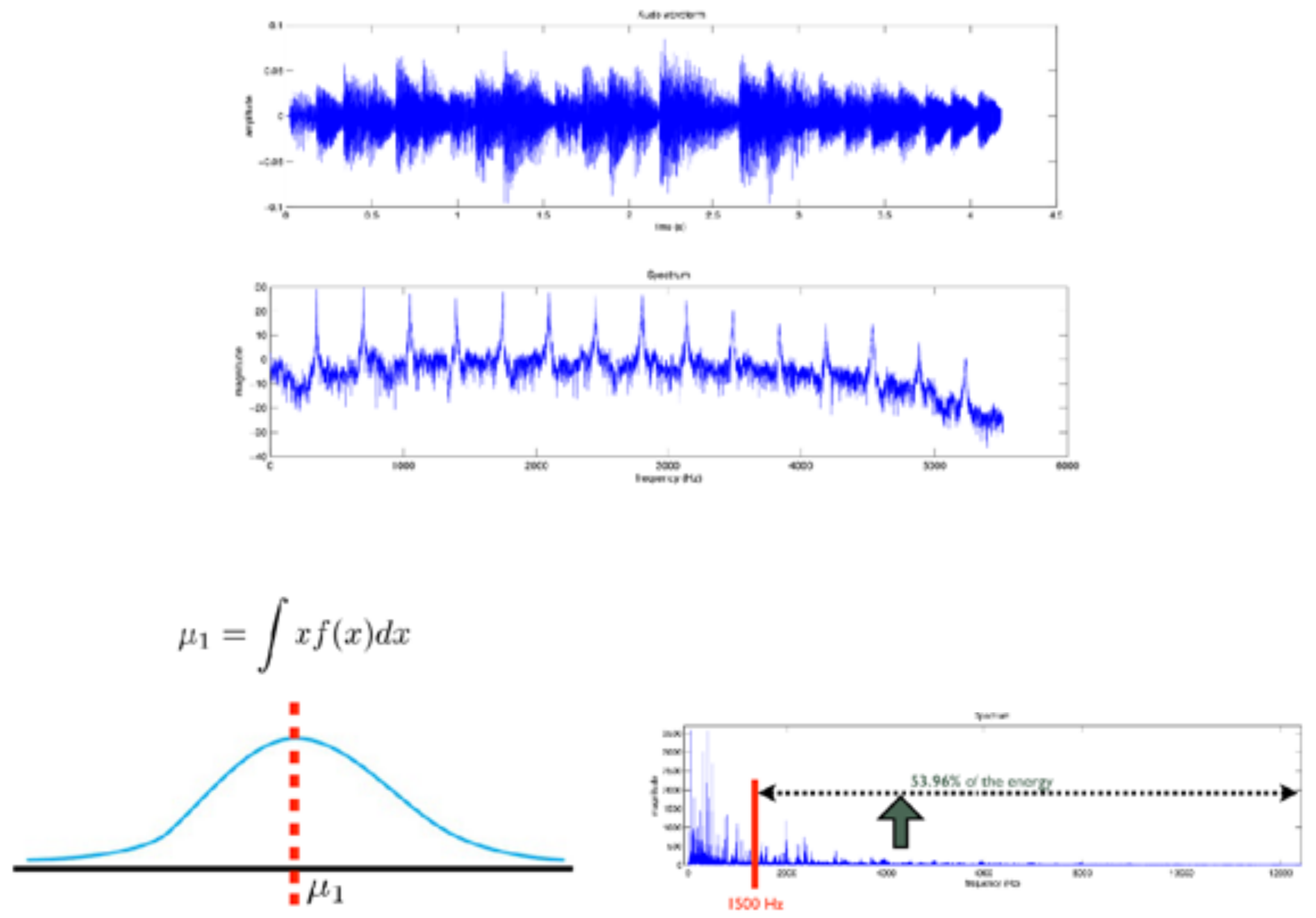
Input: audio samples

Auditory models: simulated activity of peripheral and central auditory neurons



Santoro et al., 2014, *PLOS Comp Biol*.

Music information retrieval (MIR) models: acoustic features relevant to music database



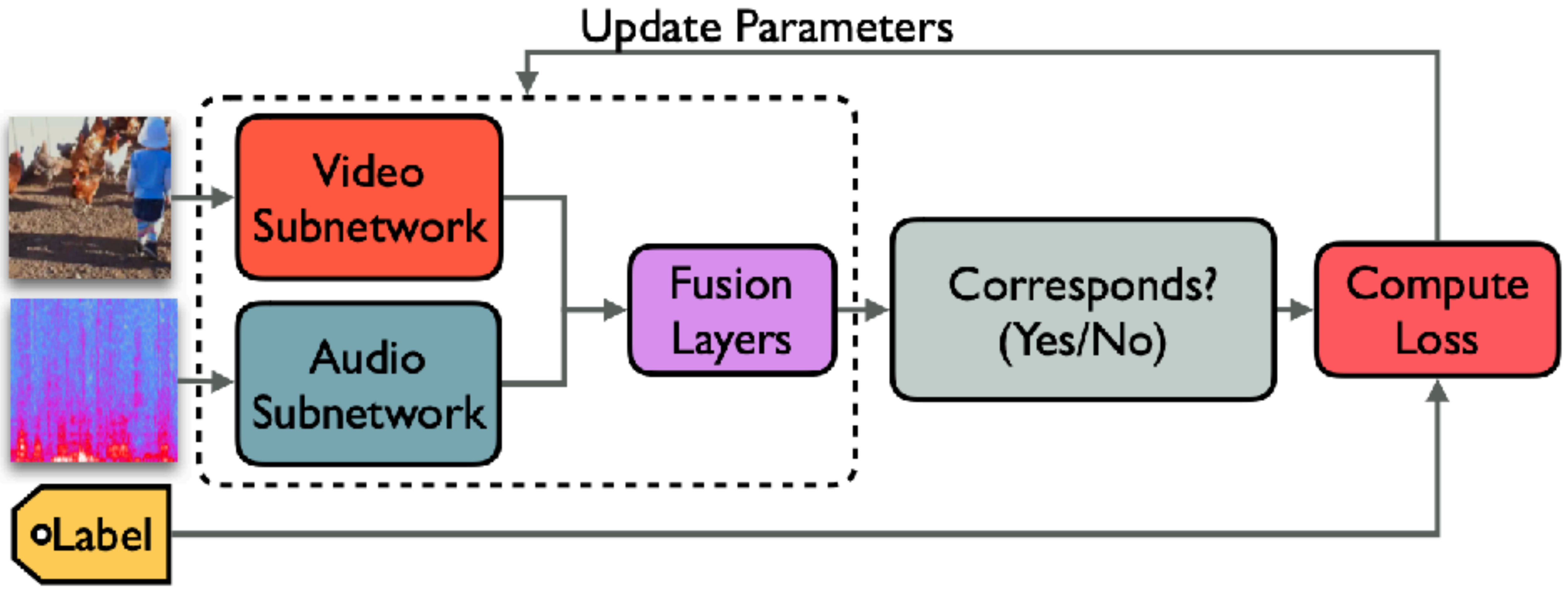
Lartillot, 2017, *MIRtoolbox User's Manual.*

Traditional models mostly simulate cochlear and primary auditory cortex activity.

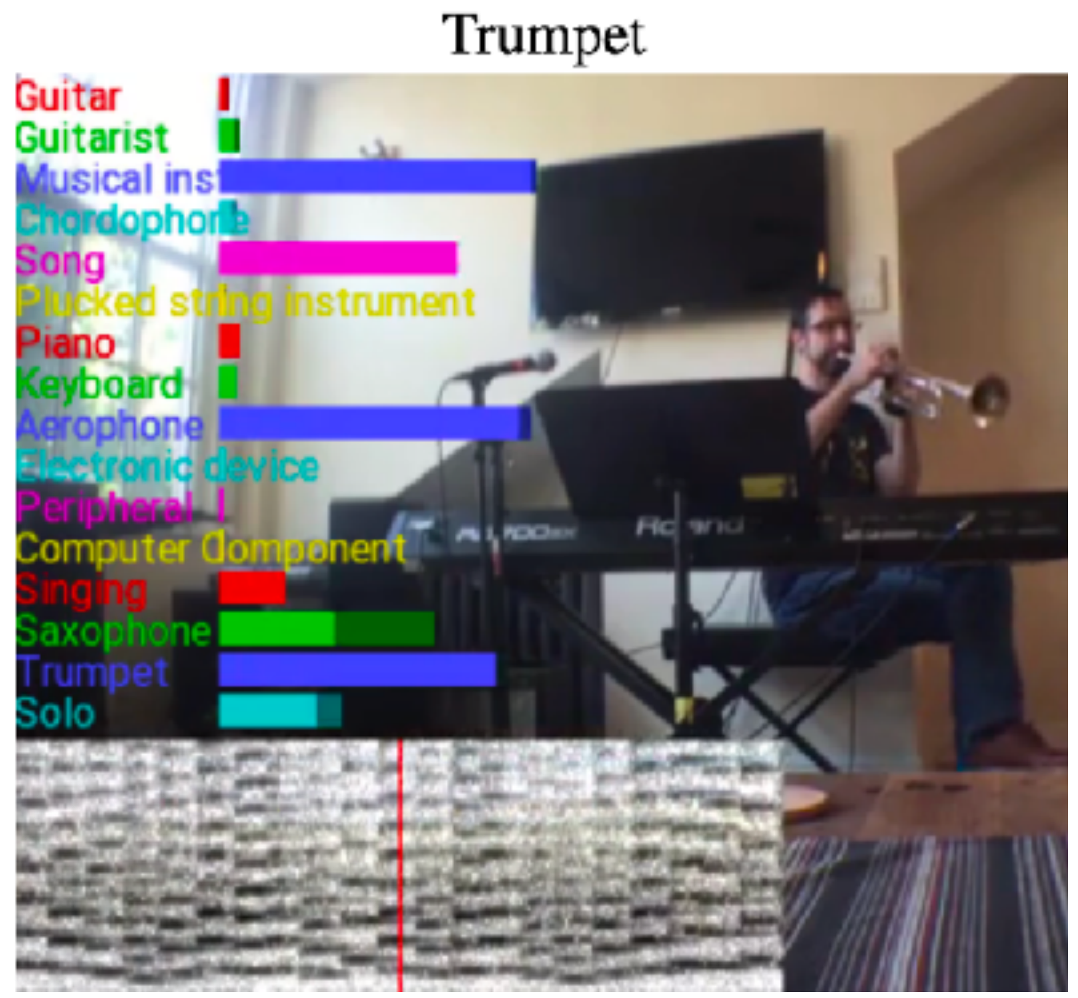
"Audio semantic" models

- **Convolutional neural networks (CNNs)** applied to short [~1 s] spectrograms to generate text labels of audio data (e.g., `"babyCry"`, `"dogBark"`)

- Trained on **video-audio correspondence** to learn **the second-order acoustics** (e.g., `"this kind of spectrogram often goes with that video"`).



Open-L3: Cramer et al., 2019, *ICASSP*



VGGish: Hershey et al., 2017, *ICASSP*

A possible mid/high-level representation of sounds

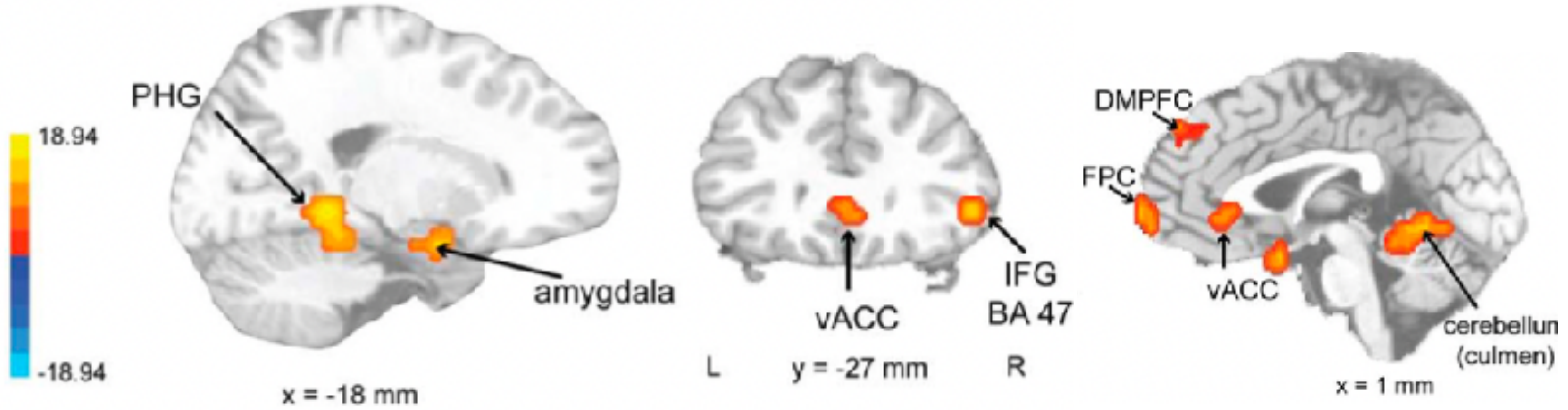
But is it really expression? Isn't it just timbre?

Example: Expressive vs. Mechanical

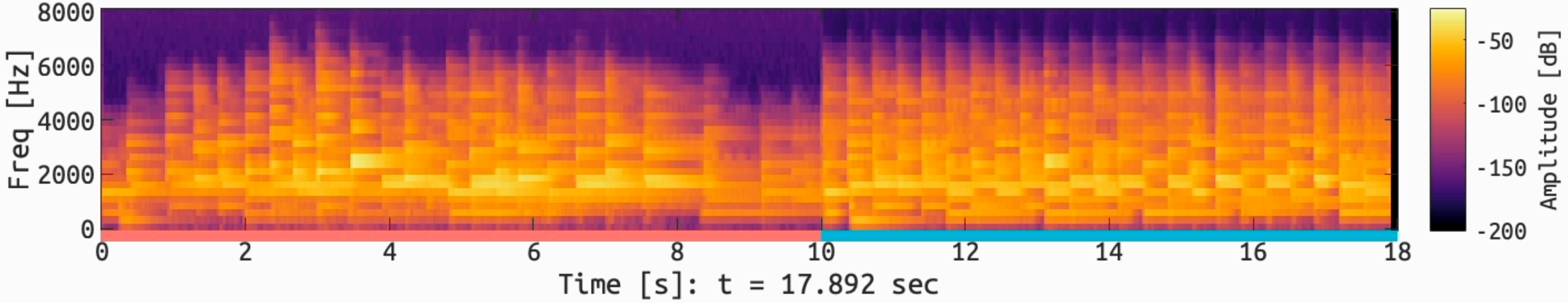
Chapin et al., 2010, PLOS ONE.

[EXPRESSIVE]: "Frédéric Chopin's Etude in E major, Op.10, No. 3 was performed by an undergraduate piano major (female, 22 years old) on a Kawai CA 950 digital piano"

Expressive > Mechanical



Chapin et al., 2010, *PLOS One*.

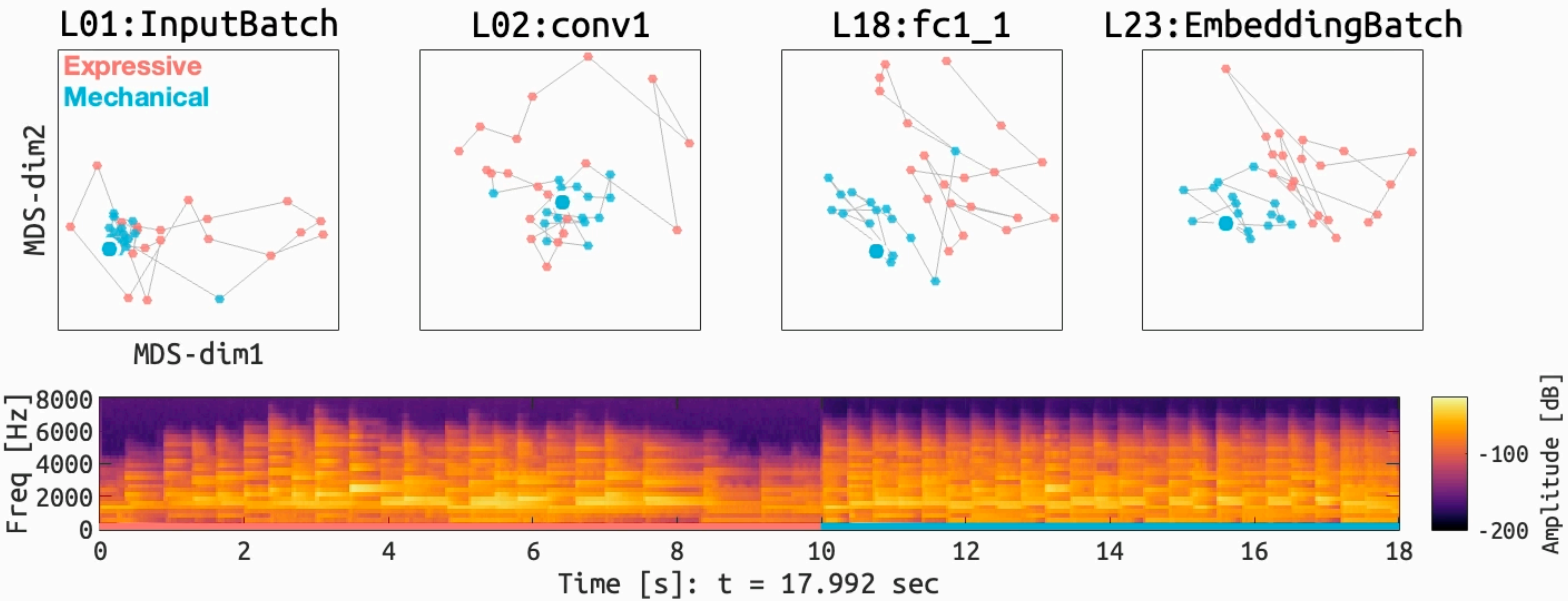


[MECHANICAL]: "The MIDI (Musical Instrument Digital Interface) onset velocity (key pressure) of each note (correlating with sound level) was set to 64 (range 0–128), and pedal information was eliminated."

Audio source: https://doi.org/10.1371/journal.pone.0013812

Example: Expressive vs. Mechanical

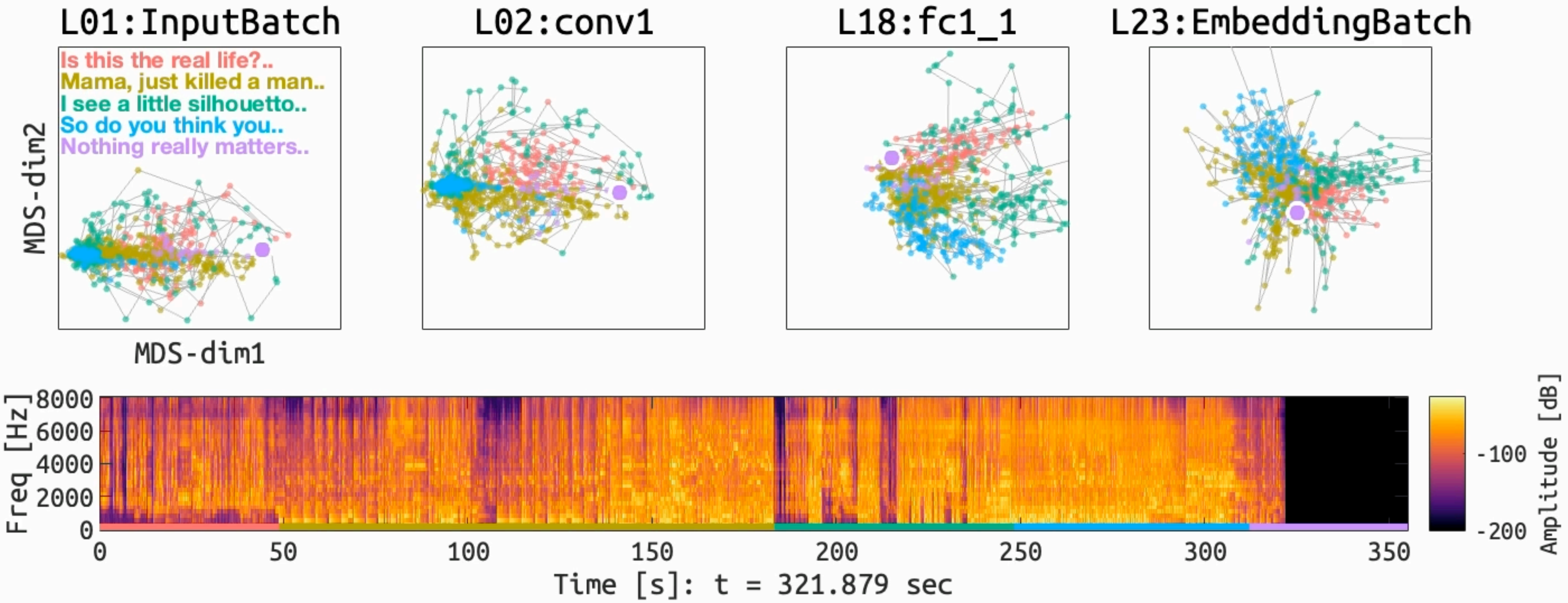
VGGish representations at various layers (from 1 to 23)



Audio source: https://doi.org/10.1371/journal.pone.0013812

Example: Queen. (1975). Bohemian Rhapsody

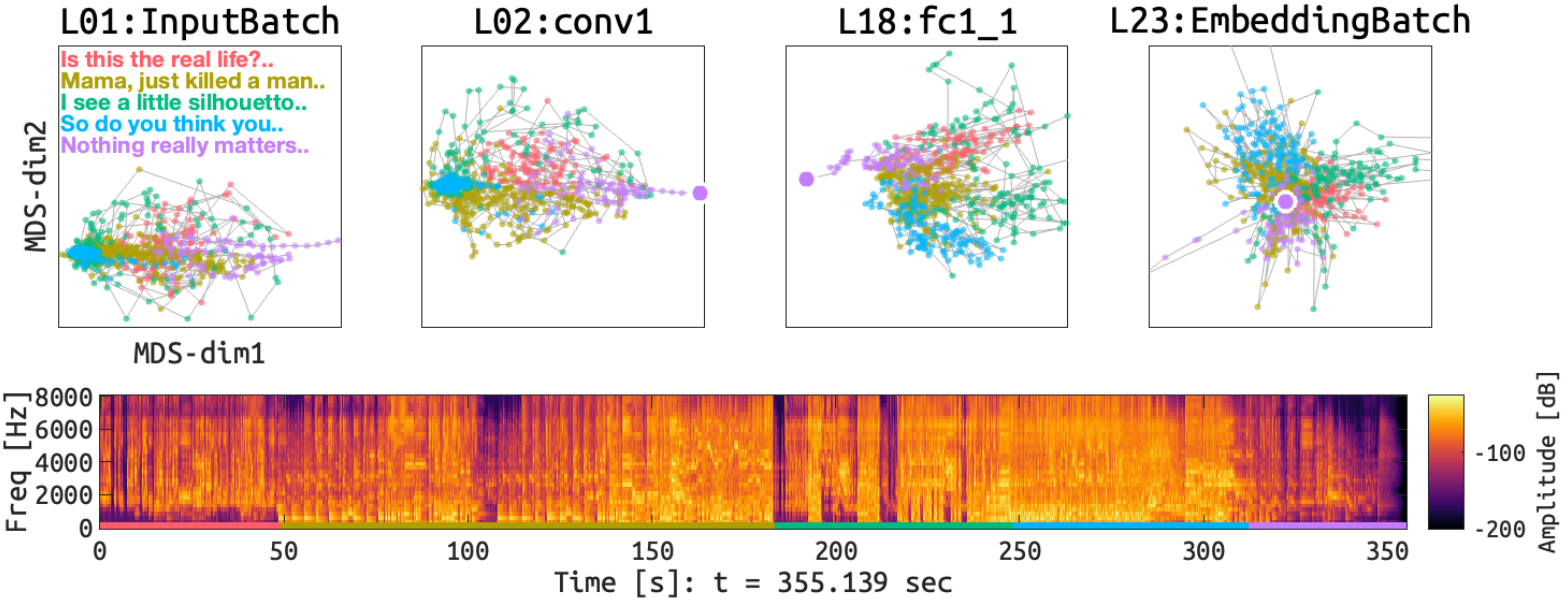
VGGish representations at various layers (from 1 to 23)



Audio source: (c) EMI

Example: Queen. (1975). Bohemian Rhapsody

VGGish representations at various layers (from 1 to 23)



CNN embedding for music emotion *recognition*

Potentially mid/high-level representation of music signal

Classifiers (SVM, NB, RF, ...) based on MFCC
recognized emotional categories

An "deep audio semantic" model called "VGGish"

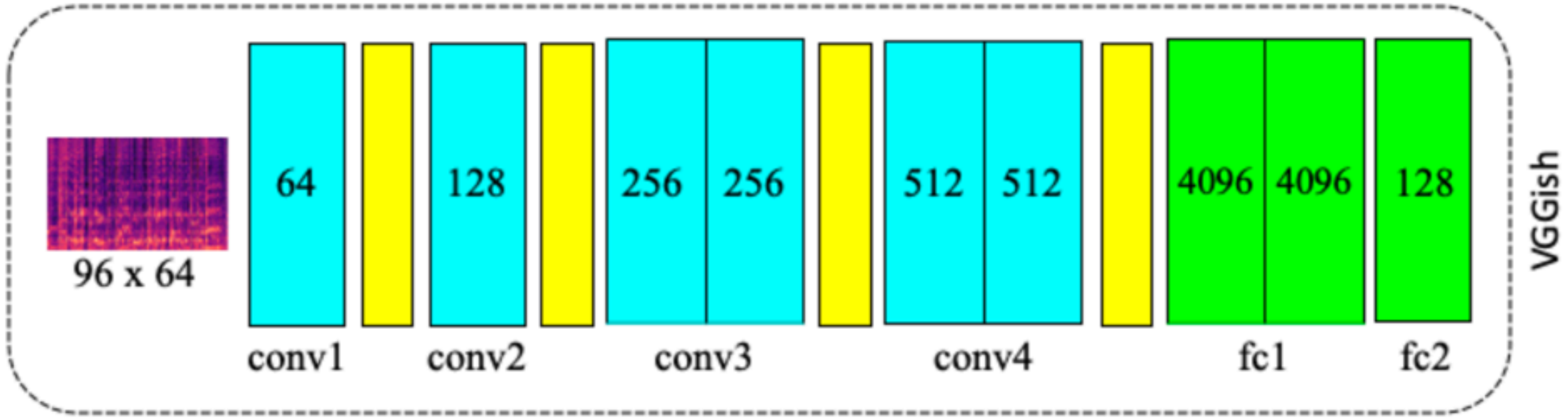
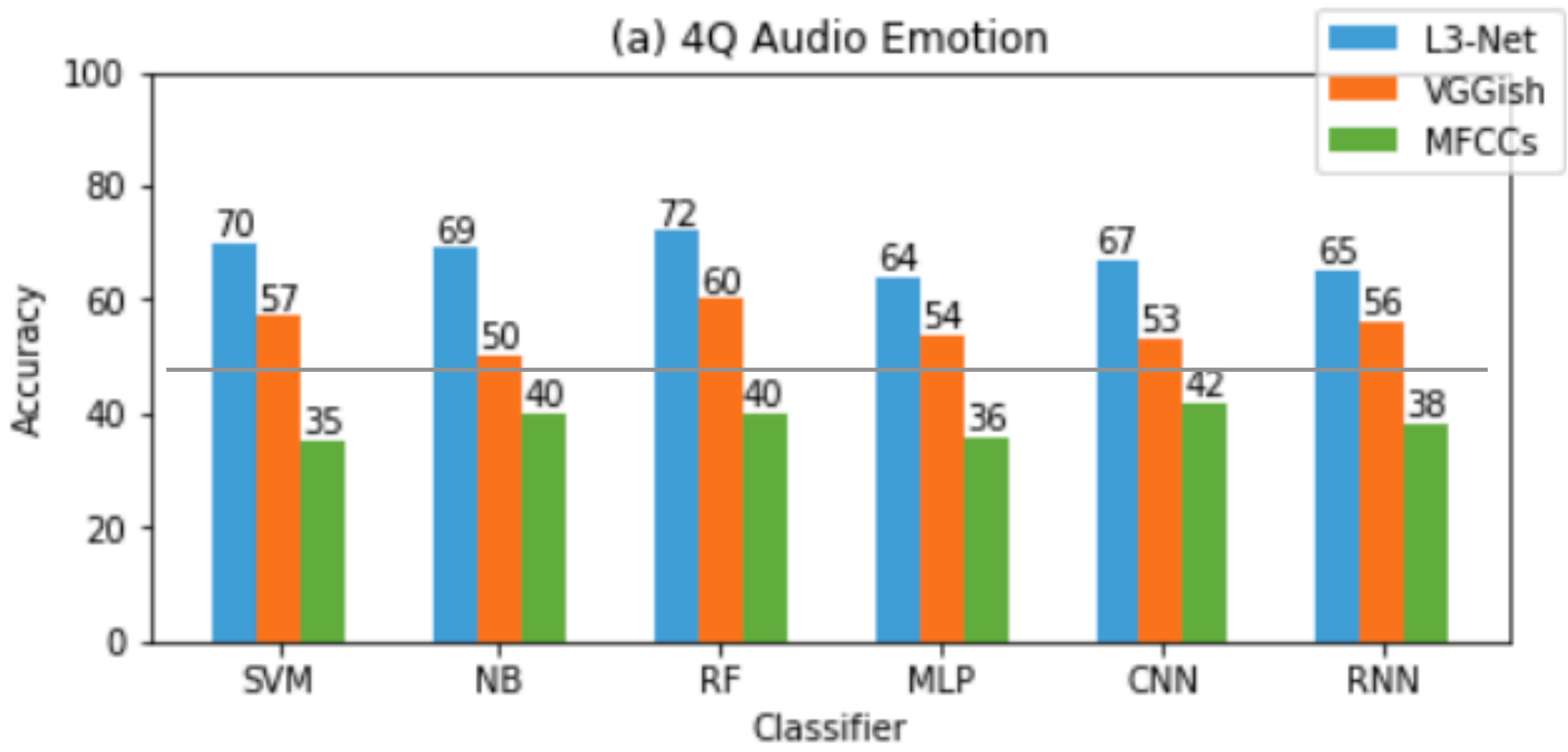


Diagram from Koh & Dubnov, 2021, *ACA*

4Q Audio Emotion Dataset: 255 music clips (30 s) for **Arousal-Valence quadrants**



Koh & Dubnov, 2021, *ACA*

Deep audio semantic models carry more information related to expressed emotions than a traditional audio descriptor.

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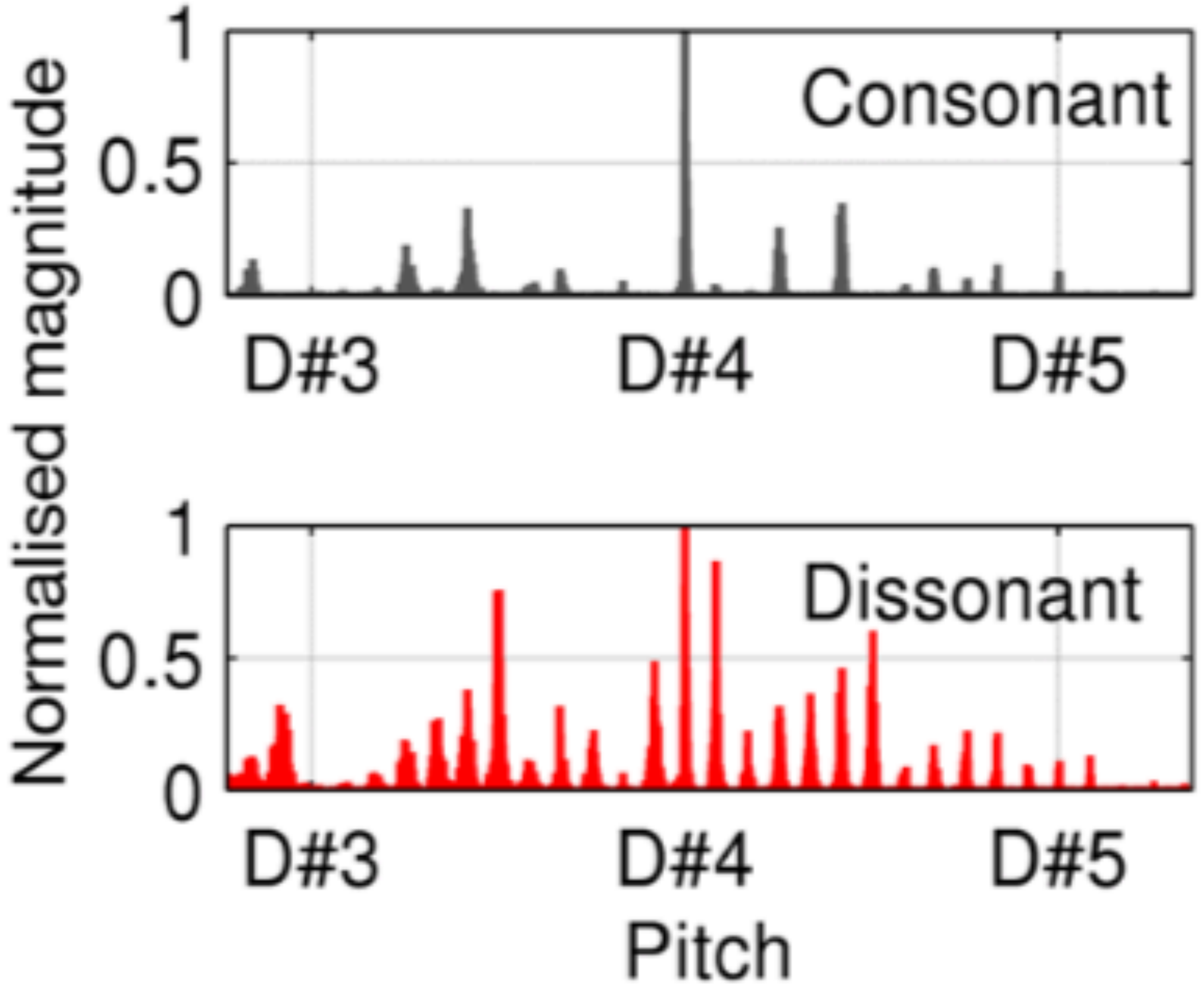
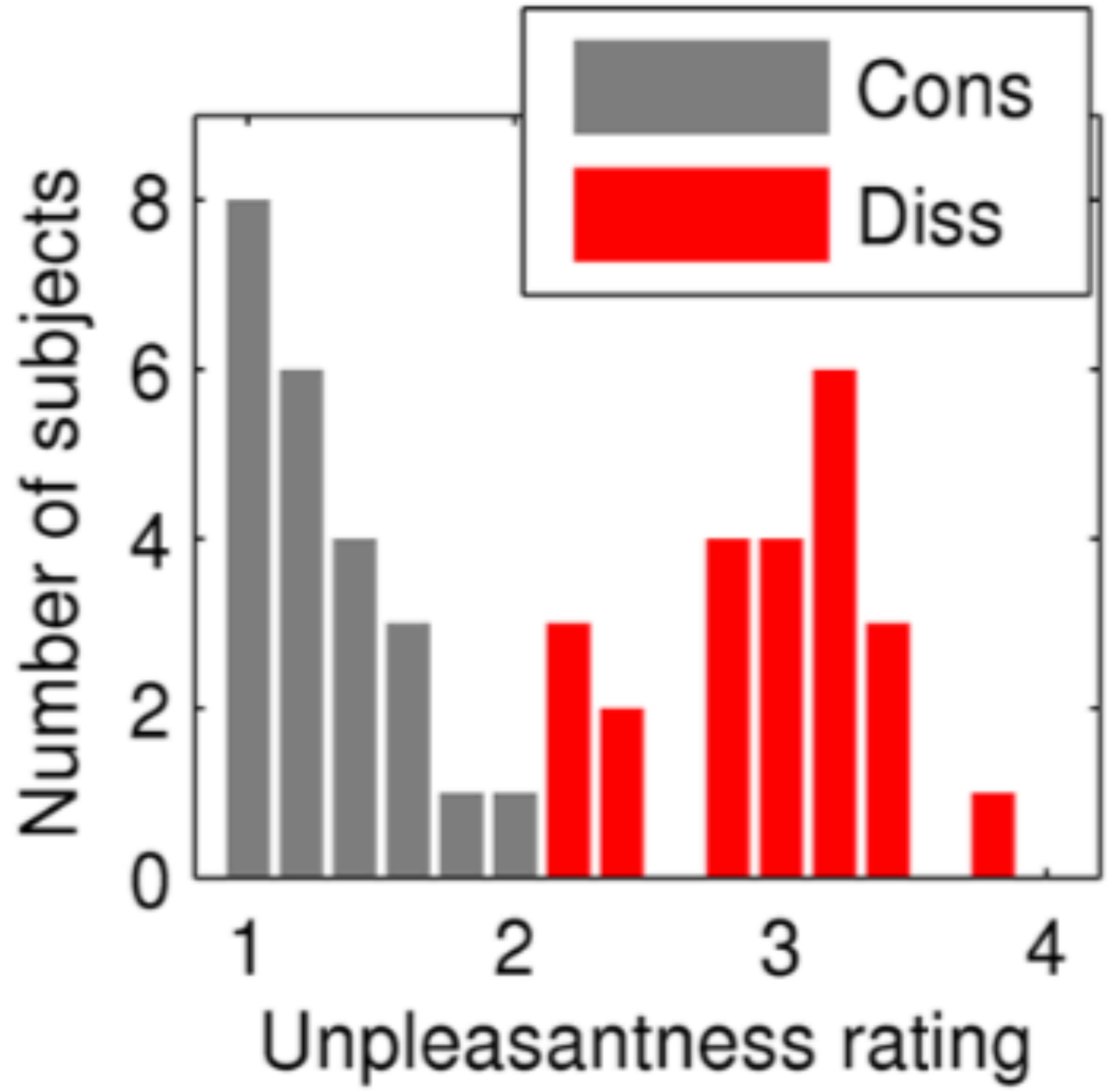
SOUND DEMO: J. S. Bach Prelude No.3 in C# major (BWV 848), consonant & dissonant

E.g., Consonant vs. Dissonant music

Music → Emotions

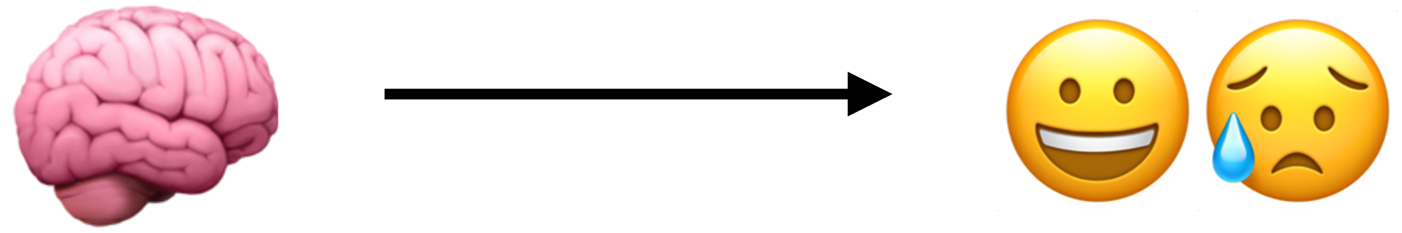




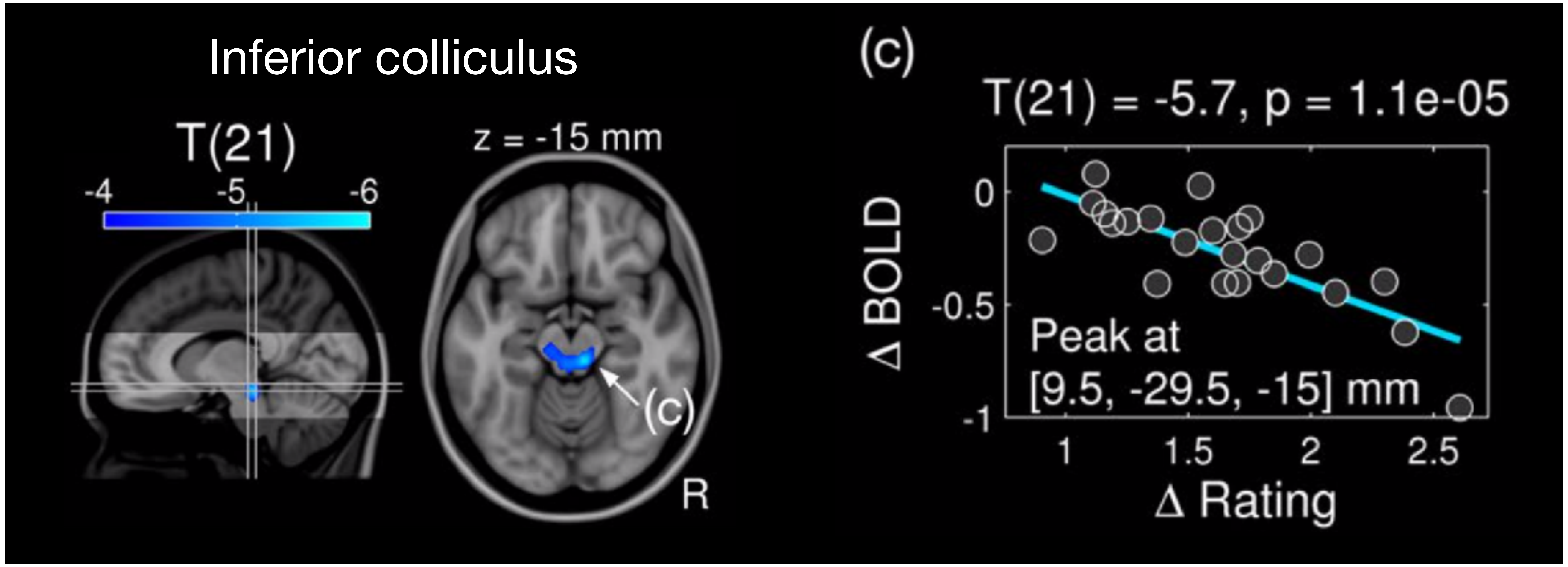
“Dissonant” stimuli were rated more unpleasant.

stimuli per condition = 20, stimulus duration = 30 s, # subjects = 23 (25.9 yo; 13 F)

Kim et al., 2017, *Sci Rep.*



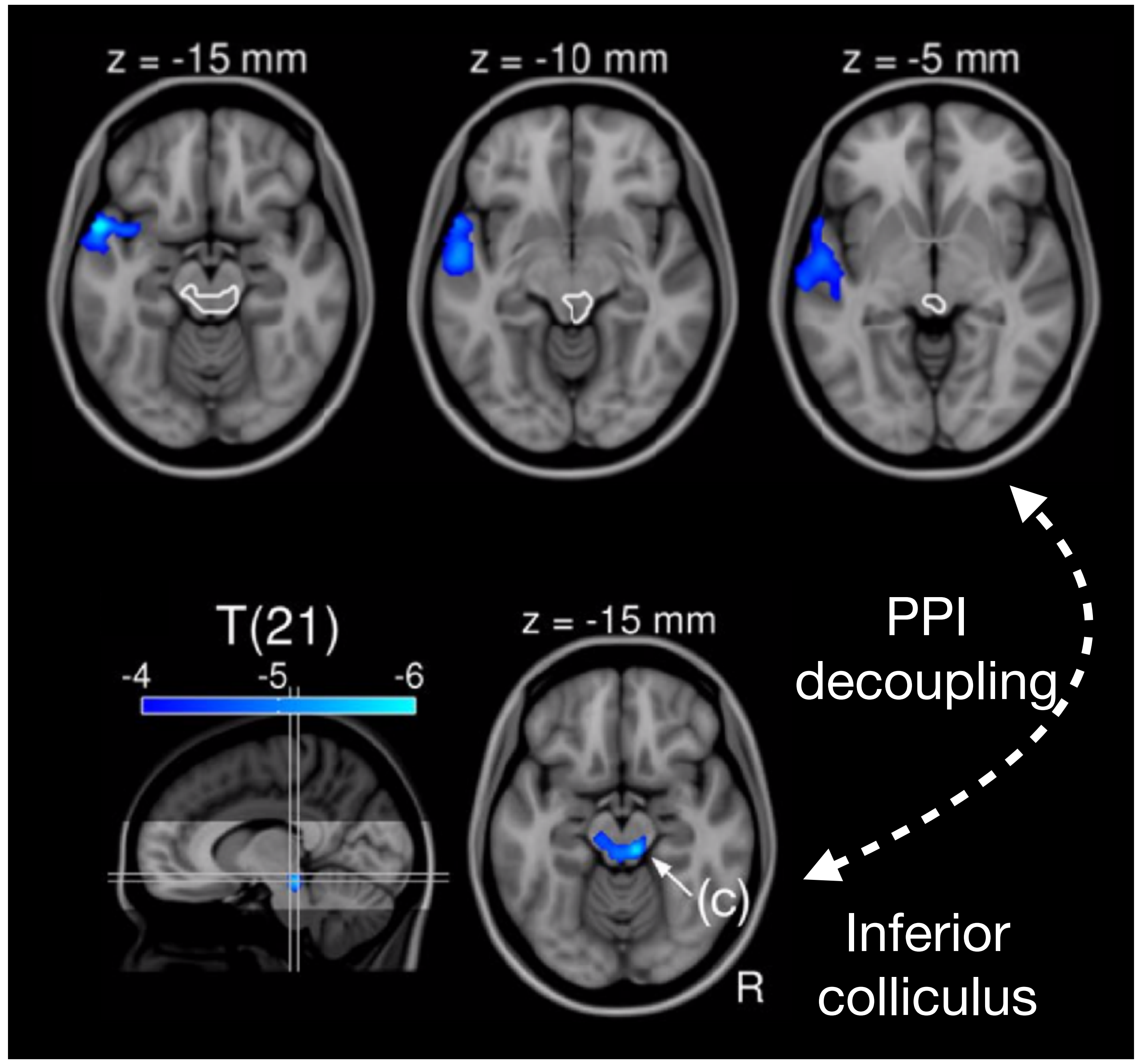
$$\Delta BOLD = \beta_0 + \beta_1 \Delta Rating + error$$



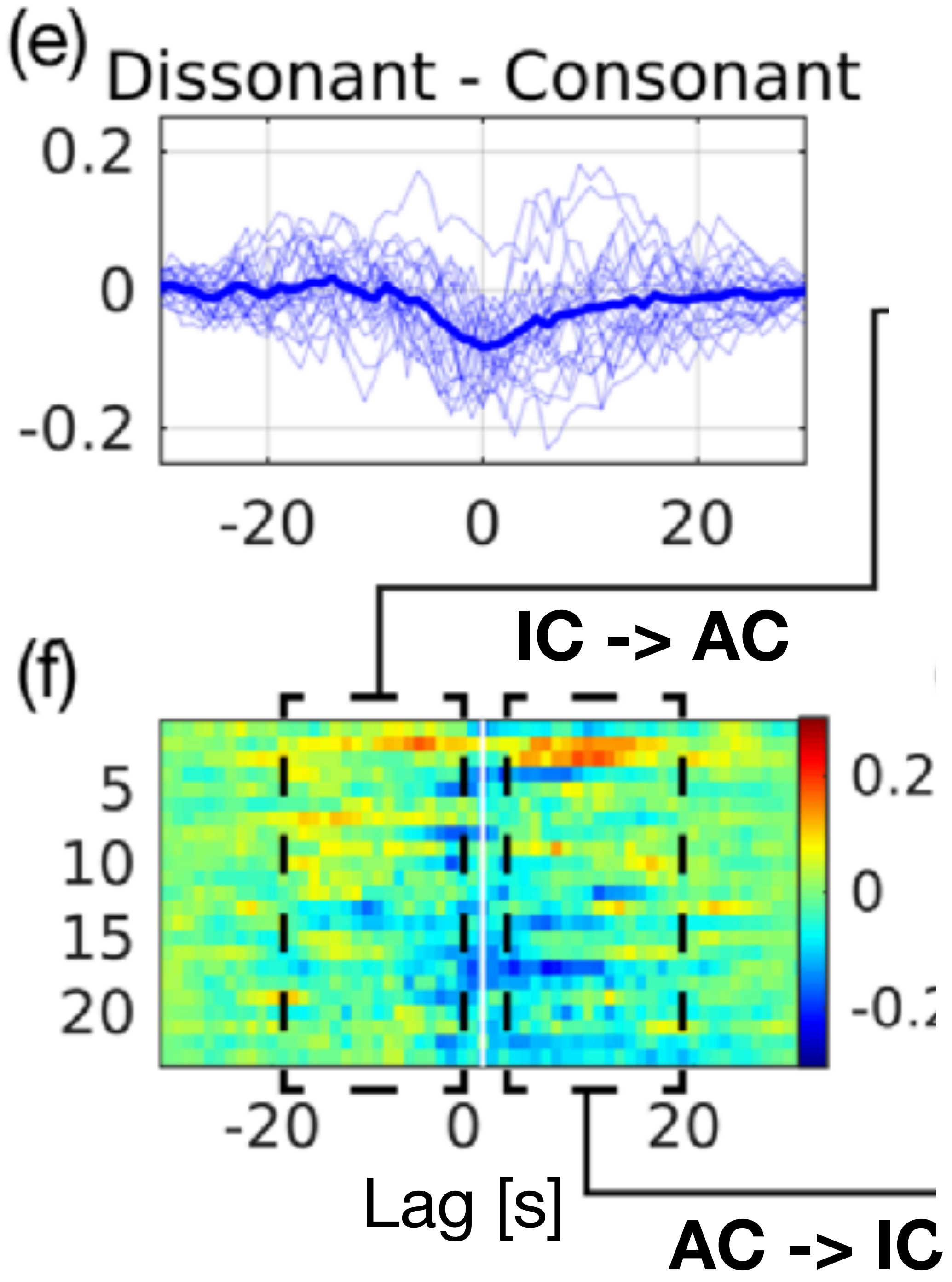
BOLD activation in the inferior colliculus (IC) decreased more in individuals who rated dissonant versions worse.

Kim et al., 2017, *Sci Rep.*

Psycho-Physiological Interaction (PPI)



Cross-correlation



The IC <u>decoupled</u> more from the left auditory cortex (top-down) in individuals who rated dissonant versions worse.

Kim et al., 2017, *Sci Rep.*

Limitations of controlled stimuli

Ceteris paribus... and the subject is not listening.

Disruptive manipulations: validity, generalizability, & specificity?

<u>Solution:</u> Use of natural(istic) stimuli to increase the external validity of neuroscientific studies.

Summary: Introduction

Music, Brain, Emotions

- **Musical emotions** 🎶: basic emotions, dimensions, and aesthetic emotions
- **Cognitive accounts** 🧐: playing with expectation, tension & resolution,
- **Affective accounts** 🥹: emotional vocalization mimicking & contagion, entrainment
- (Mnemonic accounts 💭: autobiographical memories, conditioning, imaginary, semantic associations, lyrics, ...)
- **Naturalistic experiment** 🦋: necessary complexity to investigate high-level processes

Any questions?

Introduction

Music & Emotions

Live-experiment

Go back to SESSION PLAN

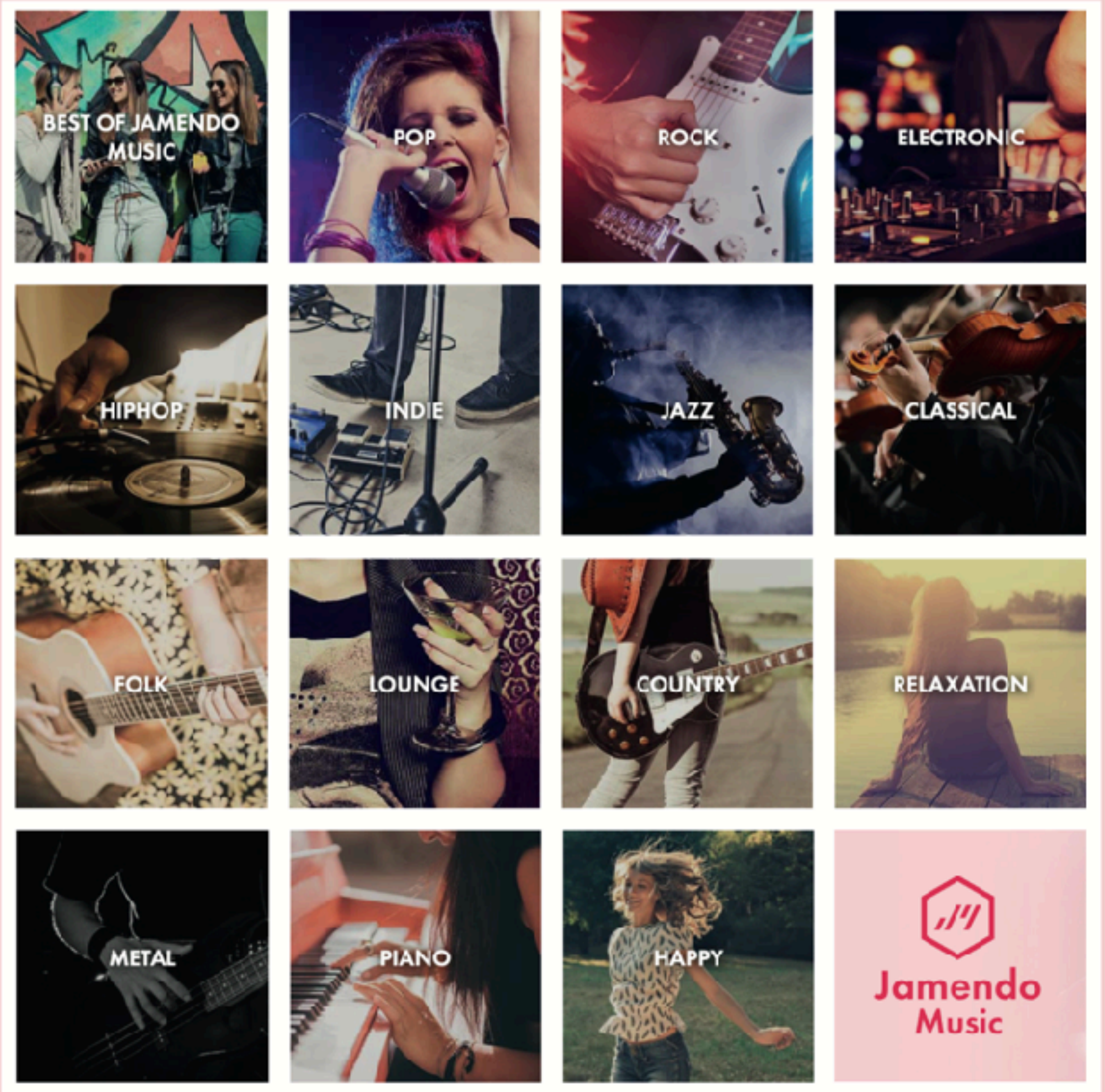
Ongoing study: "ManyMusic🎶"

Deep phenotyping of musical emotions

Music Technology Group

MTG-Jamendo dataset

55,609 audio tracks

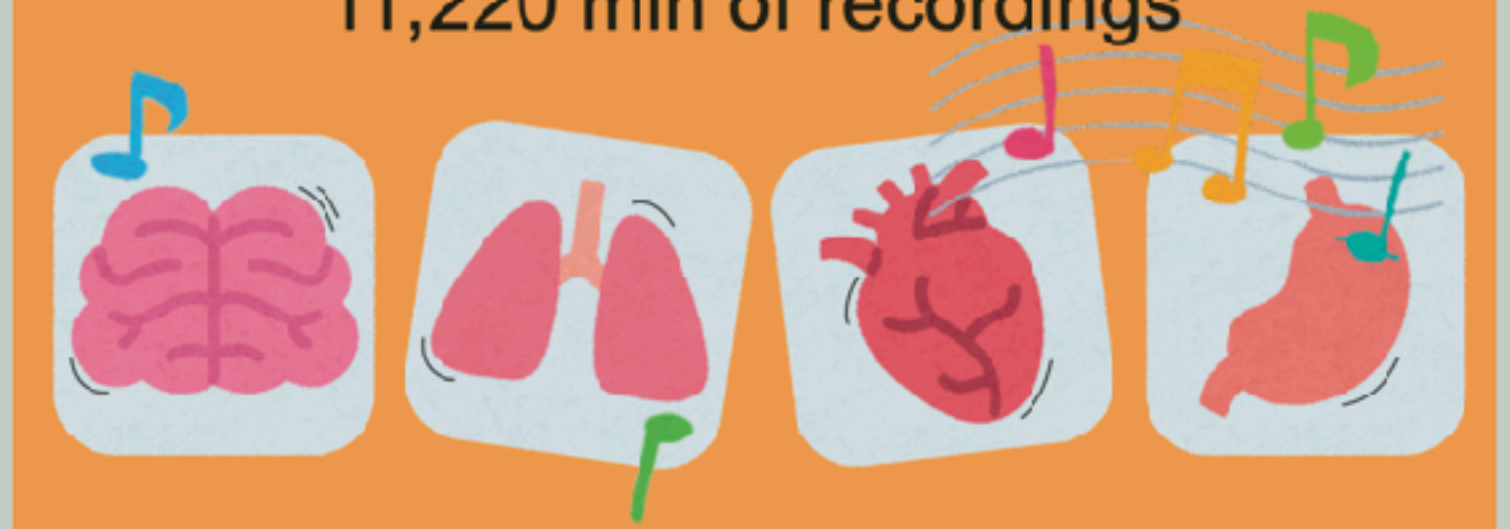


Online behavioural

1,920 tracks
2,800 participants
57,600 min of ratings

fMRI and EXG

1,021 tracks
6 participants
11,220 min of recordings



- **Stimuli**: N = 1,920
  - High-quality, diverse in styles and emotionalities (undergoing with Music Tech Group @UPF)
- **Participants**: N = 2,800
  - Prolific English speakers with minimal (2+ yr) musical experience
- **Ratings**: N = 57,600
  - 1-min around "interesting" points based on model prediction
  - 3 different "affective planes" combining 6 scales (e.g., Arousal, Valence, Liking, ...)

Kim et al., 2023, *CuttingEEG.*

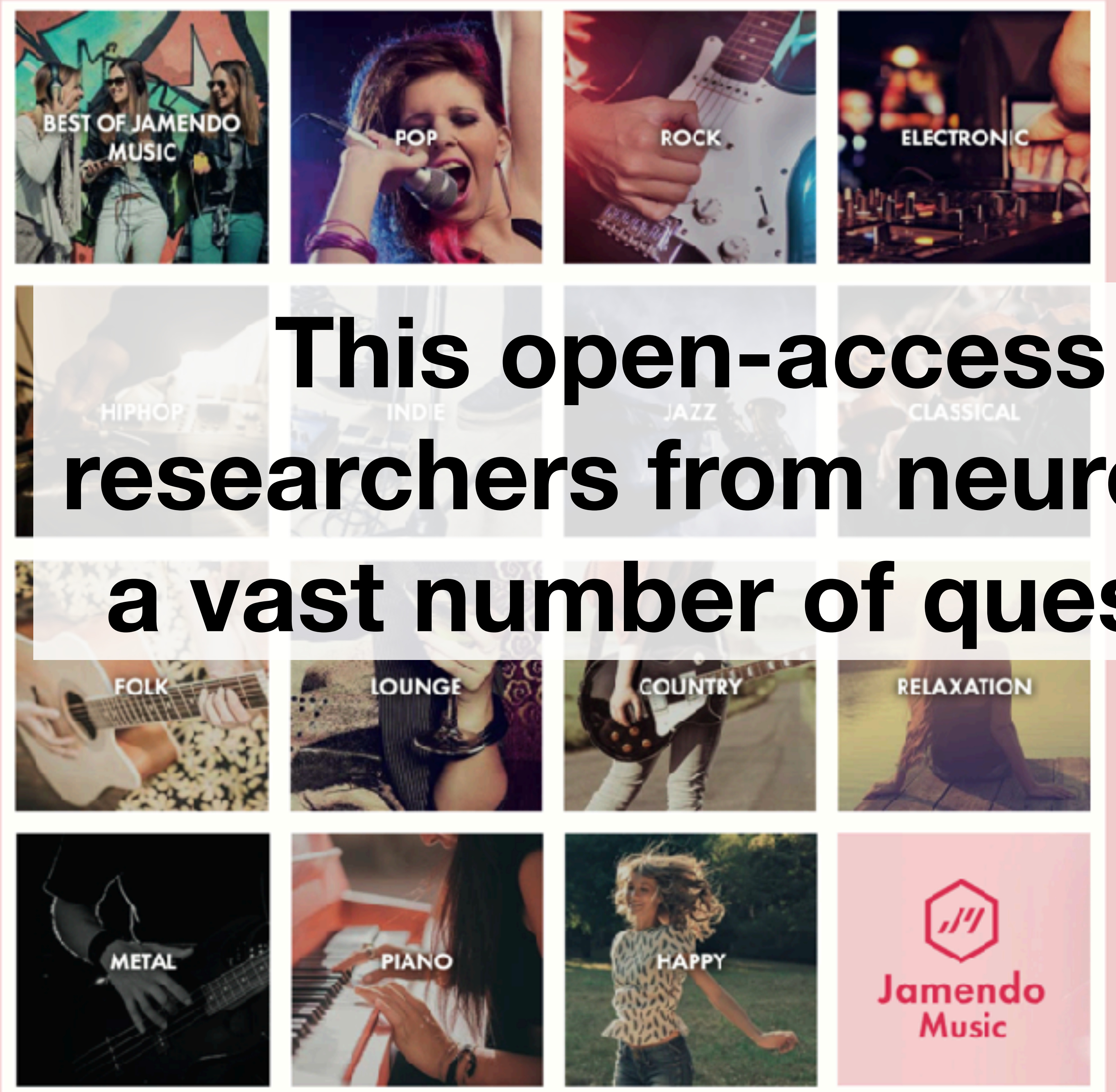
https://www.irasutoya.com/

Ongoing study: "ManyMusic🎶"

Deep phenotyping of musical emotions

JQ Young Academy
at Goethe

MTG-Jamendo dataset
55,609 audio tracks



Online behavioural
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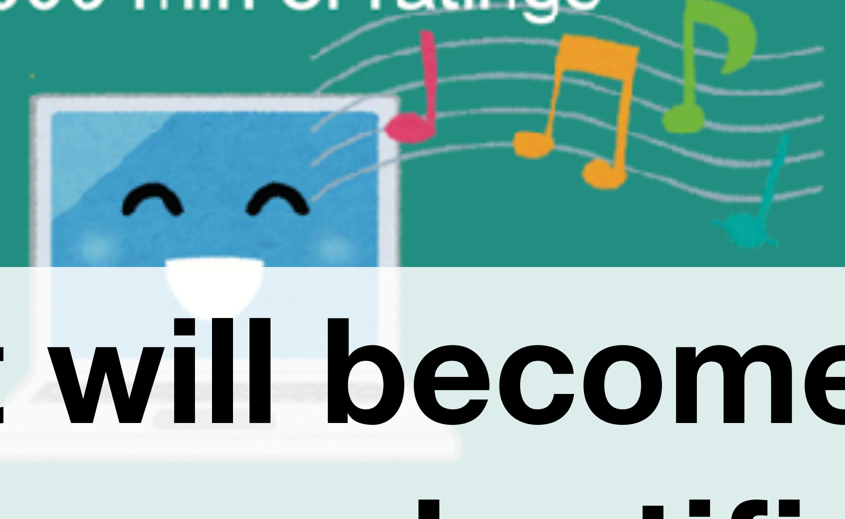


fMRI and EXG
6 participants
11,220 min of recordings

- **Stimuli**: N = 1,021
  - Top 50% from online: 960
  - Participant-selected: 60
  - Reference: "Bohemian R".
- **Participants**: N = 6
  - Musically experienced (in various genres), emotionally ... endure 36 2-hr sessions for ... (JQYA)
- **fMRI**: 17+1 sessions
  - ...
  - Listening & emotion-tracing (e.g., Arousal/Valence-plane)
- **EXG**: 17+1 sessions
  - 32-ch EEG, fEMG, Resp, Pulse, SCR, bipolar EGG
  - Listening & emotion-tracing

This open-access dataset will become a workbench for researchers from neurosciences and artificial intelligence to test a vast number of questions related to music-evoked emotions.

Kim et al., 2023, *CuttingEEG.*

https://www.irasutoya.com/

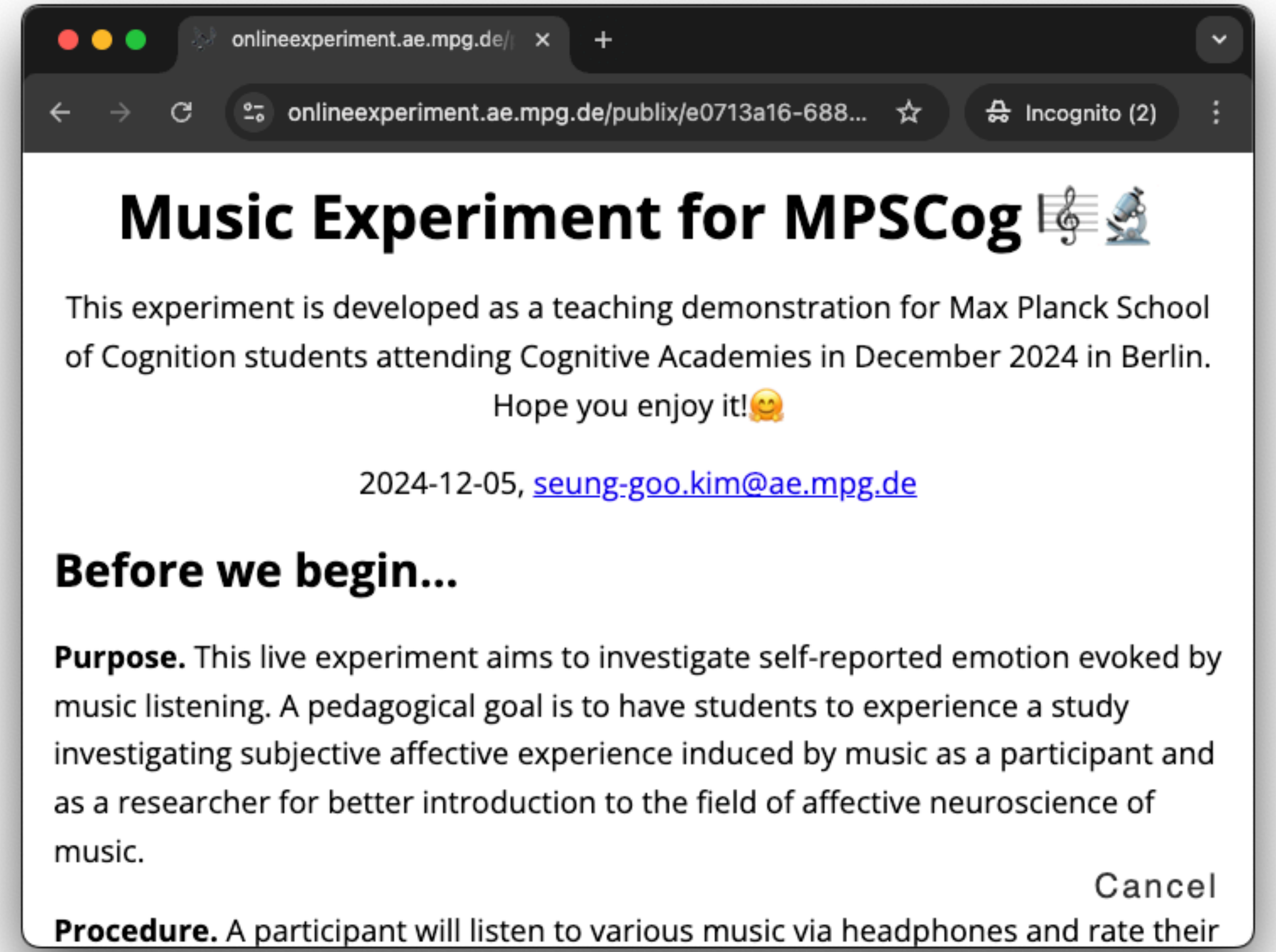
Overview of today's experiment

Pilot study of ManyMusic🎶

- **What**: Emotional rating (self-report) while listening to various music & a few questionnaires about musical emotions
- **How long**: Would take about 20–30 minutes
- **Compensation**: Data from multiple participants! 😍
- **Now you need:**
  - a sufficiently charged laptop connected to the internet 🛜
  - headphones or earphones 🎧
  - a mouse, a trackpad, or any pointer device (like a gamepad, a stylus, …) 🖱️

Study link

https://onlineexperiment.ae.mpg.de/publix/elXedE8yqVL



Time for coffee! ☕🤩

Go back to SESSION PLAN

How to analyze naturalistic experiments

Theories

Go back to SESSION PLAN

Topics: Analysis

How to analyze naturalistic experiment

- Data-driven methods:
  - **Intersubject synchrony**
  - **Event structure analysis**
- Hypothesis-based methods:
  - **Linearized encoding analysis**

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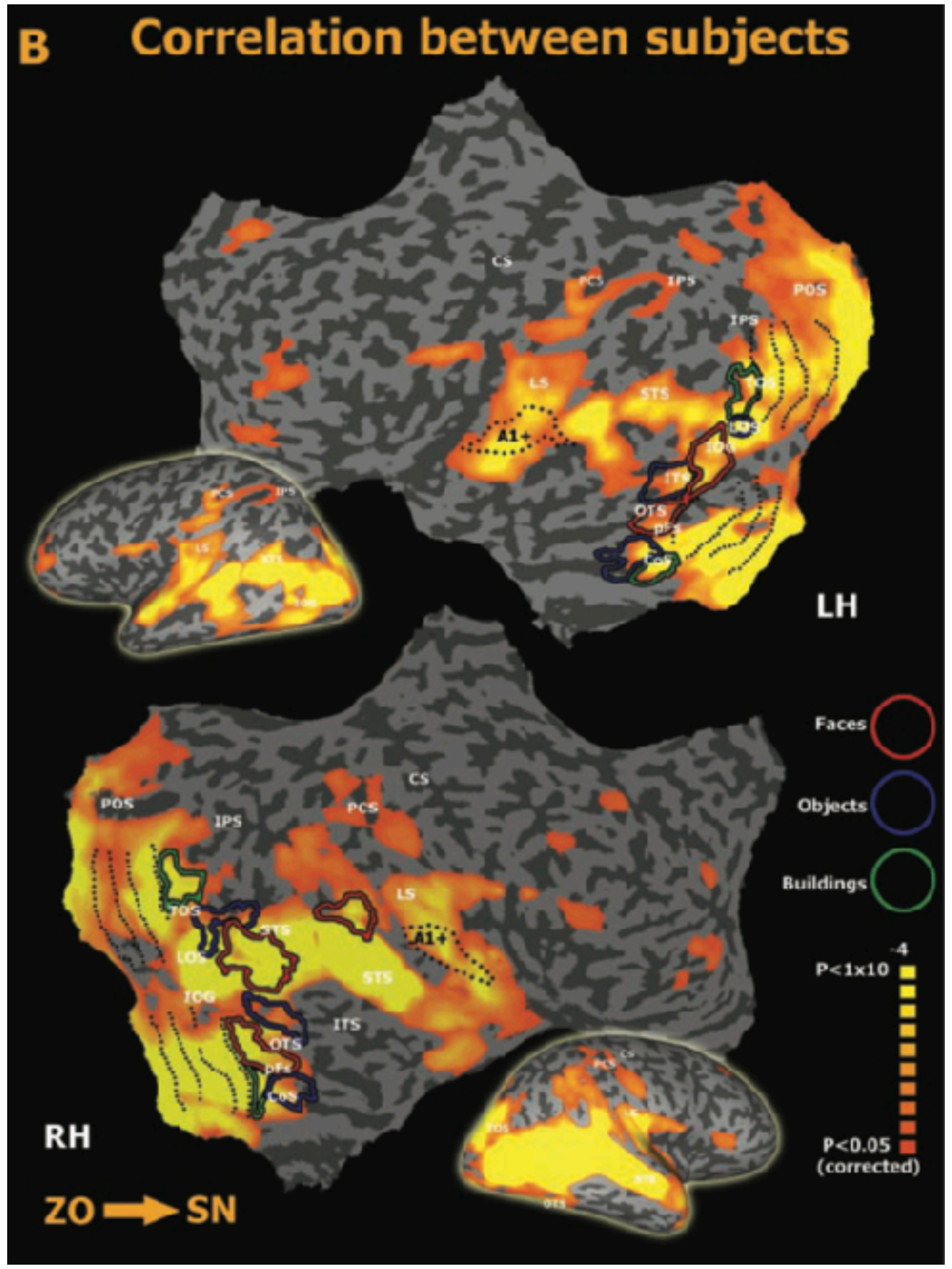
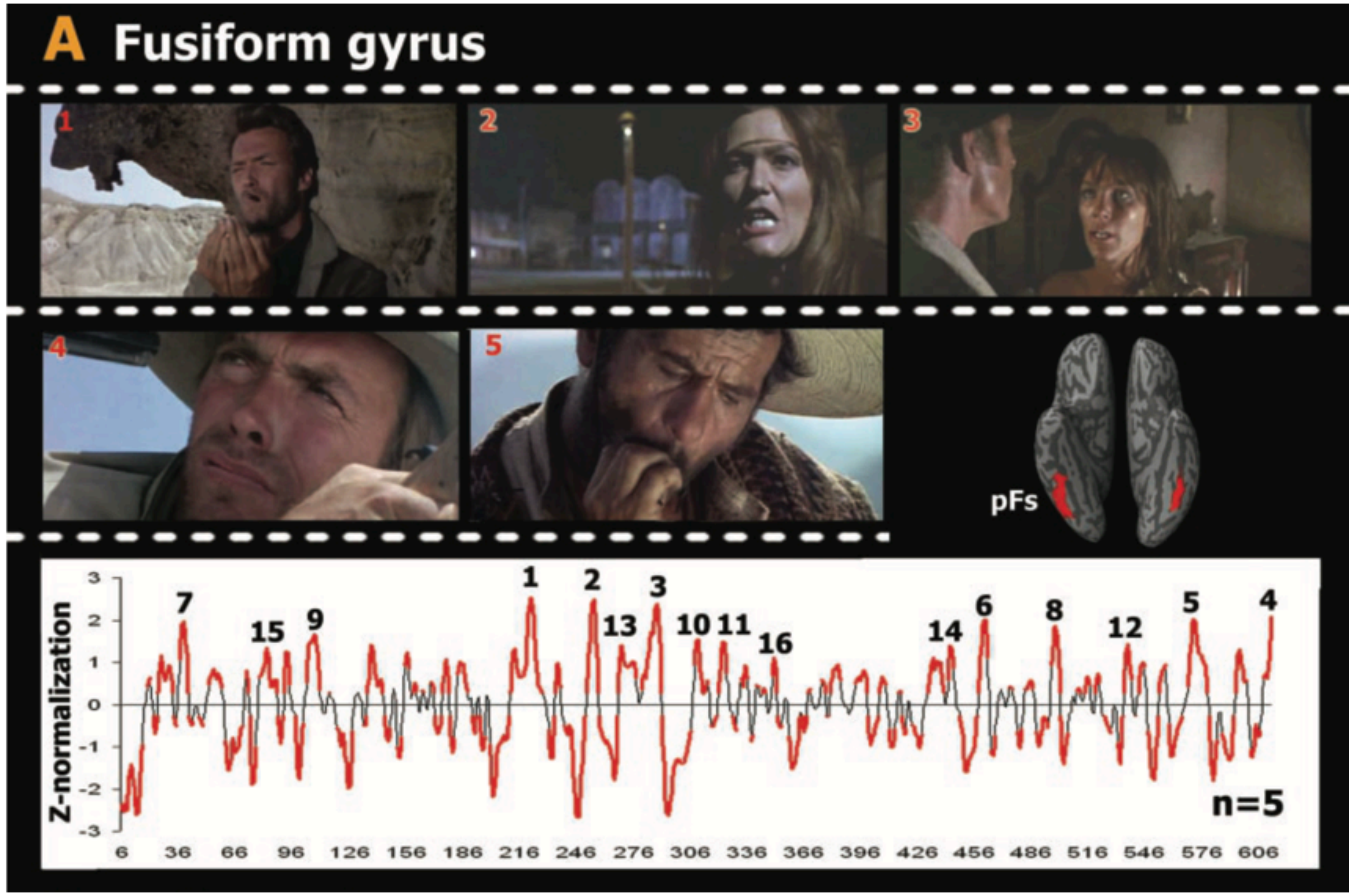
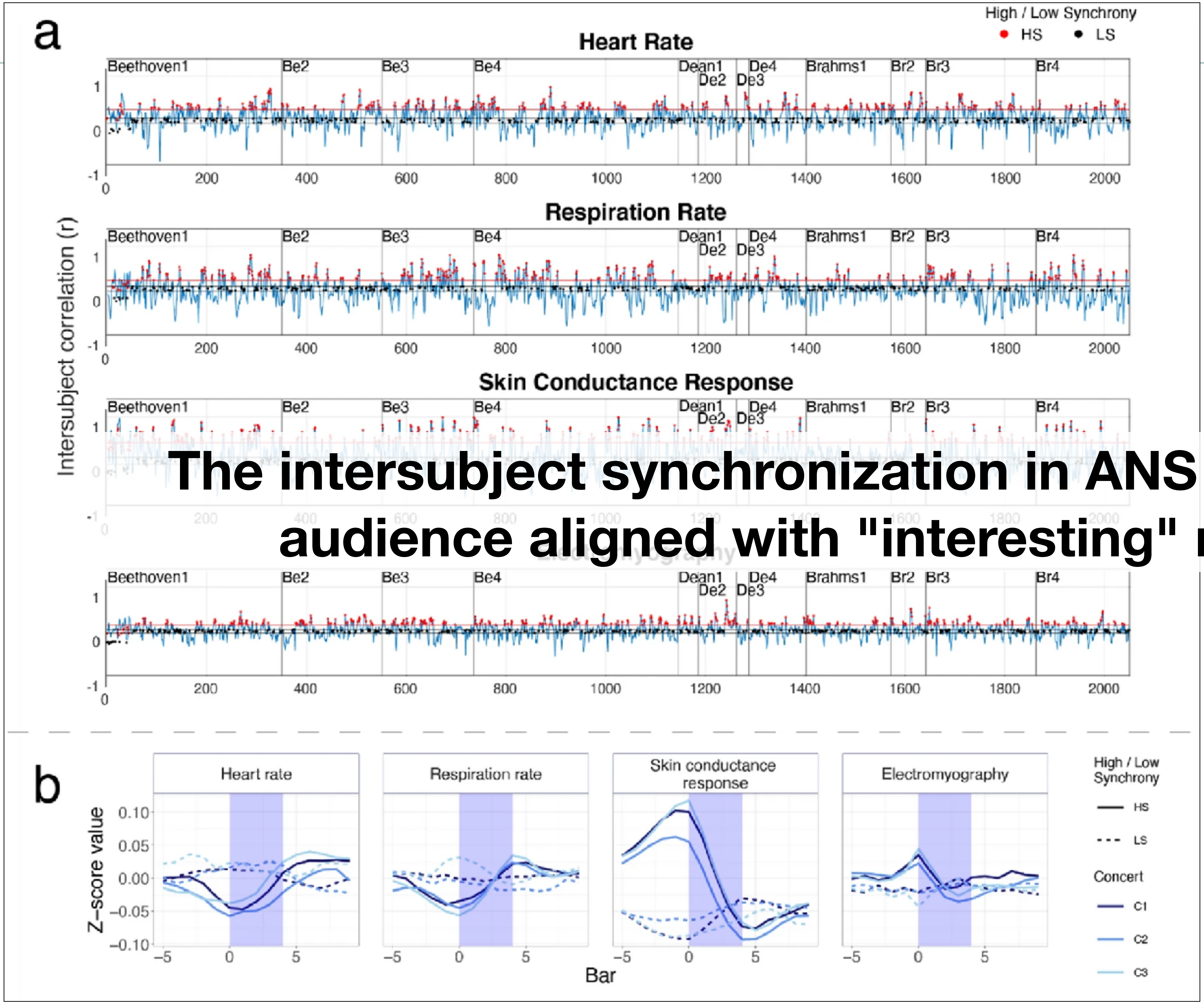
Intersubject synchrony during a movie

Hasson et al., 2004, *Science*

- 30-min movie
- 5 participants
- Free viewing + reporting the plot

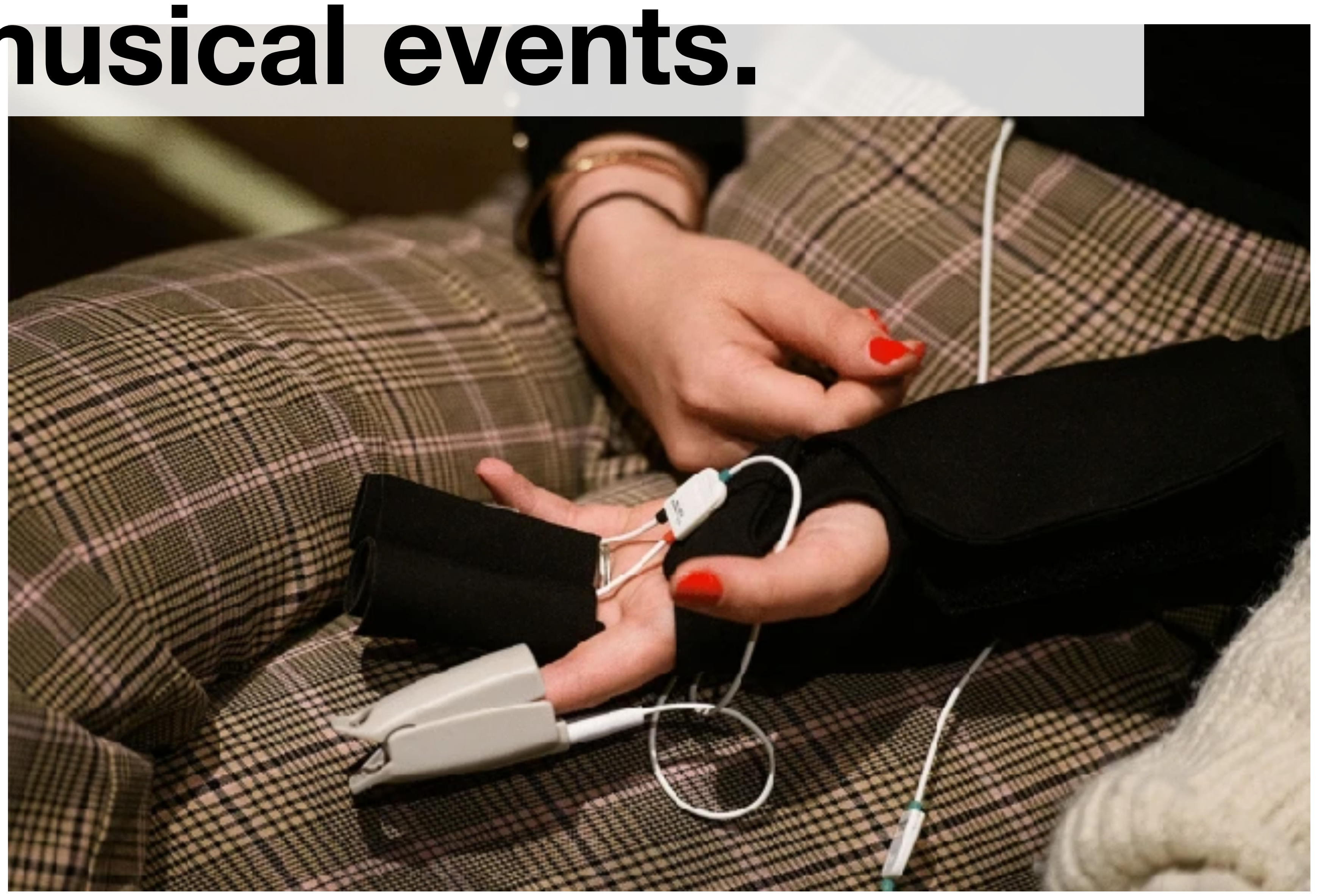






The intersubject synchronization in ANS measures amongst audience aligned with "interesting" musical events.

Czepiel et al., 2021, *Sci Rep*.



Tschacher et al., 2024, *Sci Rep*.
(Experimental Concerts in 2022, Berlin)

Topics: Analysis

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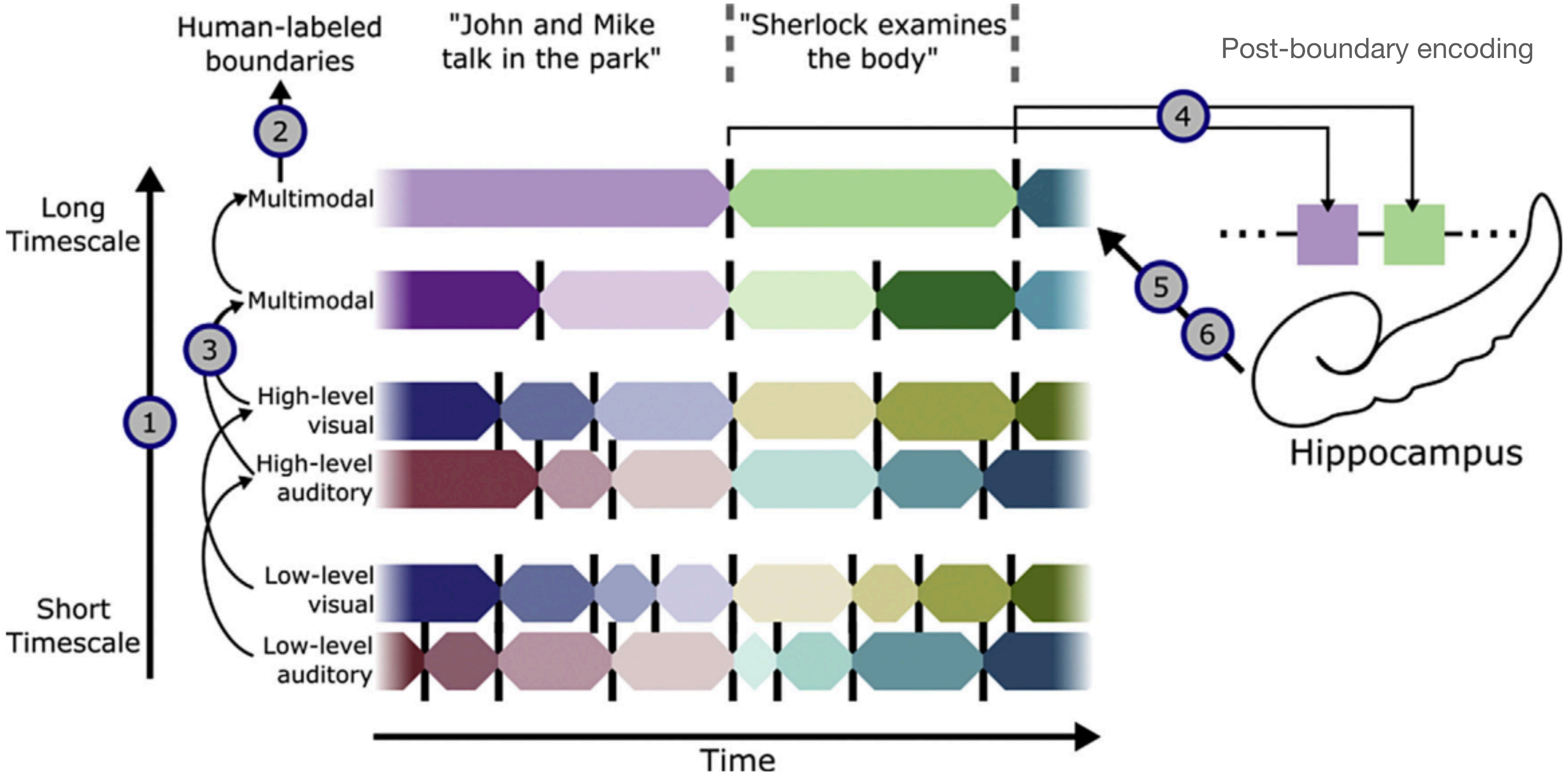
Theory of "event segmentation" & memory

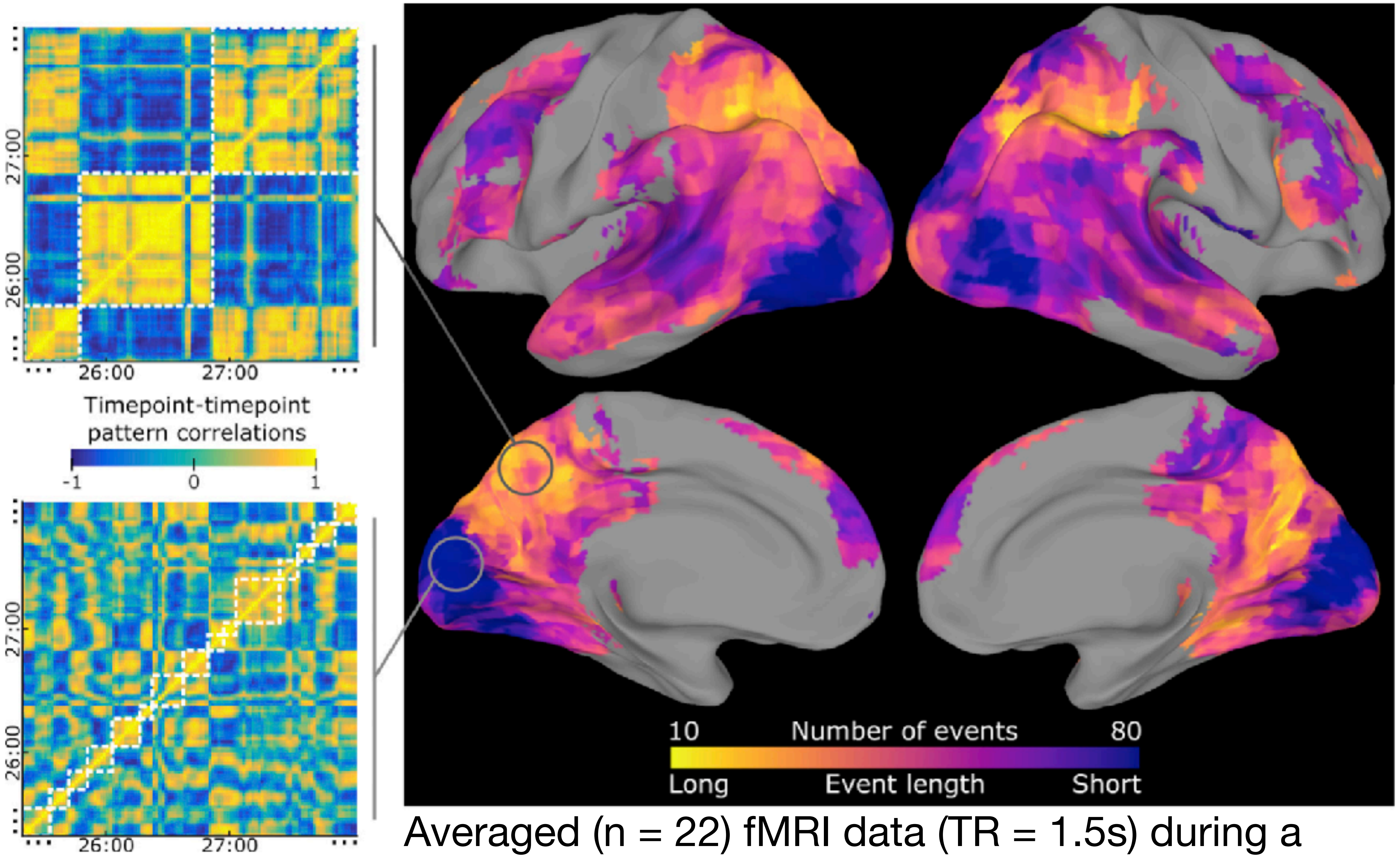
Baldassano et al., 2017, *Neuron*



SEE ALSO Zack et al., 2007, *Psychological Bulletin*, DOI:10.1037/0033-2909.133.2.273

Event time scales during a movie

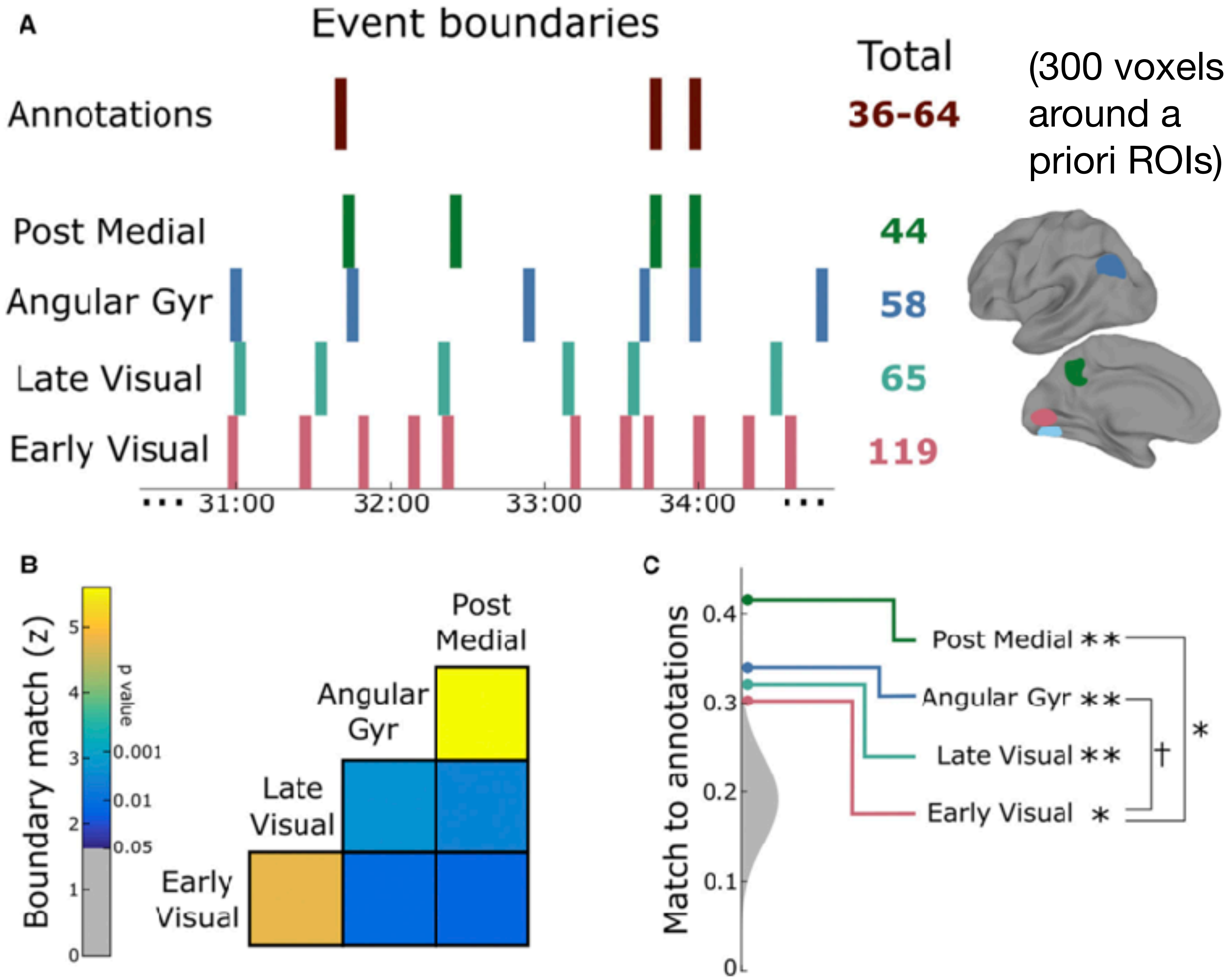
Baldassano et al., 2017, *Neuron*



Averaged (n = 22) fMRI data (TR = 1.5s) during a **50-min movie** (BBC Sherlock Ep.1)

(n=4; "major shifts in location, topic, time)

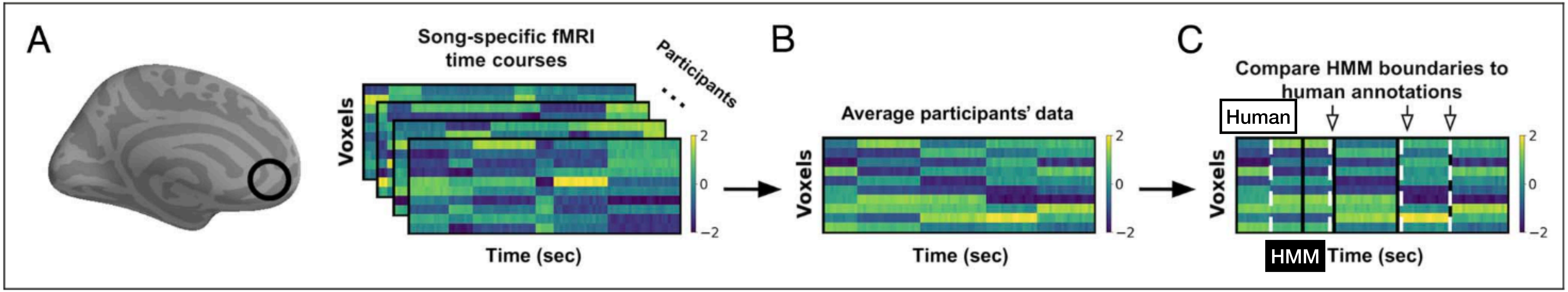
(300 voxels around a priori ROIs)

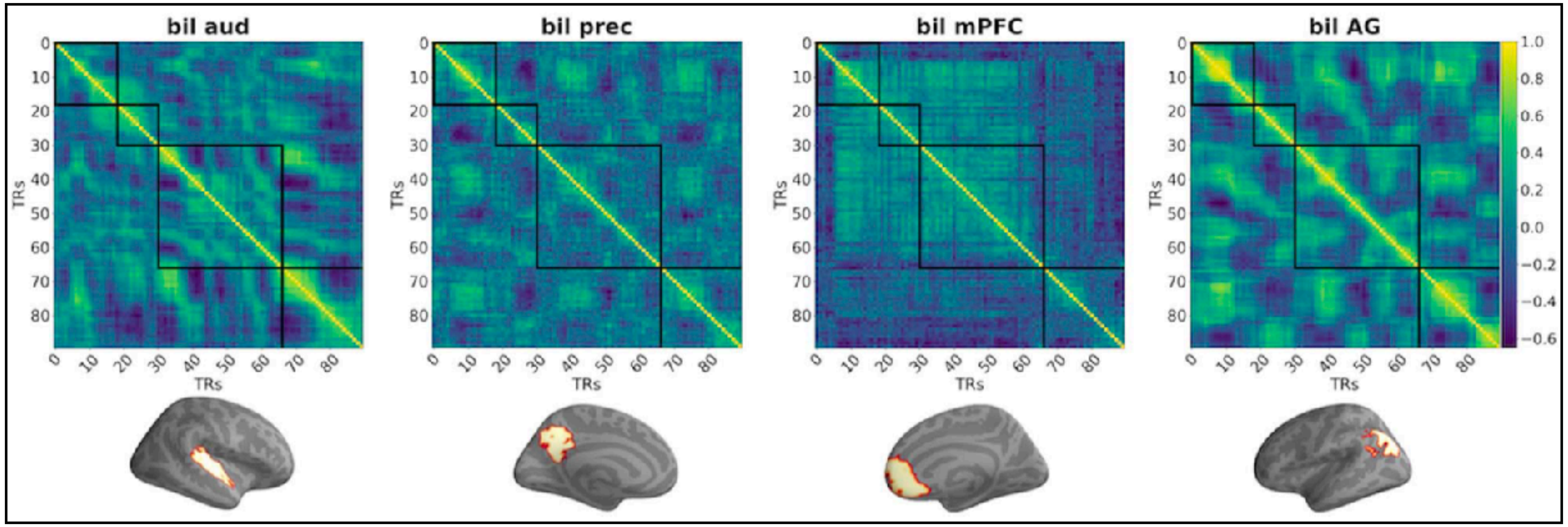


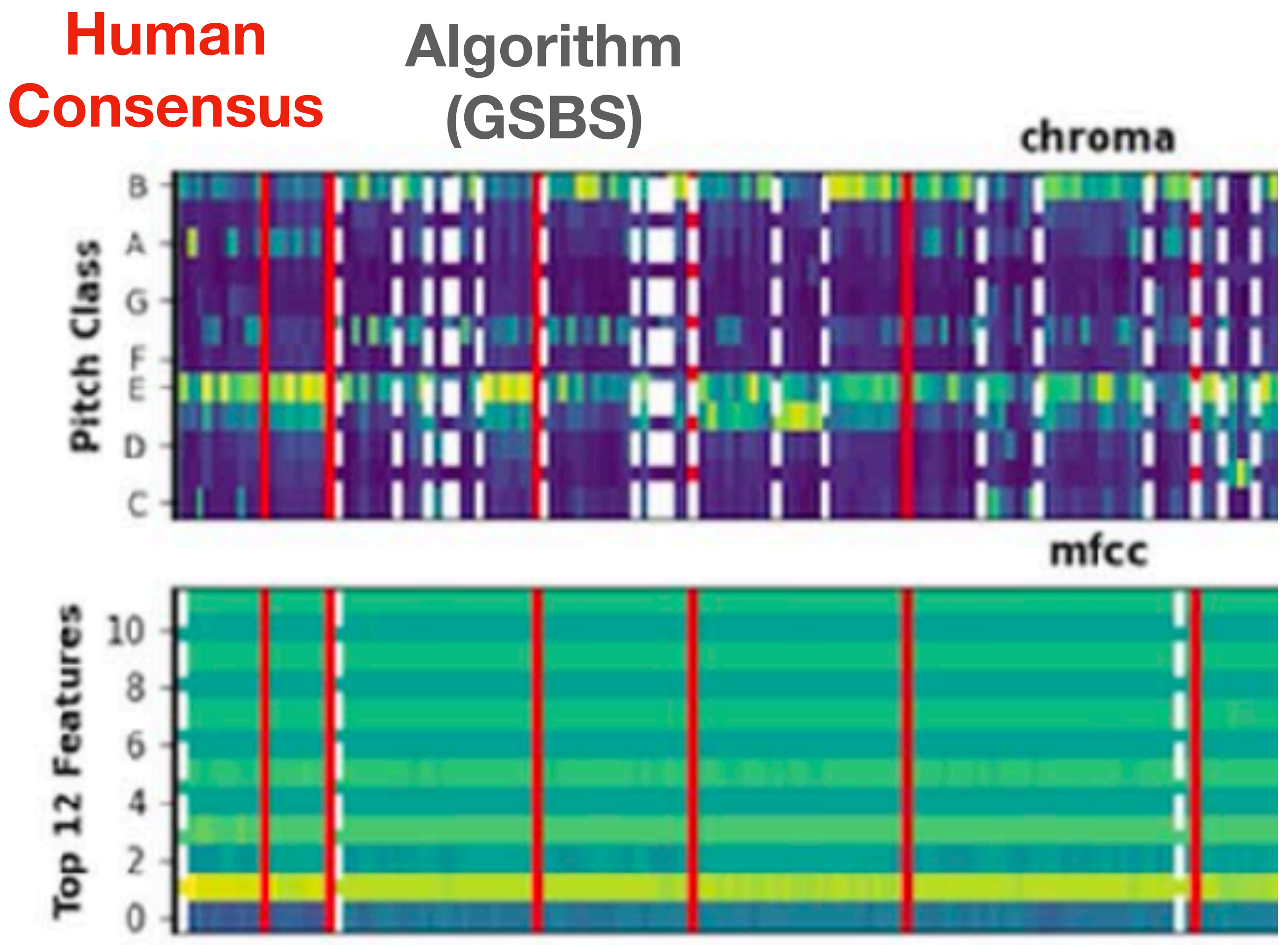
Comparison with human annotations vs. fMRI boundaries

Event structure of music in the DMN areas

Williams et al., 2022, *J Cog Neurosci*







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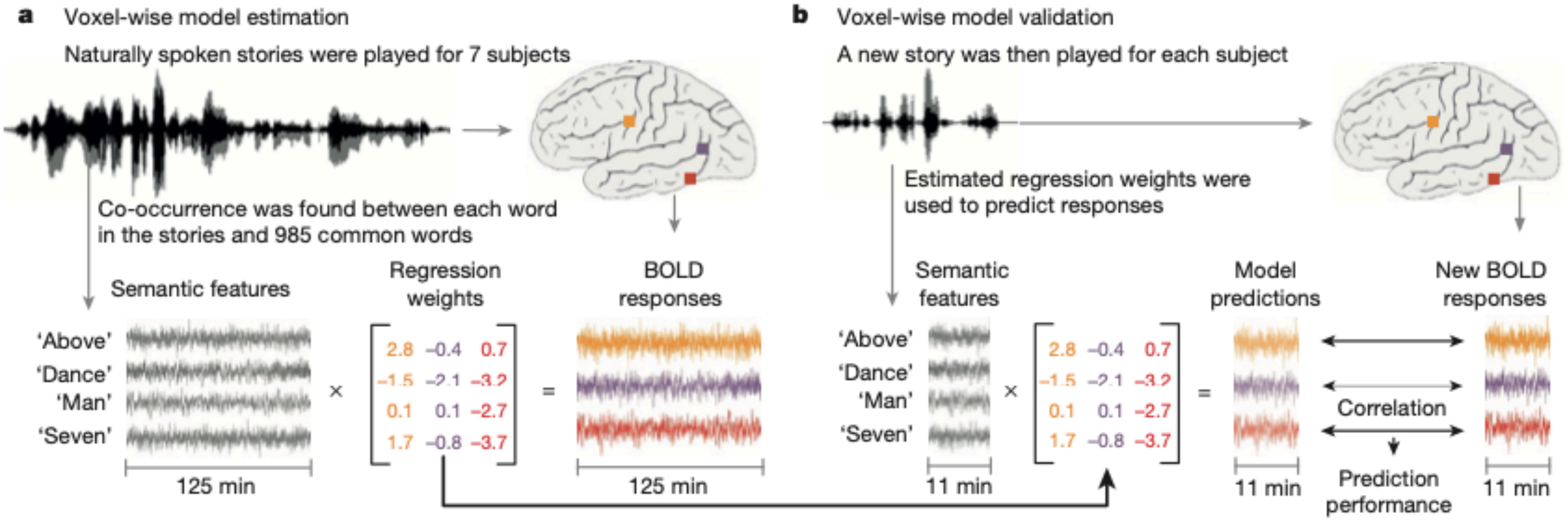
Semantic representation in the whole cortex

Non-invasive scanning of functional MRI (local paramagnetism)

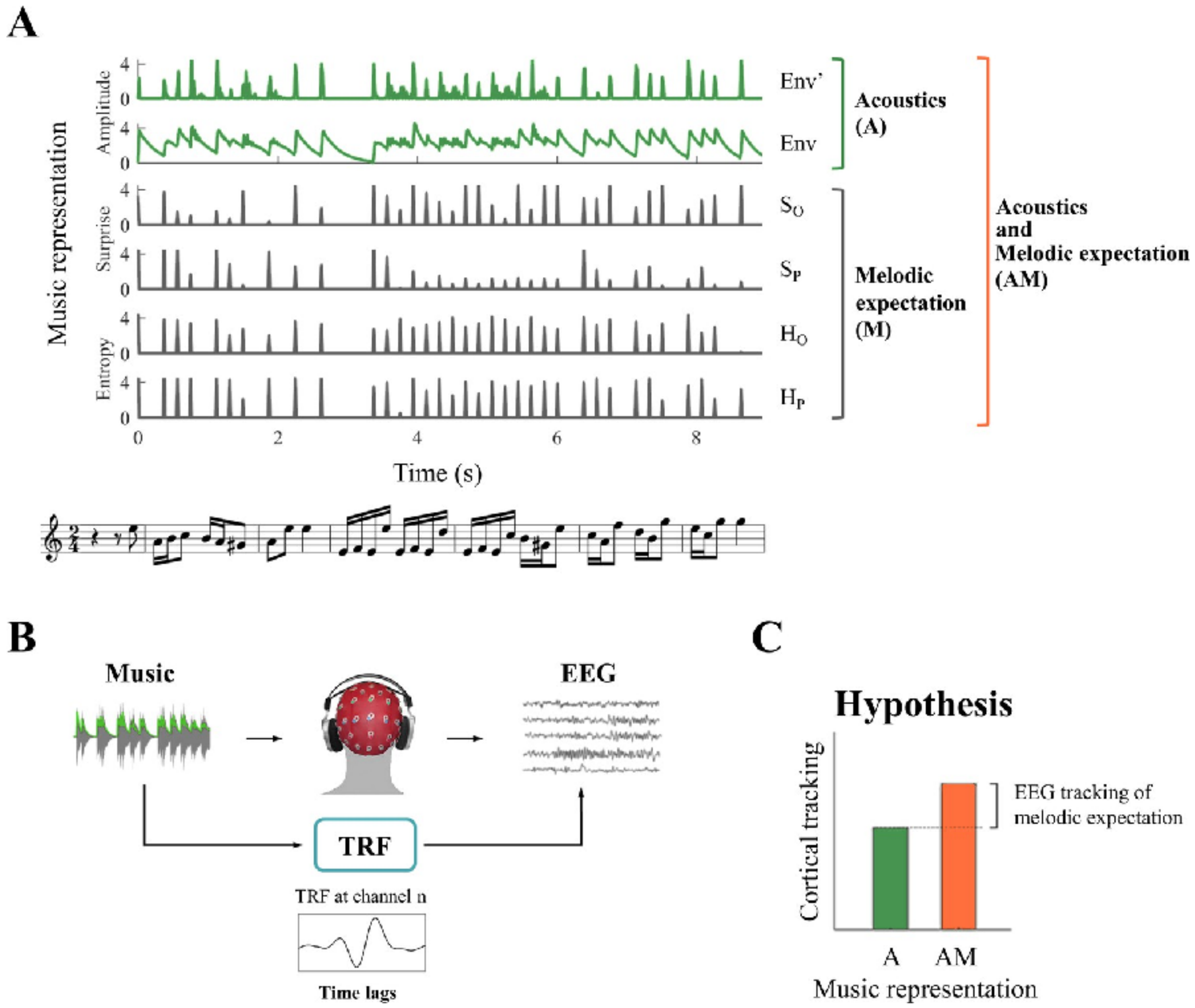


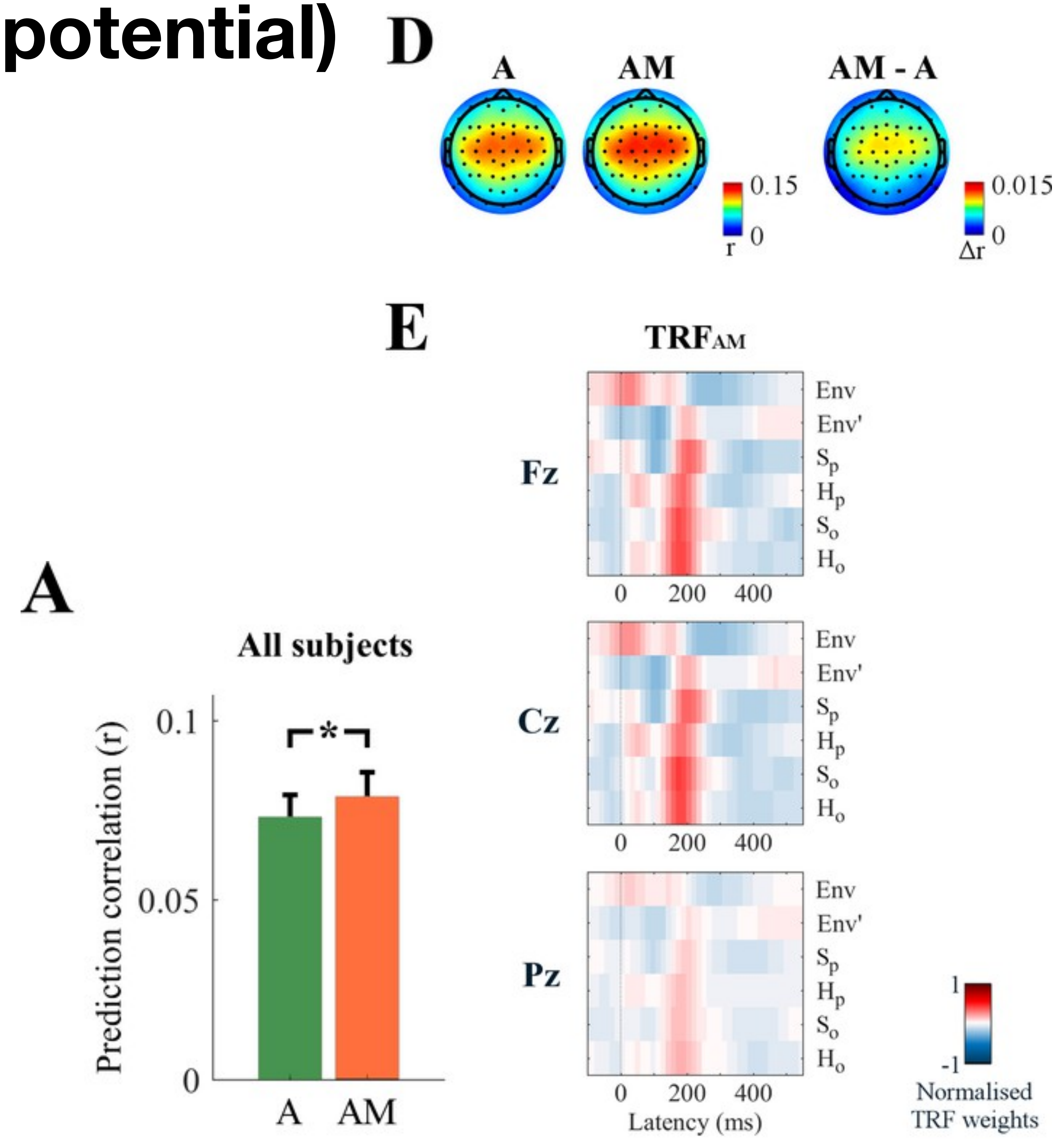
Huth et al., 2016, https://doi.org/10.1038/nature17637

Huth et al., 2016, https://doi.org/10.1038/nature17637

Temporal response function of melodic surprisal

Non-invasive recording of EEG (scalp potential)

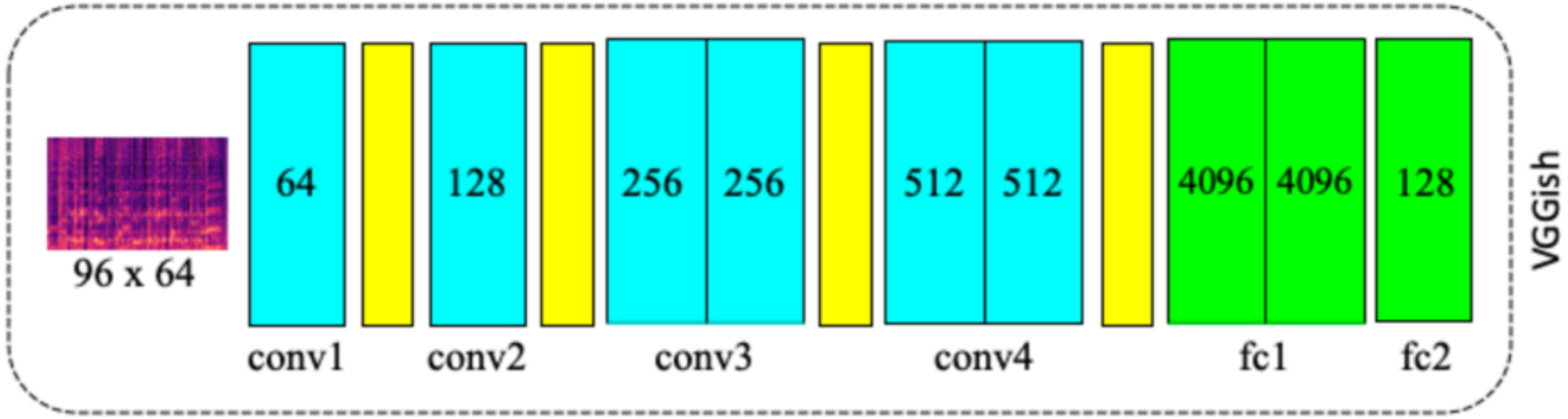


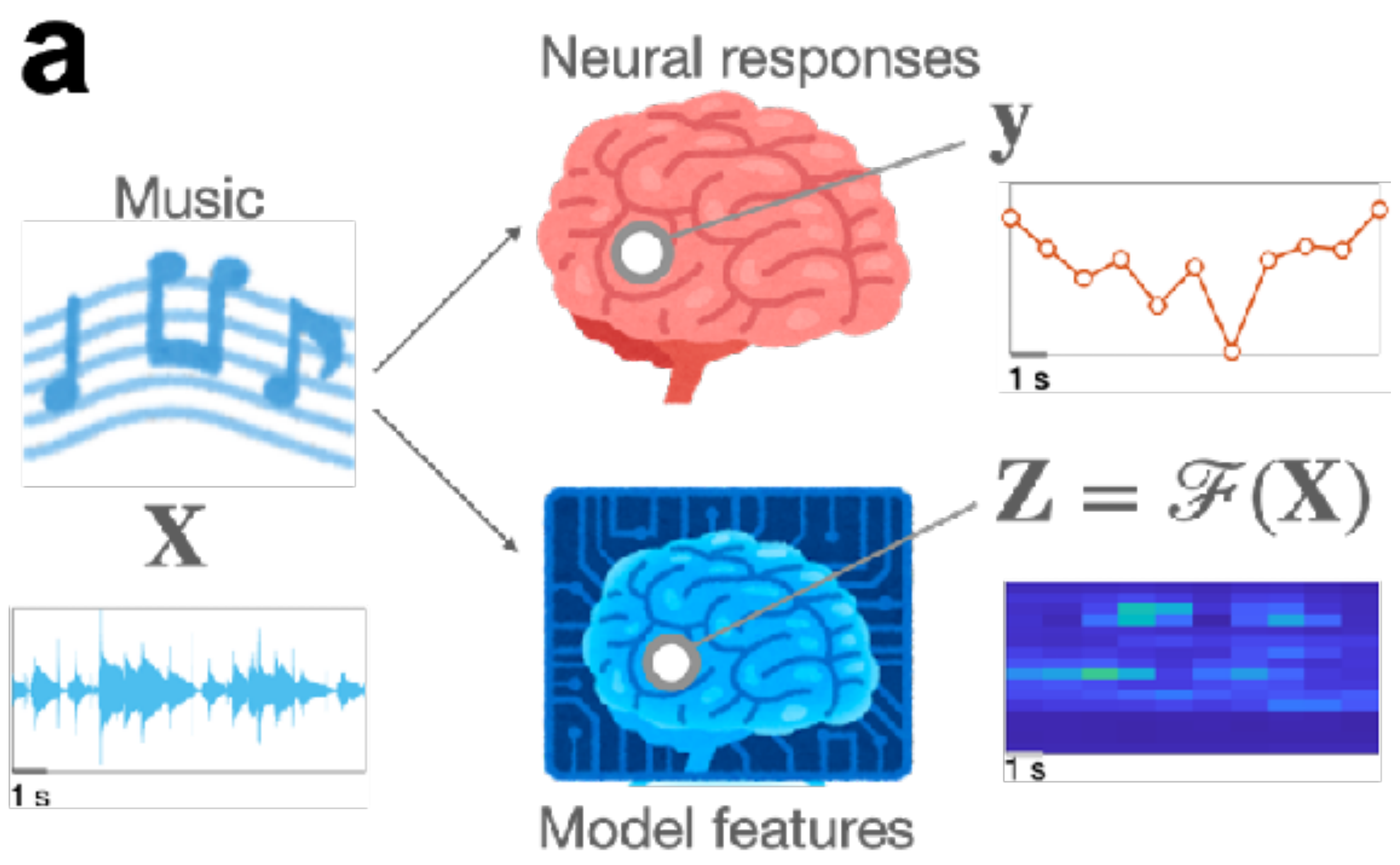


Di Liberto et al., 2020, https://doi.org/10.7554/eLife.51784

Representational gradient of musical emotions in fMRI

Non-invasive scanning of functional MRI (local paramagnetism)





Kim et al., *In Prep*.

How good the "Layer X" is for this brain area?

b

$$y^{(1)} = \mathcal{F}_1(\mathbf{X}^{(1)})\mathbf{b}_1 + \varepsilon \rightarrow r_1 = \mathrm{corr}(\hat{y}_1^{(2)}, y^{(2)})$$

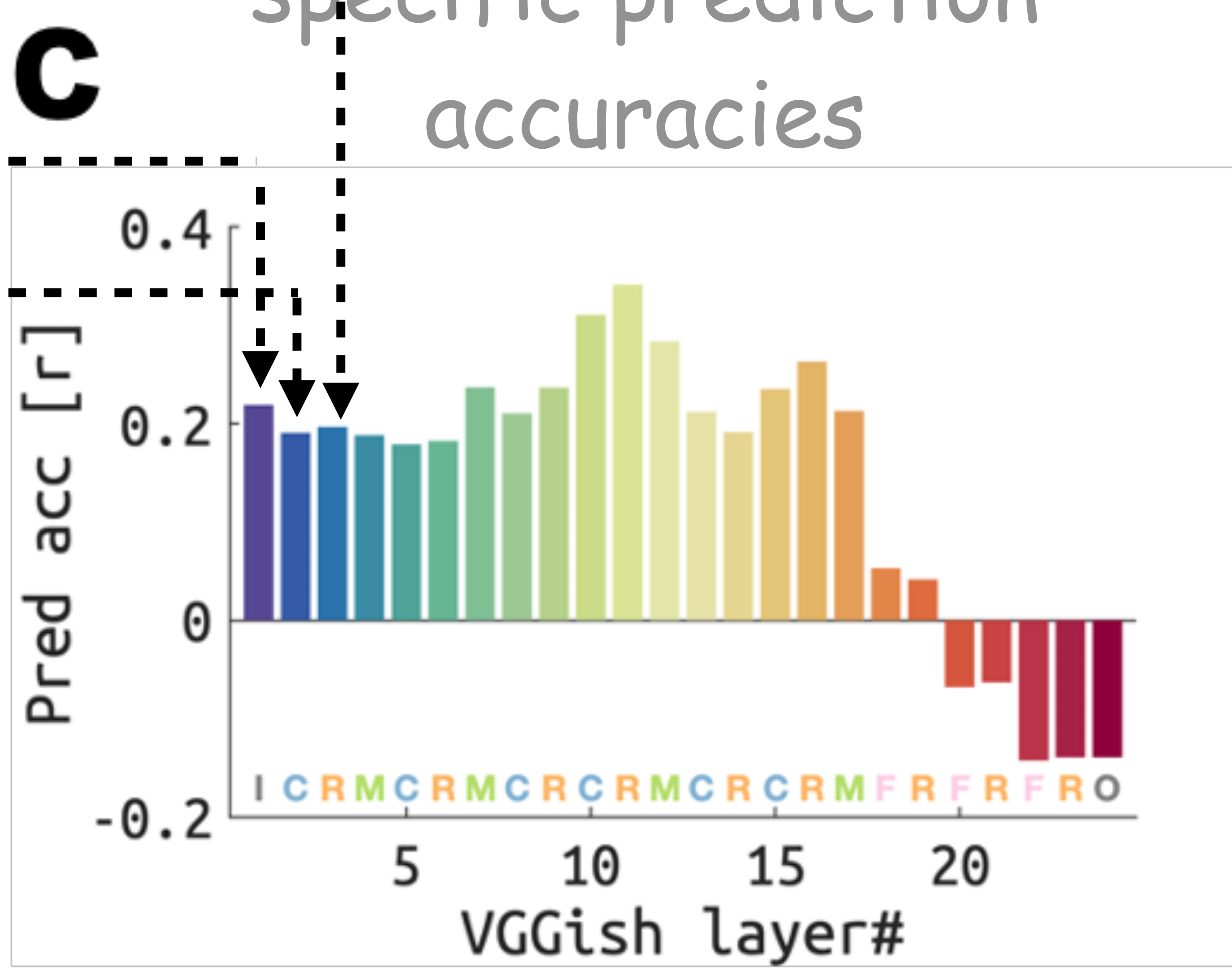
$$y^{(1)} = \mathcal{F}_2(\mathbf{X}^{(1)})\mathbf{b}_2 + \varepsilon \rightarrow r_2 = \mathrm{corr}(\hat{y}_2^{(2)}, y^{(2)})$$

$$y^{(1)} = \mathcal{F}_3(\mathbf{X}^{(1)})\mathbf{b}_3 + \varepsilon \rightarrow r_3 = \mathrm{corr}(\hat{y}_3^{(2)}, y^{(2)})$$

$$\vdots$$

$$y^{(1)} = \mathcal{F}_{24}(\mathbf{X}^{(1)})\mathbf{b}_{24} + \varepsilon \rightarrow r_{24} = \mathrm{corr}(\hat{y}_{24}^{(2)}, y^{(2)})$$

A "profile" of layer-specific prediction accuracies



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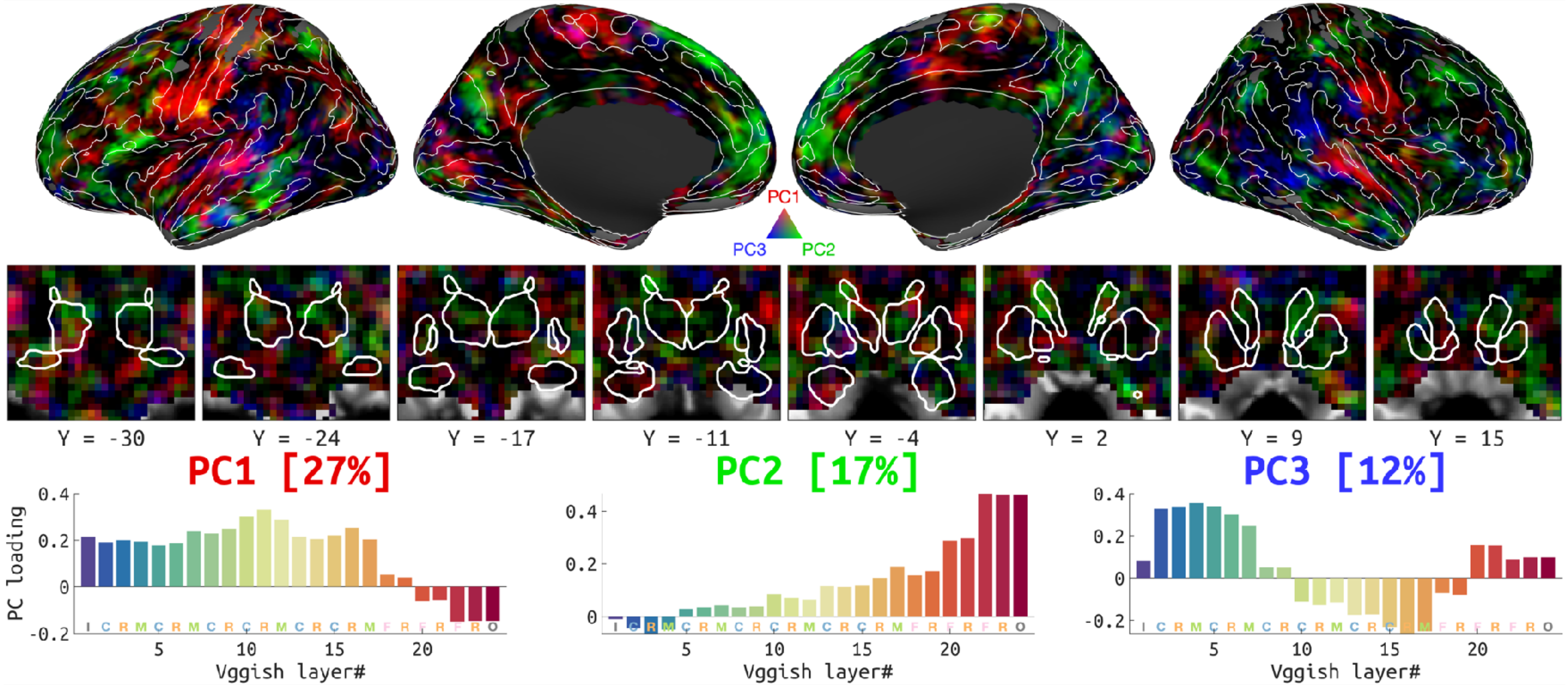

Kim et al., *In Prep*.

Summary: Analysis

How to analyze naturalistic experiment

- Data-driven methods:
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Any questions?

Analytic methods

Go back to SESSION PLAN

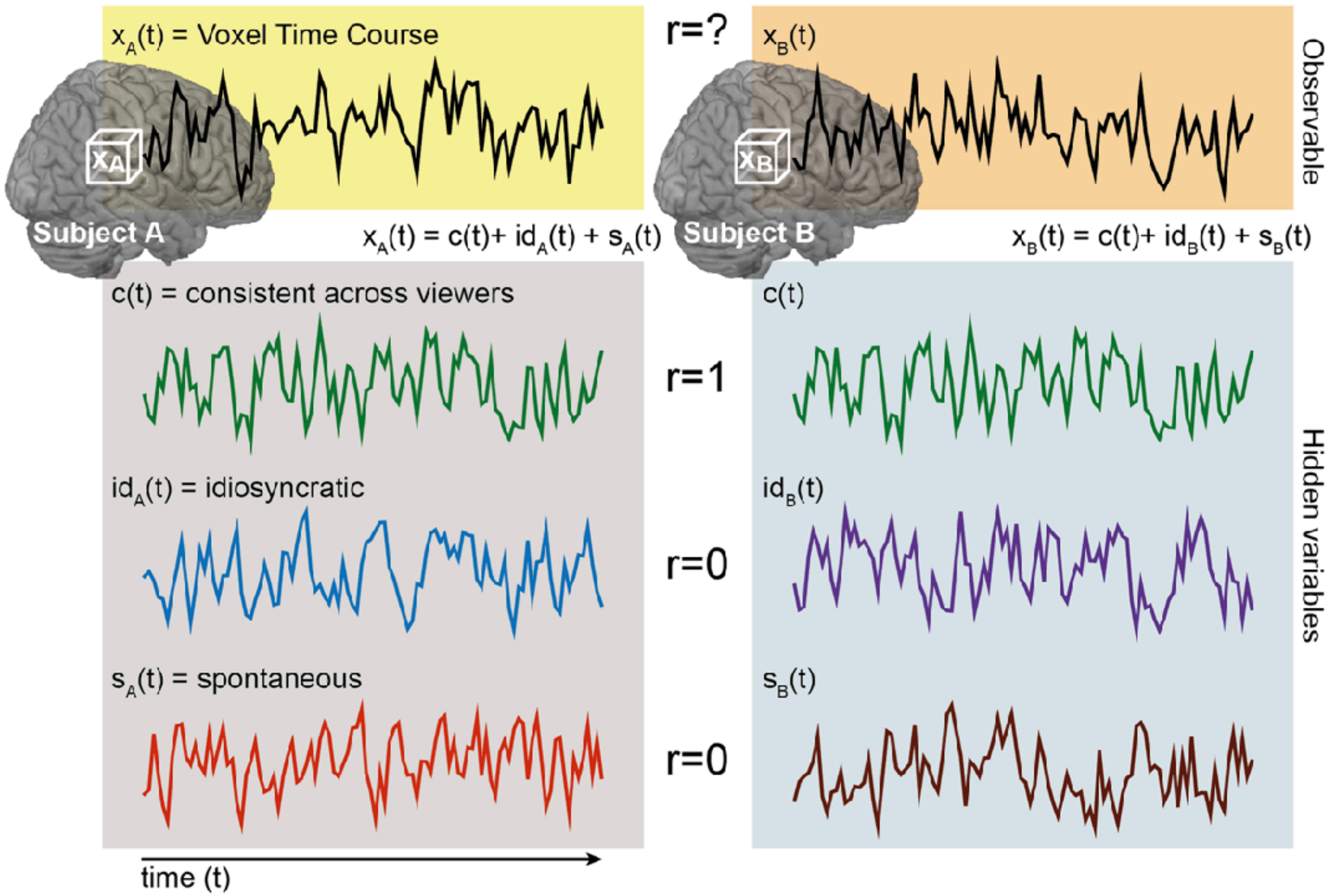
How to analyze naturalistic experiments

Hands-on

Go back to SESSION PLAN

Let's try something simple first: ISC

$$x_A(t) = \alpha_A \boxed{c(t)} + \beta_A id_A(t) + \varepsilon_A(t)$$



Nastase et al., 2019, *Soc. Cog. Aff. Neurosci*.

$$r_{AB} = r(x_A, x_B) \qquad {r_{AB}}^2 \sim \alpha_A \bullet \alpha_B$$

$$\lim_{N\to\infty} (\bar{x}(t)) = c(t)$$

$$\because \mathbb{E}[id(t)] = 0, \mathbb{E}[\epsilon(t)] = 0$$

$$\hat{c}(t) = \bar{x}_{-i}$$

- **Intersubject correlation (ISC)**: strength of stimulus-driven activity that is common across subjects
- No modeling of stimuli is required to compute ISC; but unspecific to actual activity (could be a **synchronized increase or decrease**)

Proposed pipeline

Time-resolved intersubject correlation

- Stationarization of non-stationary time series
- Intersubject correlation calculations with a sliding window
- Statistical inference with sign-flipping

Proposed pipeline

Time-resolved intersubject correlation

- **Stationarization of non-stationary time series**
- Intersubject correlation calculations with a sliding window
- Statistical inference with sign-flipping

Stationarization of non-stationary time series

Why? Because correlation assumes stationary noise

- Polynomial detrending
- High-pass filtering
- Derivatives (if downsampled enough)
- (Or not, just compute frequency-wise coherence and ignore low-frequency parts)

Proposed pipeline

Time-resolved intersubject correlation

- Stationarization of non-stationary time series
- Intersubject correlation calculations with a sliding window
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ISC calculation

Pseudocode

- `let X = sum( x(j) ) for all subjects`
- `for i-th subject:`
  - `r(i) = corr( x(i), X - x(i) )`

Time-resolved ISC calculation

Pseudocode

- `for j-th time window:`
  - `let X = sum( x(i,TW(j)) ) for all subjects`
  - `for i-th subject:`
    - `r(i,j) = corr( x(i,TW(j)), X - x(i,TW(j)) )`

🤔: Still, how do we know if this is not due to the random noise in the data?

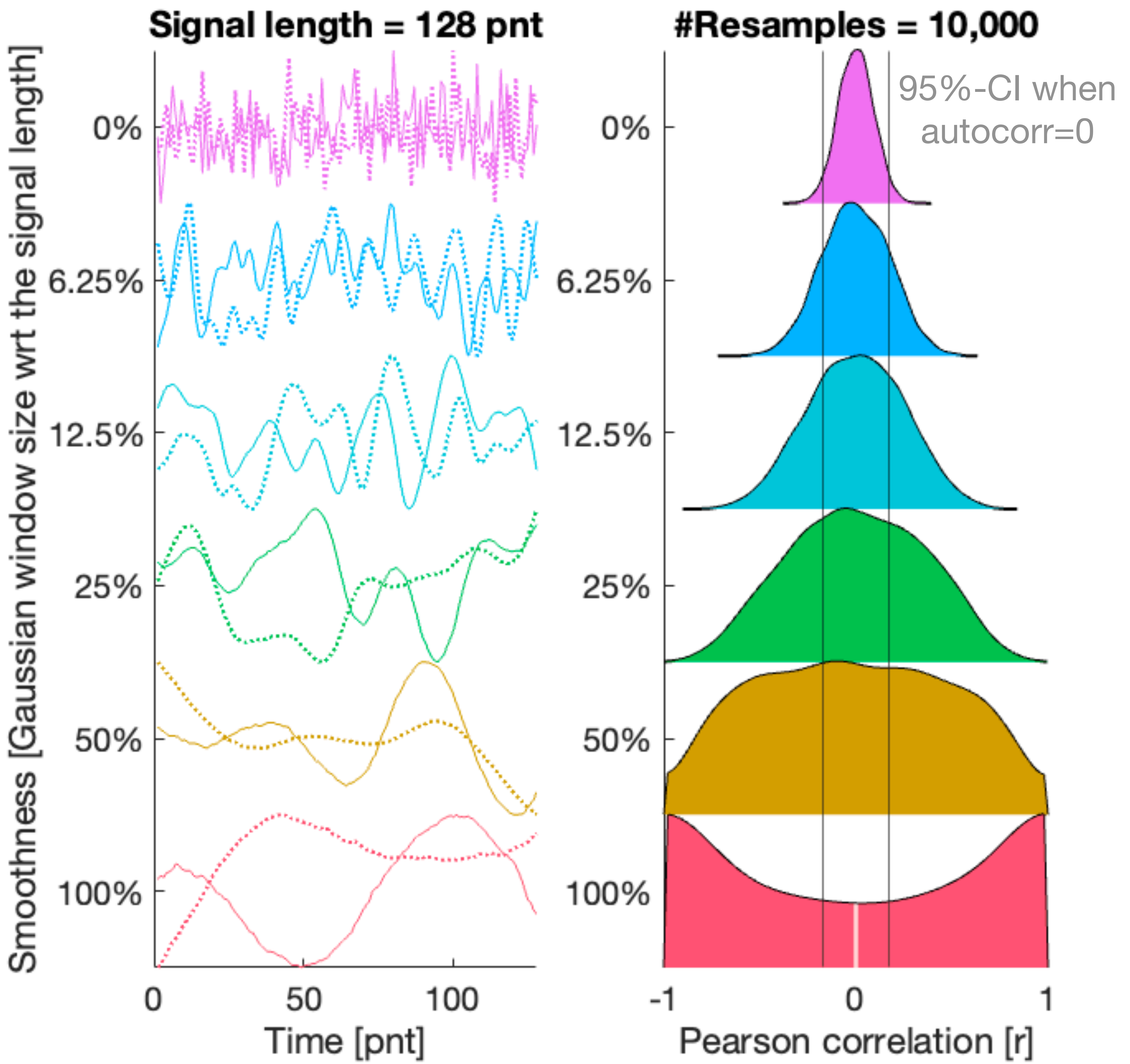
https://www.tylervigen.com/spurious-correlations

MAX PLANCK INSTITUTE FOR EMPIRICAL AESTHETICS

Statistical inference

Tests for time series

- Many **time series** look alike (i.e., spurious correlation) due to auto/serial-correlation.
- **Non-parametric statistical tests are feasible for any arbitrary noise distribution** with "proper" null (surrogate) data.
- Explicitly estimation autocorrelation from finite (non-infinite) data is hard.
- Preserving the dependency structure (e.g., serial/spatial, ...) is rather easy.
- For a signed time series, simply randomizing its polarity (sign-flipping) would preserve serial correlation structure.



Proposed pipeline

Time-resolved intersubject correlation

- Stationarization of non-stationary time series
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- Statistical inference with sign-flipping

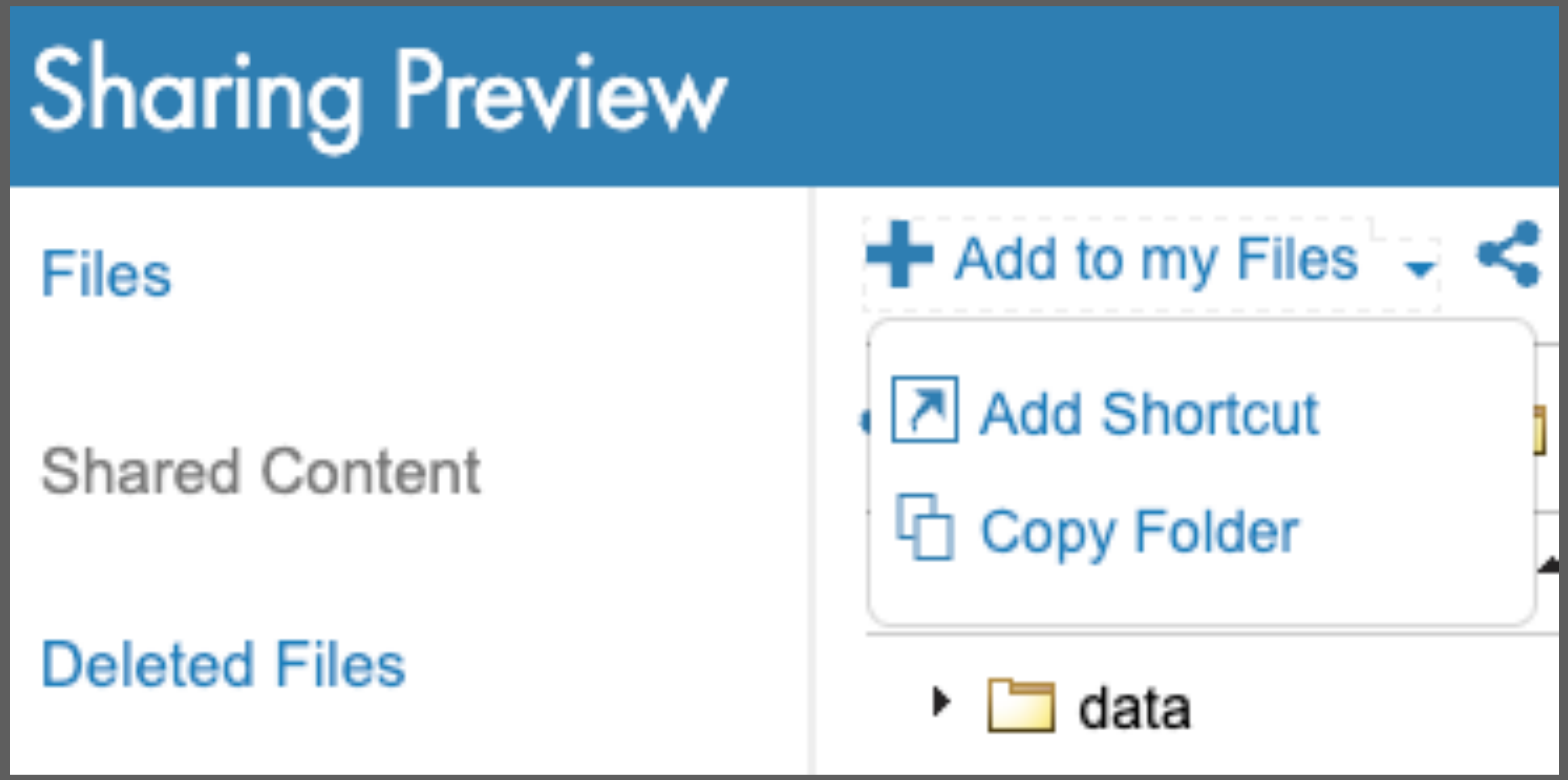
MATLAB ONLINE

How to add the SHARED drive to your account

1. log in https://MATLAB.mathworks.com

2. Scan the T-rex or click on the share link [https://drive.mathworks.com/sharing/1f26fcd8-c113-4efc-8f07-f7b480b4b74d]

3. Clink on "Add to my Files" and "Copy Folder"



(Would we have time for this?)

Linearized Encoding Analysis (LEA👧)

- **Extracting music features**
- Preprocessing of non-stationary time series
- **Modeling neural delays using finite impulse response**
- **Ridge regression with cross-validation**
- Statistical inference with smooth time series
- https://seunggookim.github.io/teaching/teach_w_ksmpc24/

Summary of the session

Music, Brain, and Emotions 🎶🧠😀😥

- Music may evoke intense emotions while the underlying mechanisms remain unclear.
- Behavioral/physiological responses to **naturalistic music** can be analyzed using novel methods and computational models.
- **Deep phenotyping** of musical emotions may help to better understand how musical information is transformed to evoke emotions.

Resources

https://github.com/seunggookim/mpscog-ca25-mbe

https://seunggookim.github.io/

Thank you for your attention and participation! 😎