Introduction to EEG Decoding for Music Information Retrieval Research

INTER-SUBJECT CORRELATIONS

Inter-Subject Correlations (ISCs)

- **Synchrony** of cortical responses has been found to index focused engagement with narrative works.
  - Engaging content will drive the subjective experiences of audience members in a similar fashion.
  - An engaged audience will experience and process content in a similar fashion.
  - Engagement may be measureable through brain activity.

- In a state of focused attention, the brain response will be driven more by **exogenous** factors (the stimulus) by endogenous factors → greater correlation of audience members' cortical responses → higher ISCs

Inter-Subject Correlations (ISCs)

- Early studies (fMRI)
  - Hasson et al. (2004)[1]
    - Participants viewed naturalistic audiovisual stimuli (film excerpts)
    - Correlating voxel-wise time series across participant pairs
    - ISCs were higher during emotionally arousing film scenes
  - Hasson et al. (2008):[2] A proposed field of "Neurocinematics"
  - ISCs provide a truly **data-driven** approach to data analysis
    - Facilitates use of complex, naturalistic stimuli
    - Do not need to know in advance where to look (as is the case with event-related analyses)

[1] Hasson et al. (2004). *Science*. [2] Hasson et al. (2008). *Projections.*

Cortical Measures of Engagement

- Electroencephalography (EEG)
  - + Non-invasive, low expense to operate
  - + Millisecond-scale temporal resolution
  - - Activity recorded at the scalp is spatially smoothed
  - - **Low SNR (-20 dB)**
  - - **Conventional EEG analyses rely upon averaging and require tens or hundreds of stimulus presentations**
  - - **Not conducive to studying audience engagement with full-length naturalistic works**

Reliable Components Analysis (RCA)[1]

- Spatial filtering technique for EEG
- Computes linear weighting of electrodes to maximize correlation of data records in time
- Given two data matrices $X_1 \in \mathbb{R}^{M \times N}$ and $X_2 \in \mathbb{R}^{M \times N}$,
- RCA computes a spatial filter such that projected data

$$y_1 = X_1 w \quad \text{and} \quad y_2 = X_2 w$$

  are maximally correlated in time.
- Note: The X_i matrices are paired concatenations of single trials of data (see paper for details)

[1] Dmochowski et al. (2012). *Frontiers in Human Neuroscience*.

Reliable Components Analysis (RCA)[1]

- Formally, RCA maximizes the Pearson Product Moment Correlation Coefficient

$$\hat{w} = \arg\max_{w} \frac{y_1^T y_2}{\|y_1\| \, \|y_2\|}$$

  which reduces to an eigenvalue equation.
- Thus, multiple reliable components (RCs) are computed, in descending order of reliability explained.

[1] Dmochowski et al. (2012). *Frontiers in Human Neuroscience*.

Reliable Components Analysis (RCA)[1]

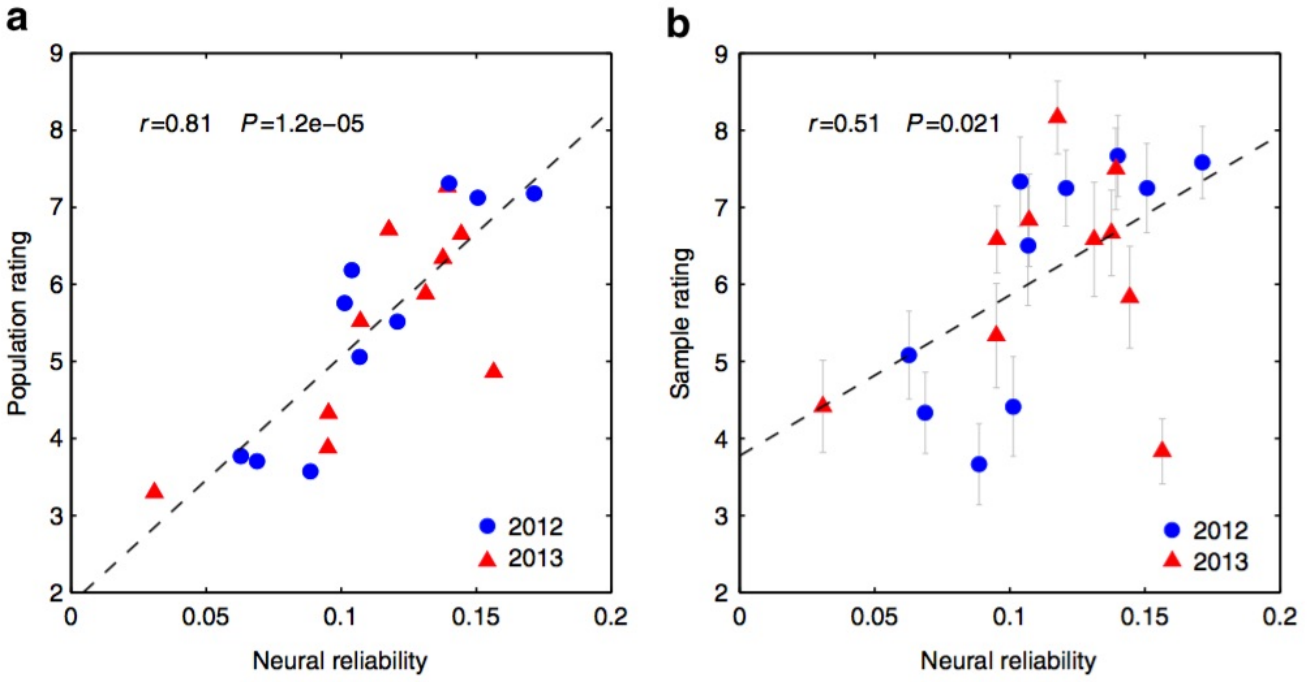
- Publicly available Matlab implementation.[2]
- Returns a number of variables
  - Weight matrix W
  - Data, projected from electrode space to component (RC) space
  - Forward-model matrix A (derived from W), used for plotting topographies of components
- We can look at the projected **topography** of the component, and compute **ISCs** from the component-space EEG data.

[1] Dmochowski et al. (2012). *Frontiers in Human Neuroscience*. [2] Dmochowski (2014). GitHub.

EEG-ISC studies using RCA

Dmochowski et al. (2014)[1]

- Participants (N=12) watched SuperBowl television ads and rated them
- Neural reliability correlates more highly with Facebook voting results (r = 0.81) than with ratings delivered by study participants (r = 0.51)!



[1] Dmochowski et al. (2014). *Nature Communications*. Figure used with permission.

EEG-ISC studies using RCA

- Important: RCA method efficiently transforms EEG data to component space.
- Enables analysis of responses to full-length, naturalistic stimuli in a single-presentation experimental paradigm!

EEG-ISCs in a Musical Setting

- Introduce state-of-the-art EEG analysis technique for the first time to the study of music
- What do RCs for responses to music look like? Are they contingent on musical structure?
- Do periods of heightened cortical synchrony correspond to salient musical events?
- Validate a method for quantifying engagement in the context of music

Participants and Procedure

- 16 stimuli
  - Hindi pop songs (popular yet novel, foreign language, easy-to-grasp musical structure, steady beat)
  - 4 songs x 4 conditions: Original, reversed, measure shuffled, phase scrambled
- 48 participants
  - 18-35 years of age
  - variety of musical backgrounds
  - No Hindi experience
- 12 participants assigned to each stimulus.
- ISCs use pairwise comparisons:
  12 choose 2 → effective sample size of 66
- 128-channel EEG recorded while participants listened attentively to stimuli
- Assigned stimuli presented twice

Kaneshiro (2016). Doctoral Dissertation.

Stimuli

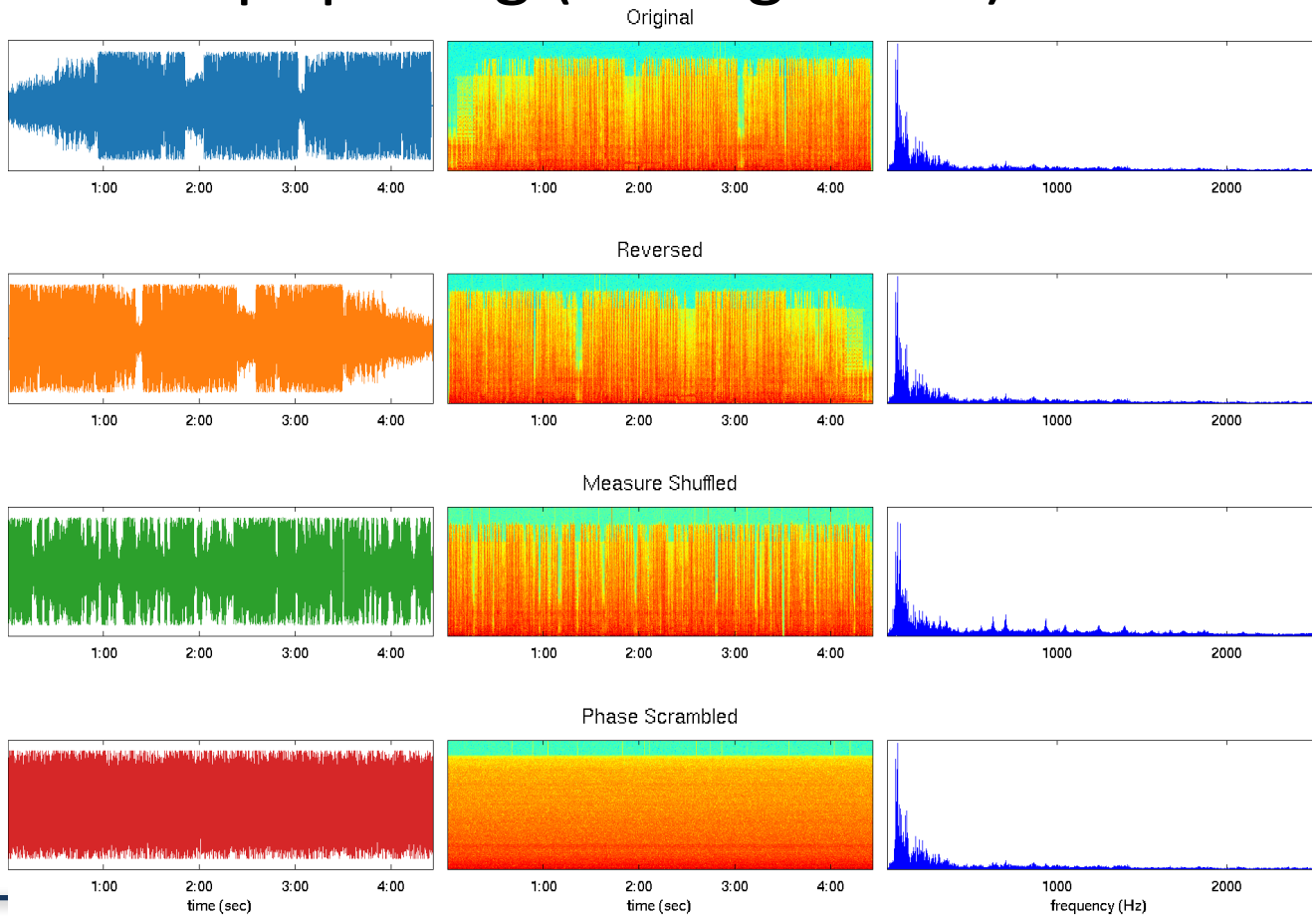
- 4 versions of Hindi pop song (4 songs total):

Original

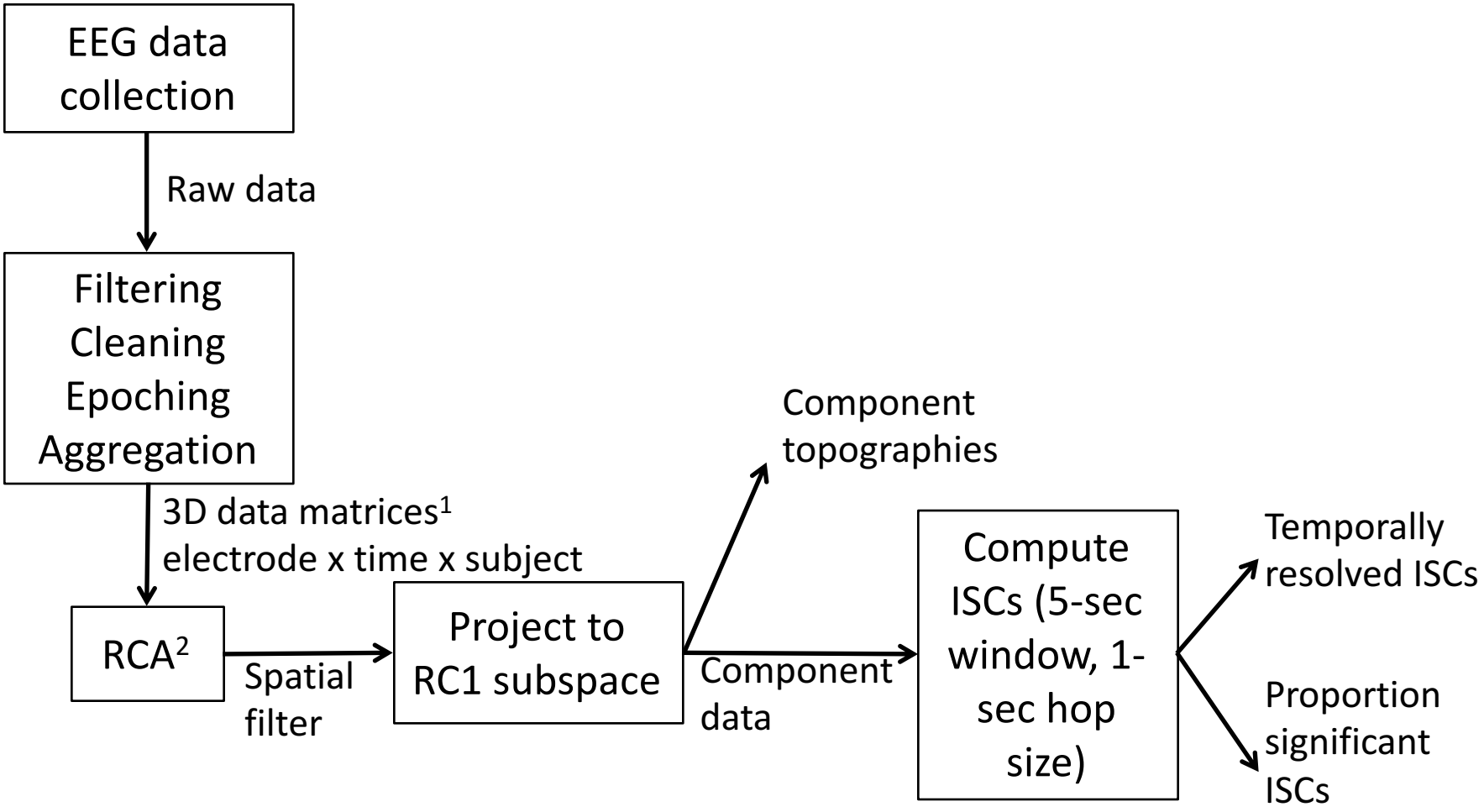
Reversed

Measure shuffled

Phase scrambled



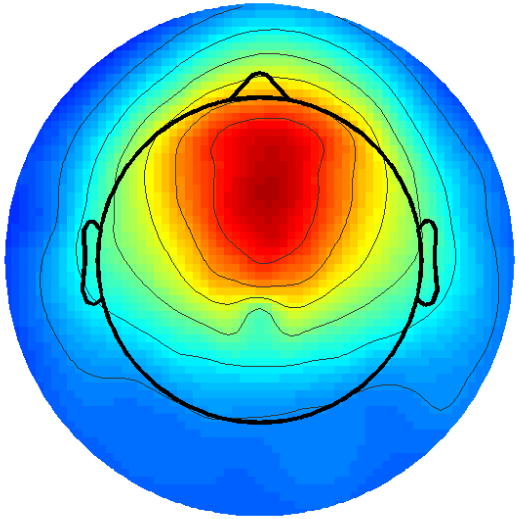
Analysis



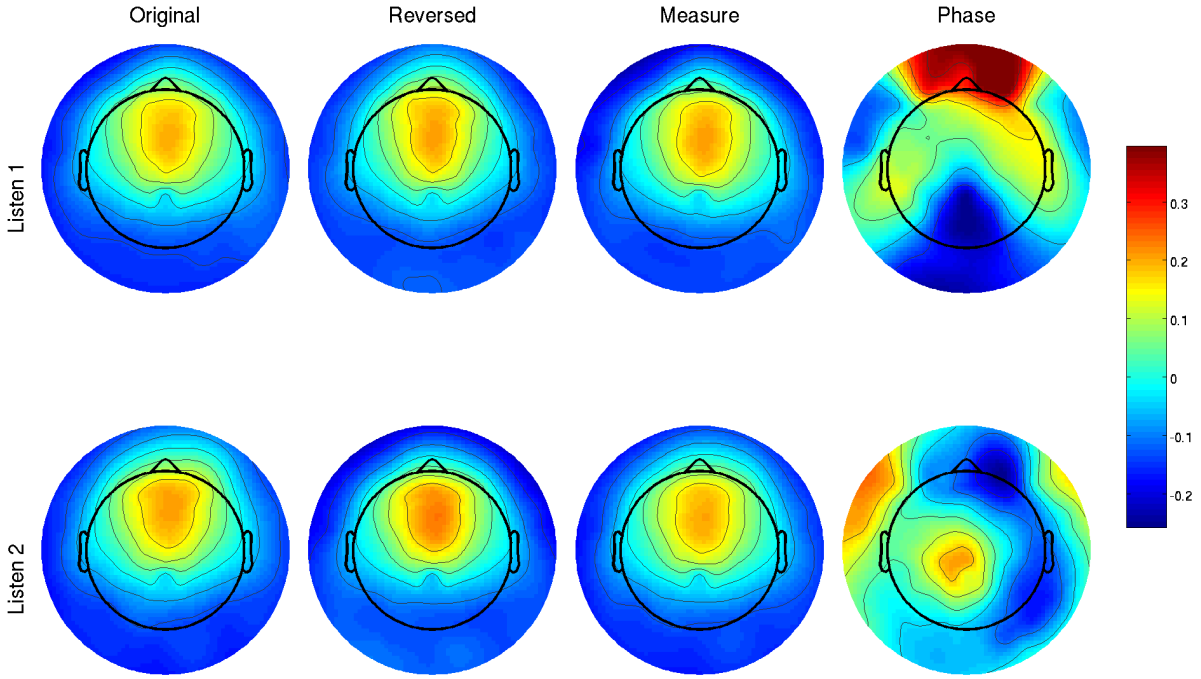
[1] Kaneshiro et al. (2016). Stanford Digital Repository. [2] Dmochowski (2014). GitHub.

RC1 Topographies

RCA over all data

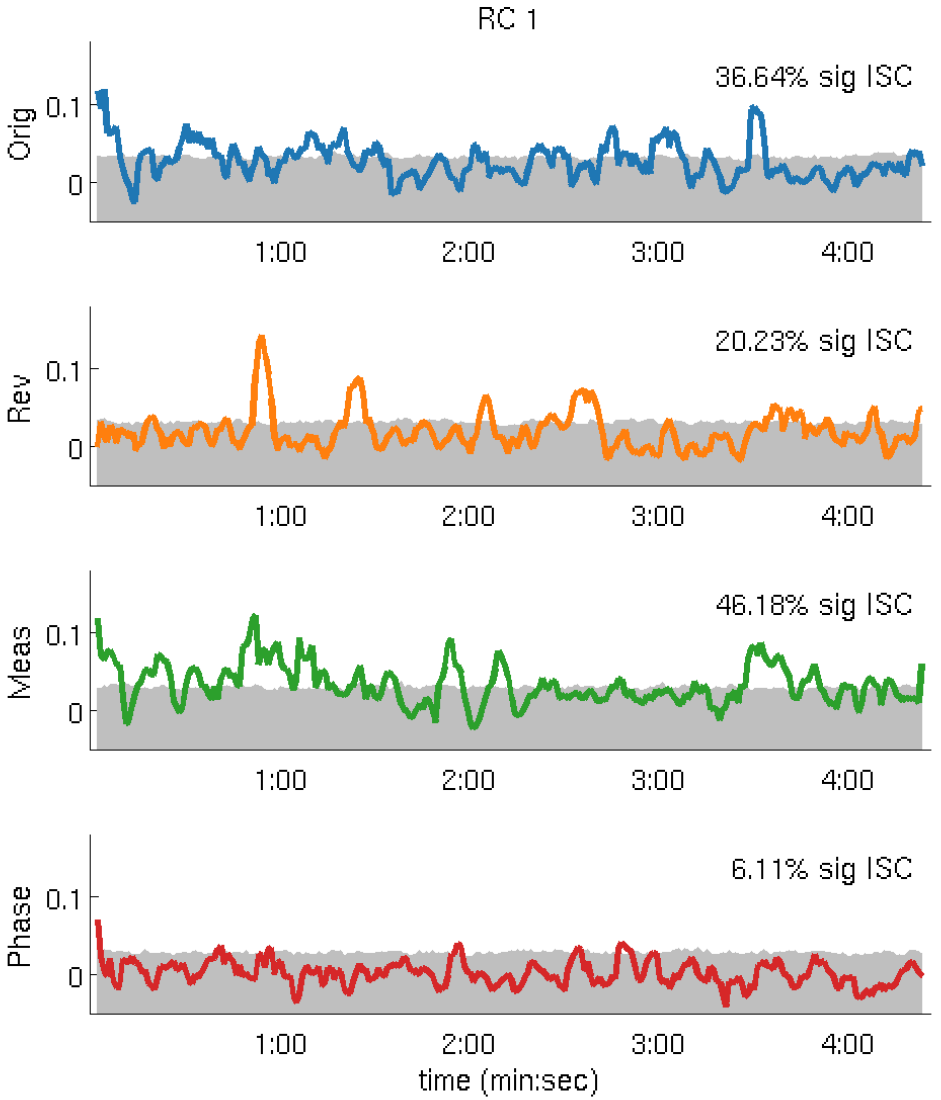


Separate RCA for each stimulus condition and listen

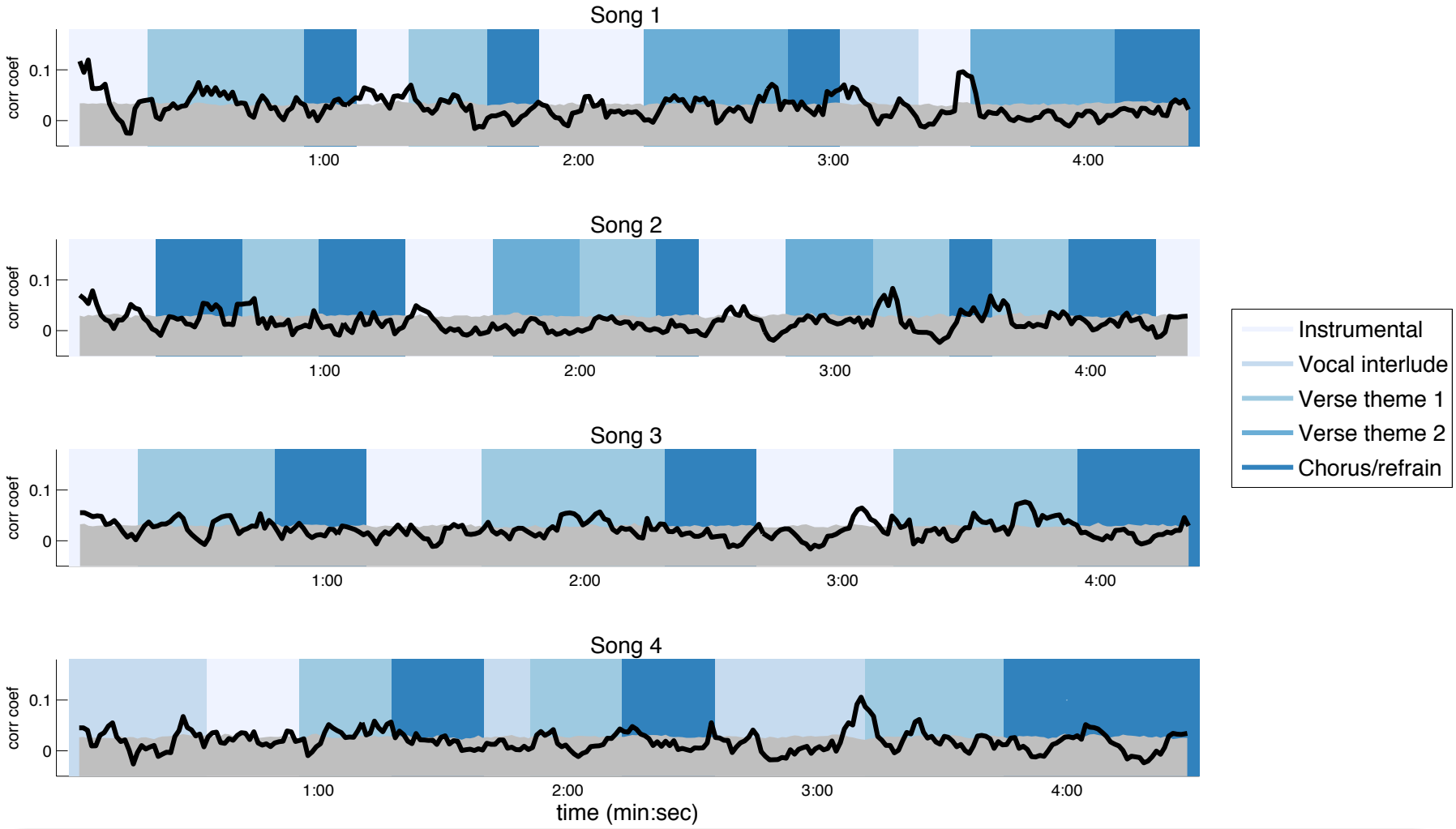


ISCs for Intact vs Control Stimuli

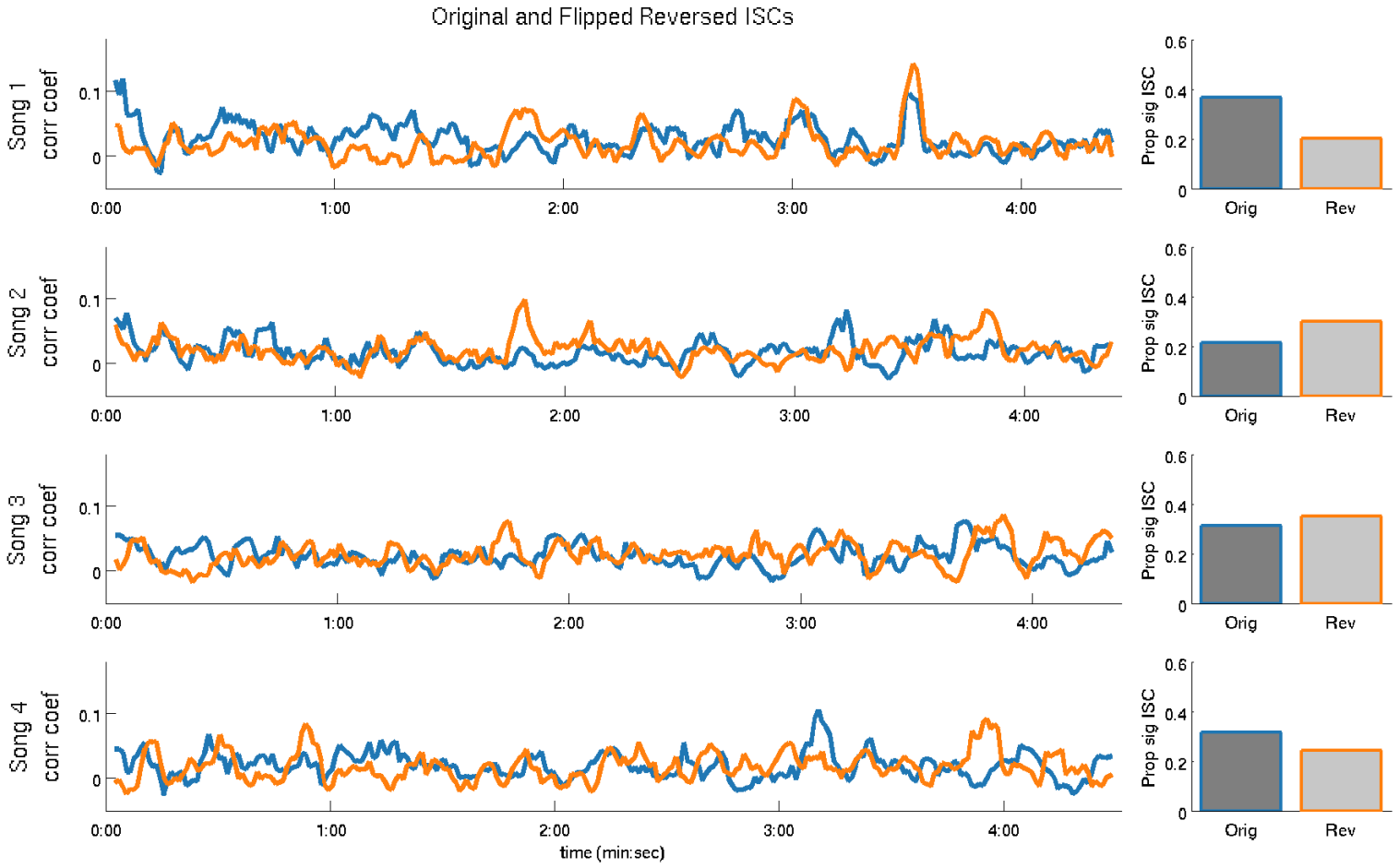
- ISCs are higher for the stimulus conditions that retained musical structure.
- Phase-scrambled always produces lowest proportion of significant ISCs
- Measure-shuffled always produces highest proportion of significant ISCs



Temporally Resolved ISCs



Forward vs Flipped Reversed ISCs

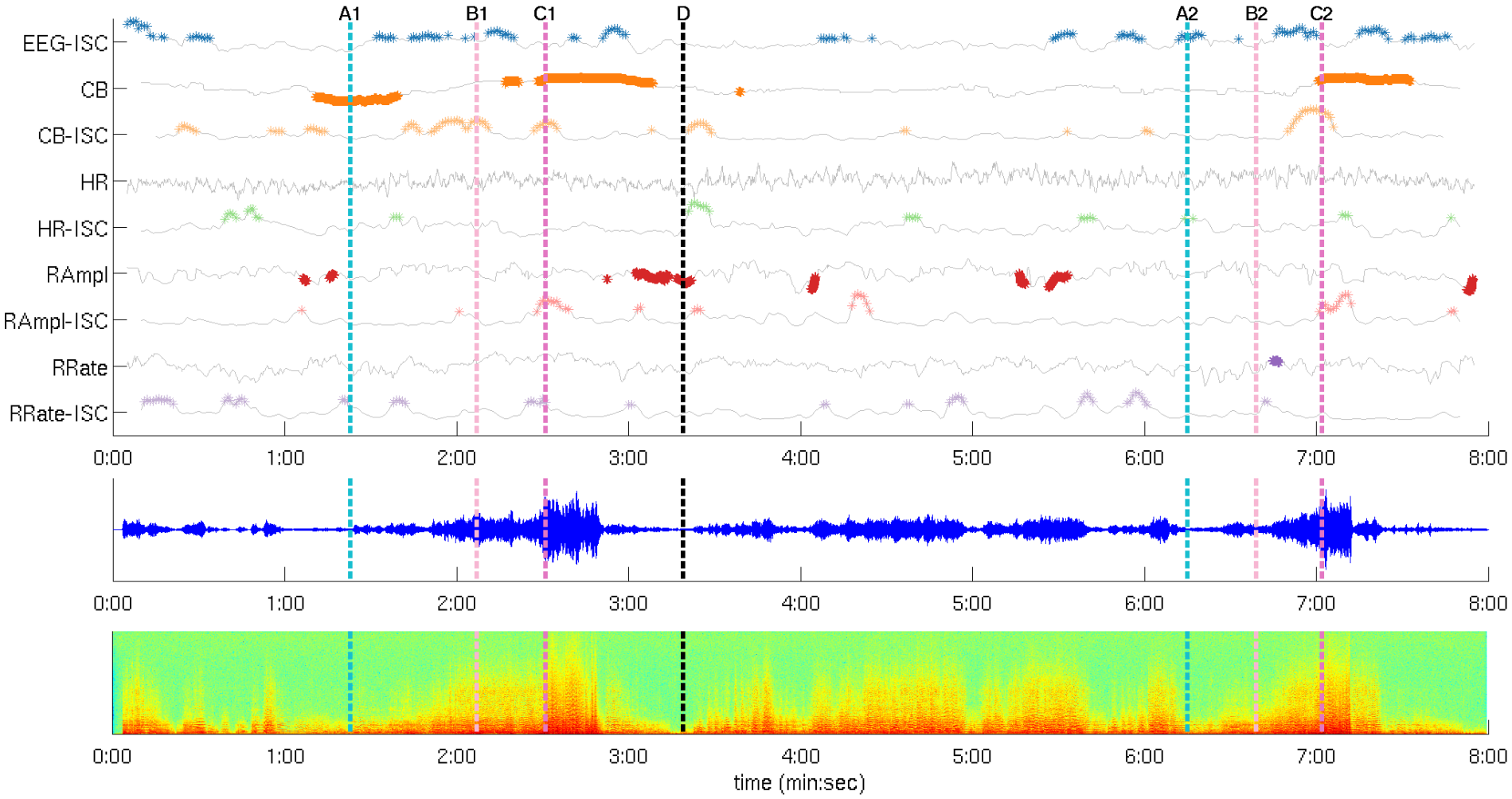


A New Paradigm for Music EEG Research

- ISCs index the ability of a stimulus to **reliably** evoke a response in an audience – thought to reflect a state of focused engagement
- Enables use of full-length, naturalistic stimuli
- RCA permits a **truly** single-presentation EEG paradigm
- Temporal resolution of EEG allows response to be mapped back to specific stimulus events
- Can be compared to behavioral ratings[1-3] and other continuous responses (physiological and behavioral[3])
- Findings have been shown to generalize to large-scale audience preferences[1]

[1] Dmochowski et al. (2014). *Nature Communications.* [2] Kaneshiro et al. (2016). Doctoral Dissertation. [3] Kaneshiro et al. (2016). ICMPC.

Ensemble EEG-ISCs with Physiology and Behavior



[1] Kaneshiro et al. (2016). ICMPC.