Cortical Encoding of Auditory Objects in the Cocktail Party Problem

Jonathan Z. Simon
University of Maryland

Ding & Simon, PNAS (2012)

Introduction

- Auditory Objects
- Magnetoencephalography (MEG)
- Decoding Neural Signals/Encoding Stimuli
- Cortical Representations of Auditory Objects I
- Cortical Representations of Auditory Objects II

Auditory Objects

- What is an Auditory Object?
  - Perceptual/Psychophysical Construct
  - Some Commonalities with Visual Objects
  - *I know it when I see it* vs. Formal Definition

Auditory Object Definition

- E. g., Griffiths & Warren
  - an object corresponds with something in the sensory world
  - information related to the object is separate from information related to the rest of the sensory world
  - abstracted so that object information can be generalized among particular sensory experiences in any one sensory domain

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

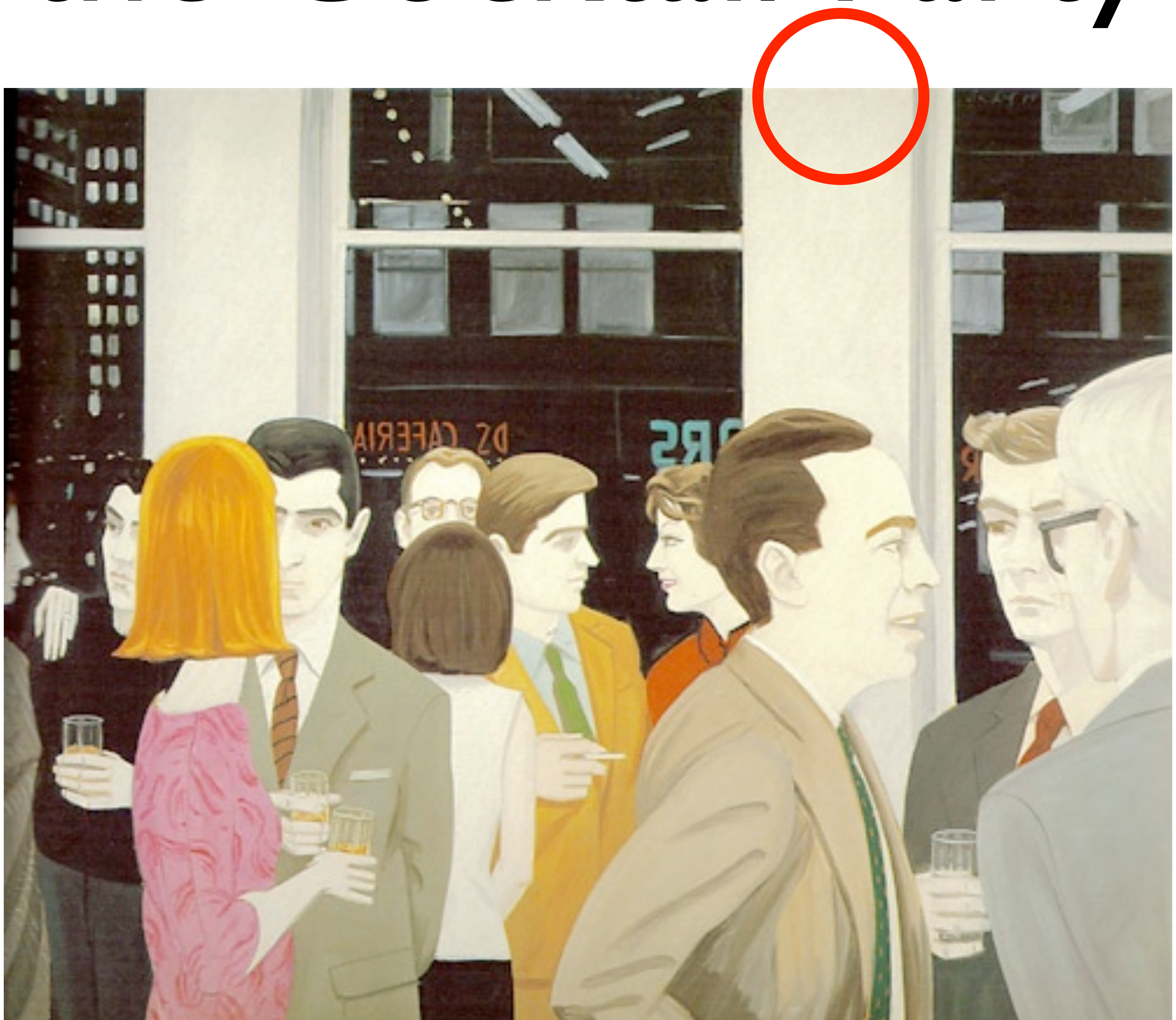
Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

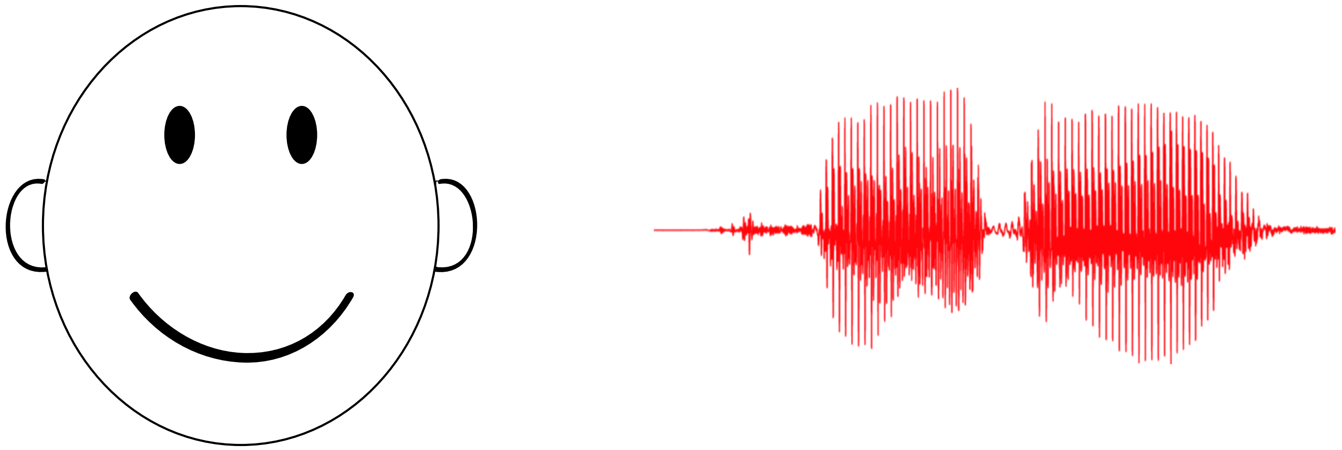


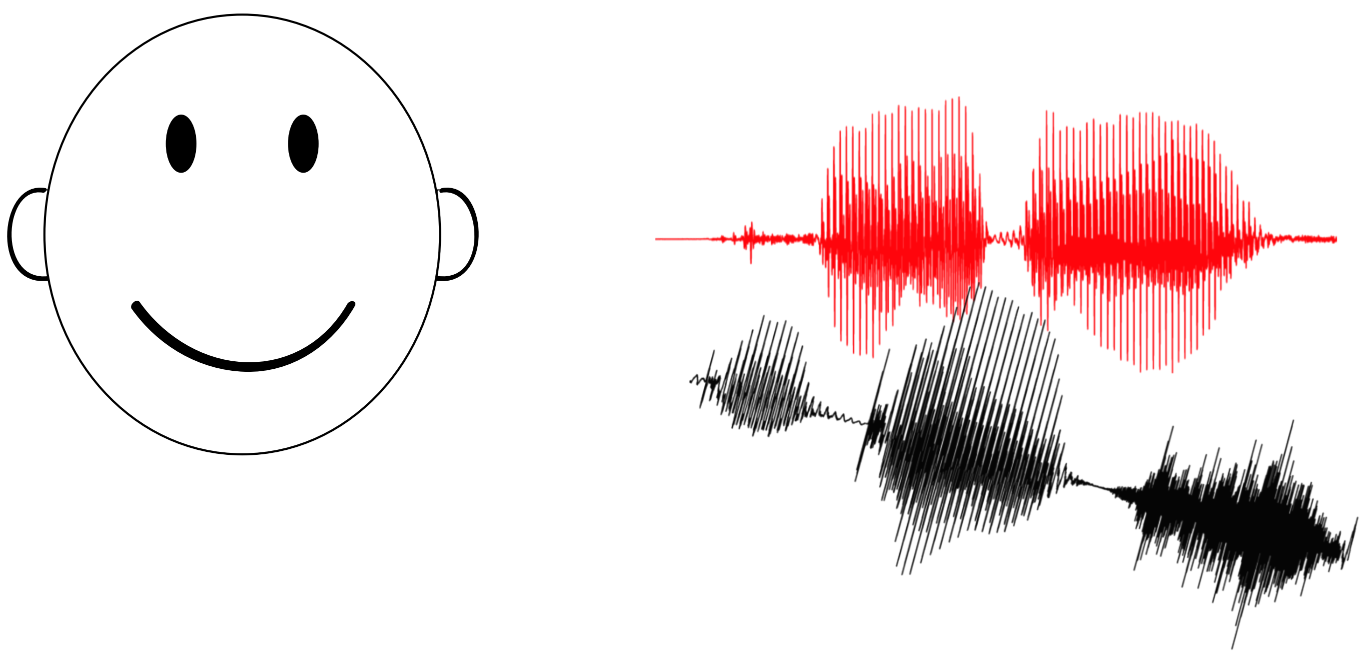
Alex Katz,
The Cocktail Party

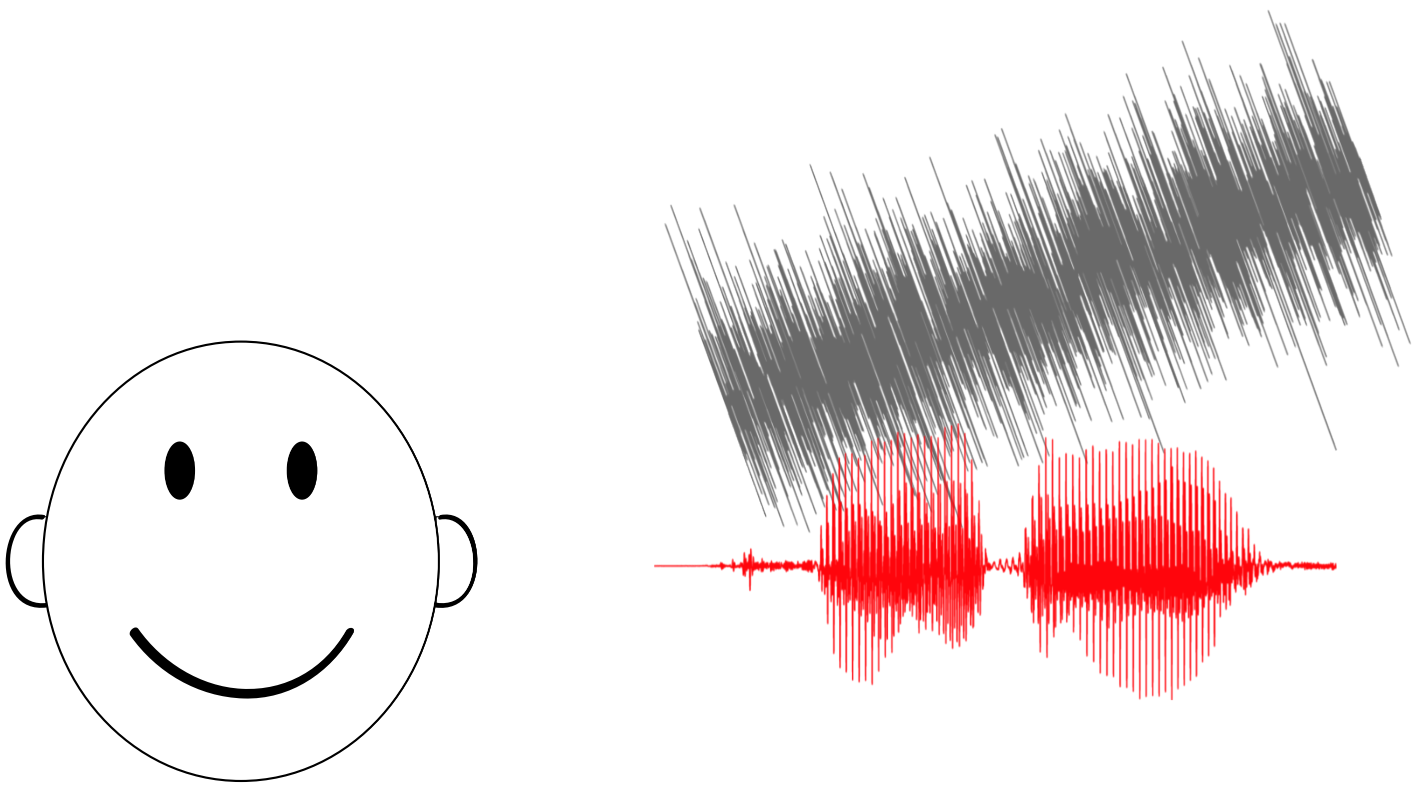
Auditory Objects at the Cocktail Party

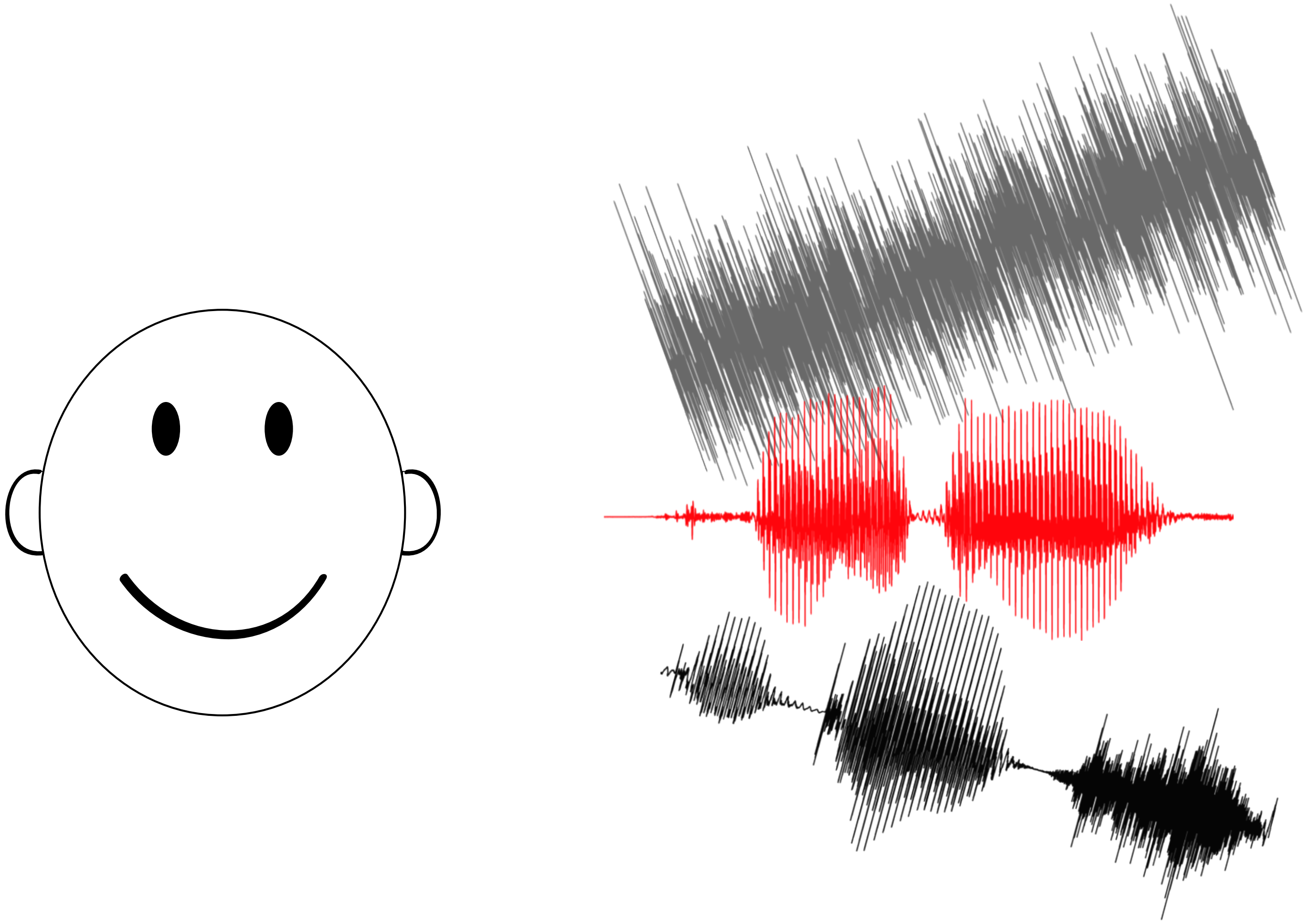
Alex Katz,
The Cocktail Party

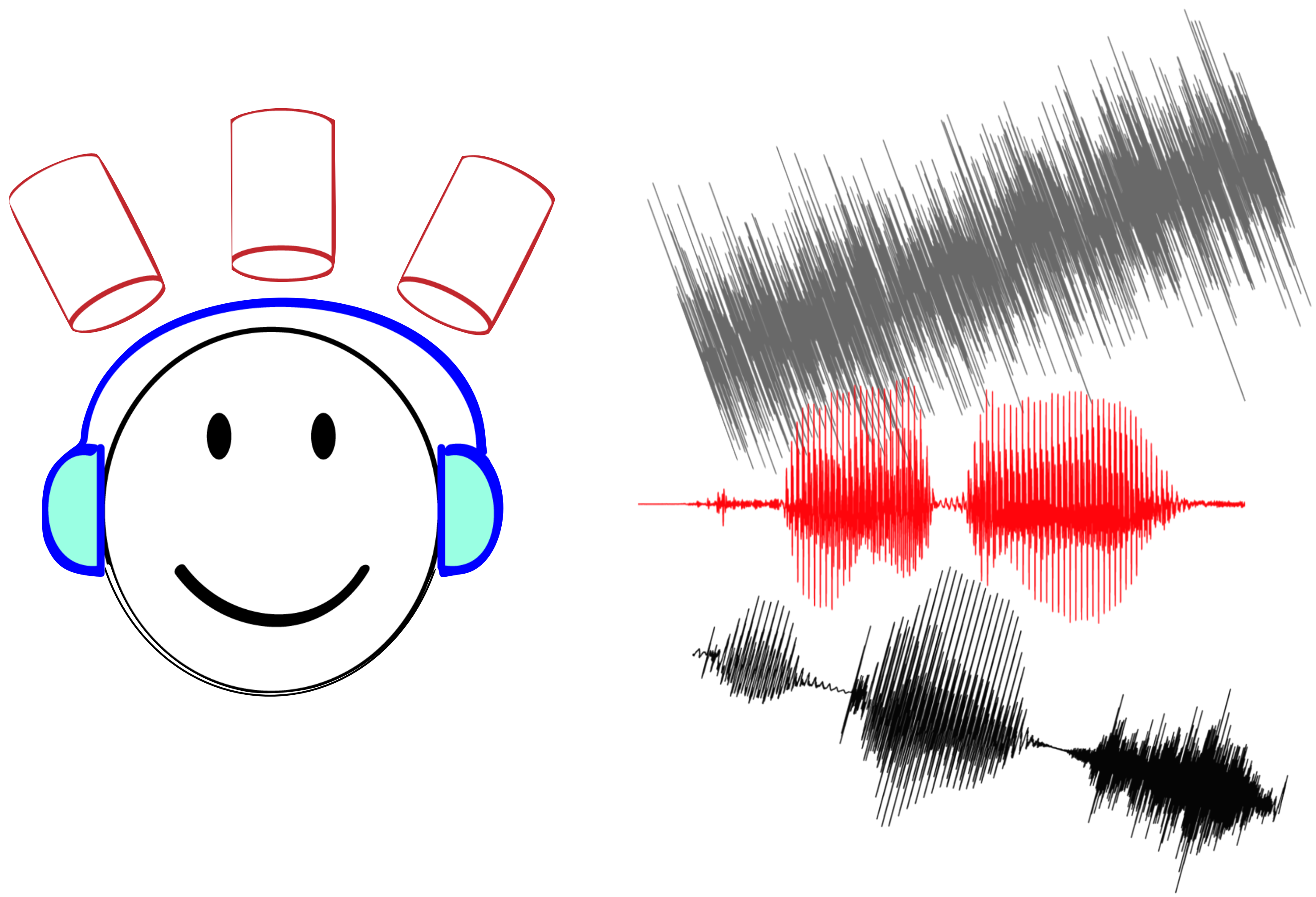
Auditory Objects at the Cocktail Party





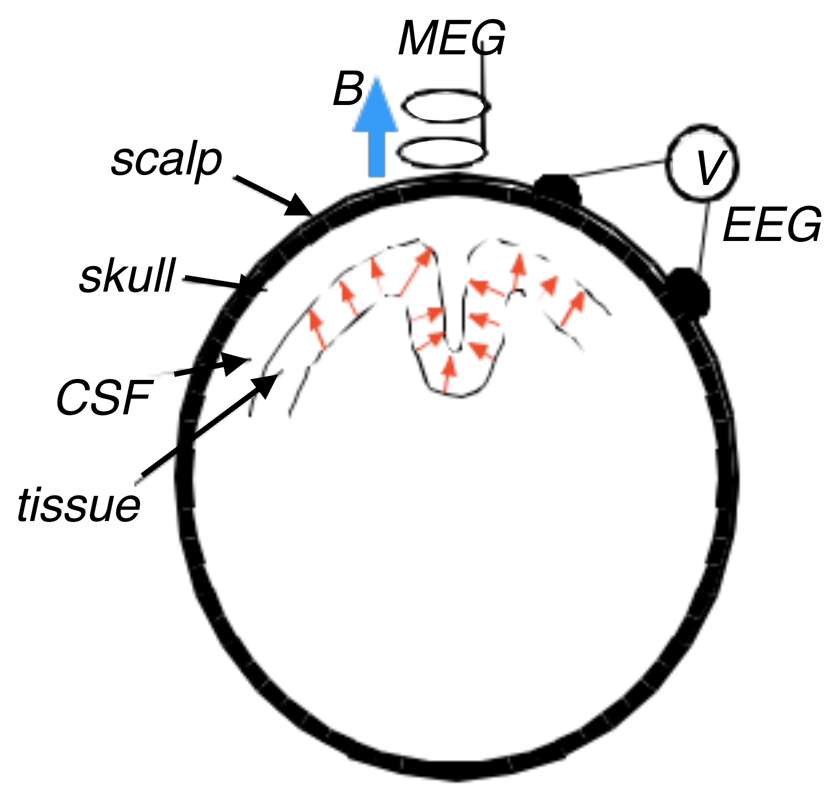


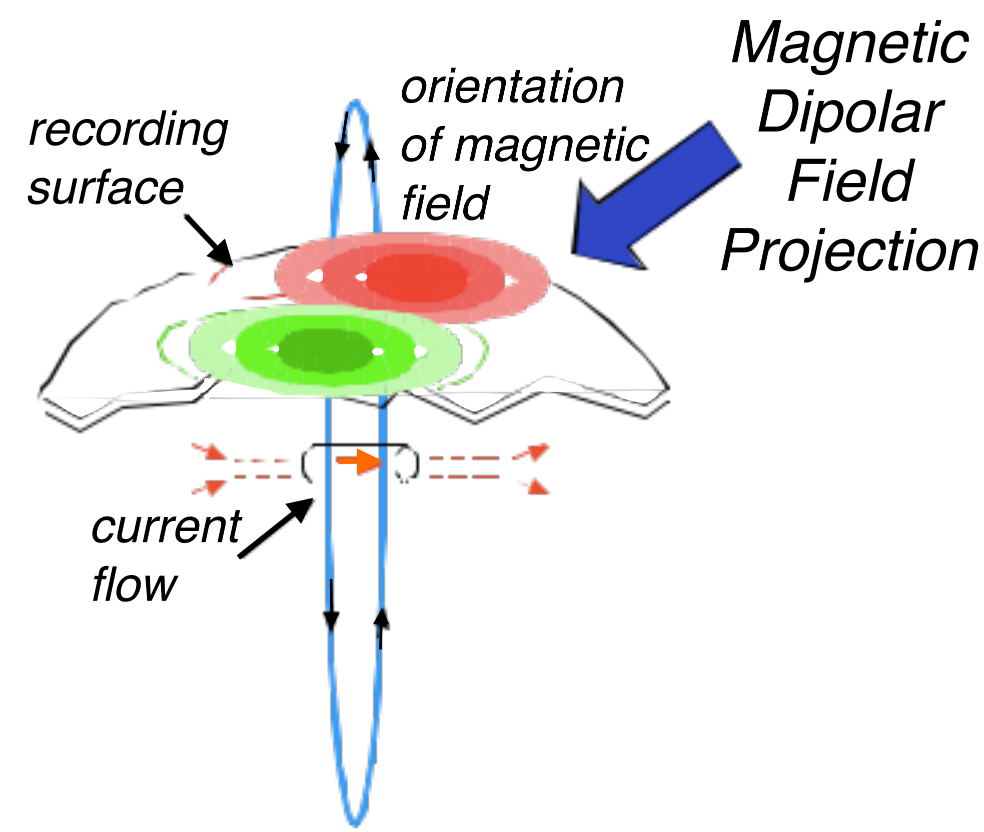




Magnetoencephalography (MEG)

Photo by Fritz Goro

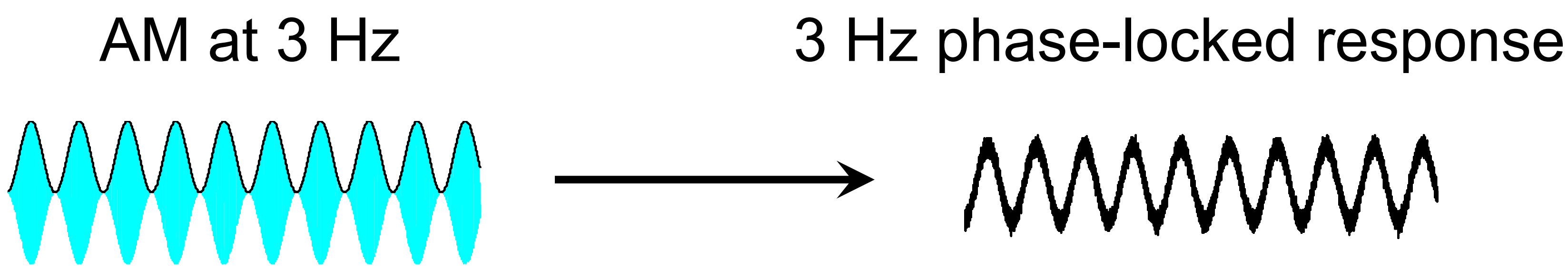




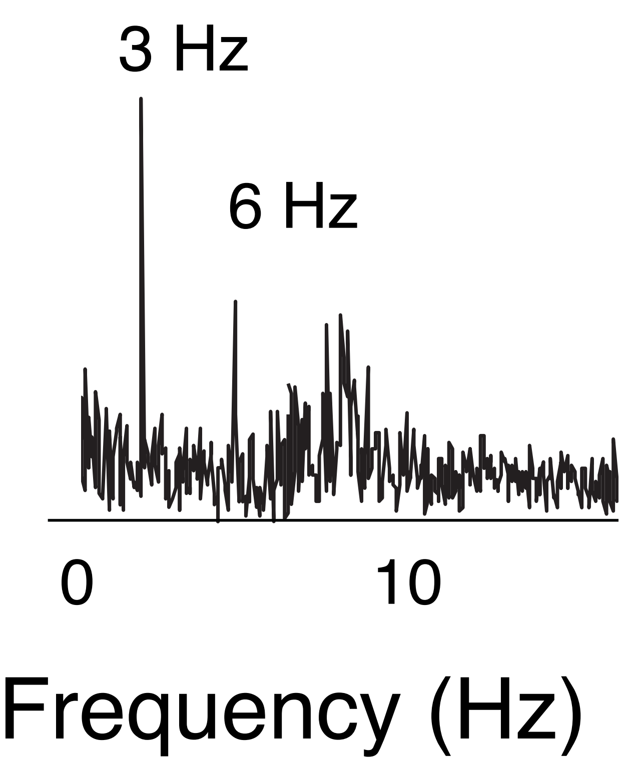
- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source

- Measures spatially synchronized cortical activity
- Fine temporal resolution (~ 1 ms)
- Moderate spatial resolution (~ 1 cm)

MEG Phase Locking to Slow Temporal Modulations



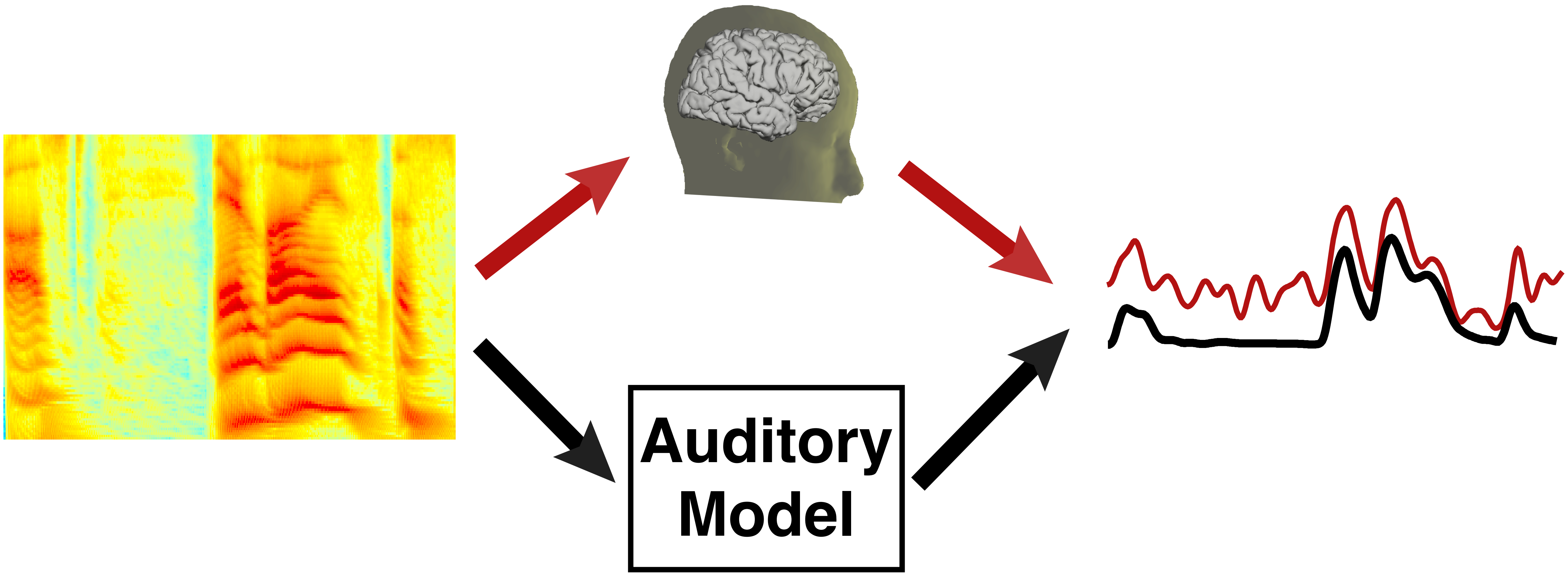
response spectrum (*subject R0747*)



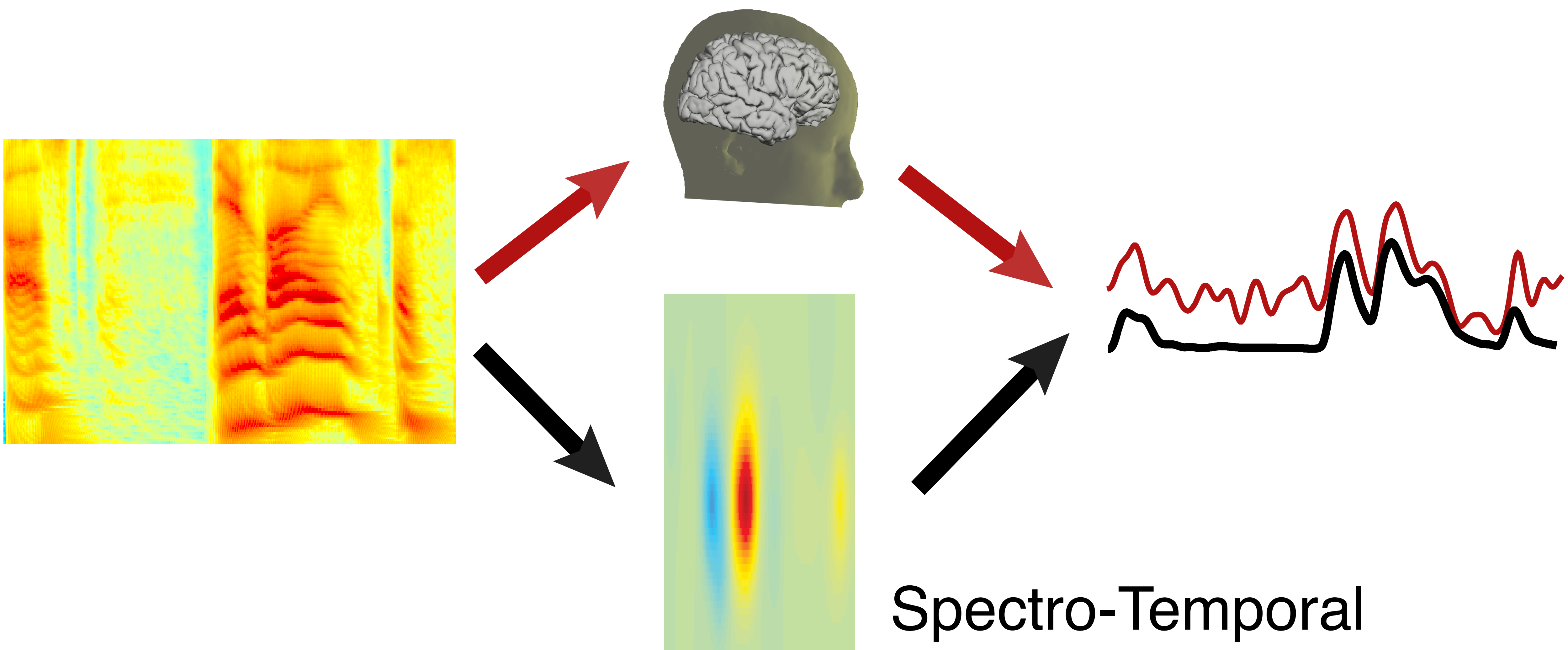
MEG activity is precisely phase-locked to temporal modulations of sound

Ding & Simon, J Neurophysiol (2009)
Wang et al., J Neurophysiol (2012)

Modeling MEG Response to Speech Modulations



Modeling MEG Response using STRF model

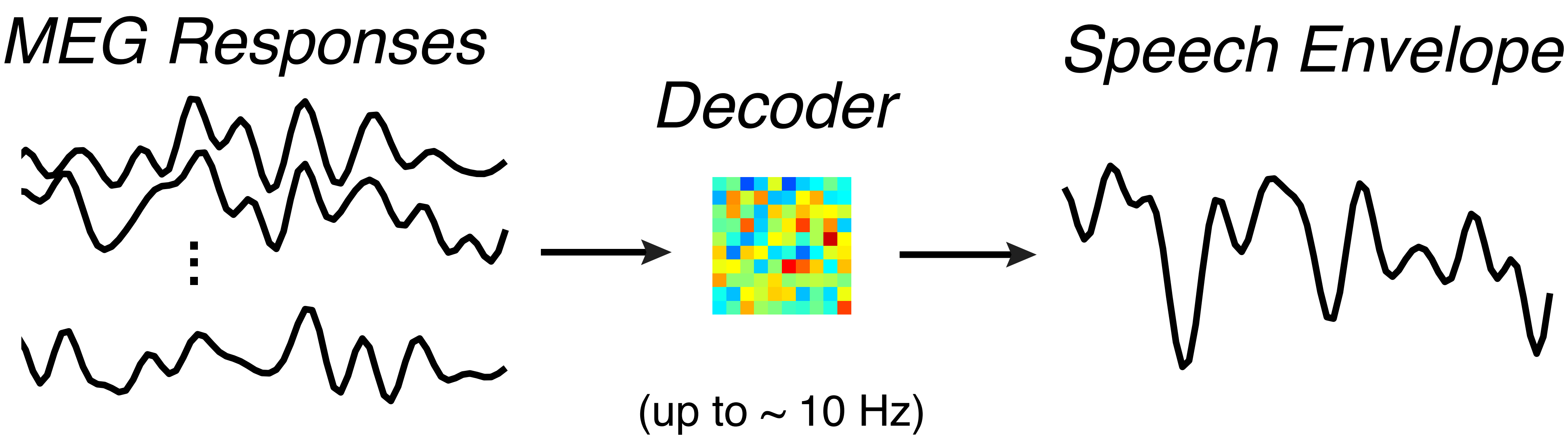


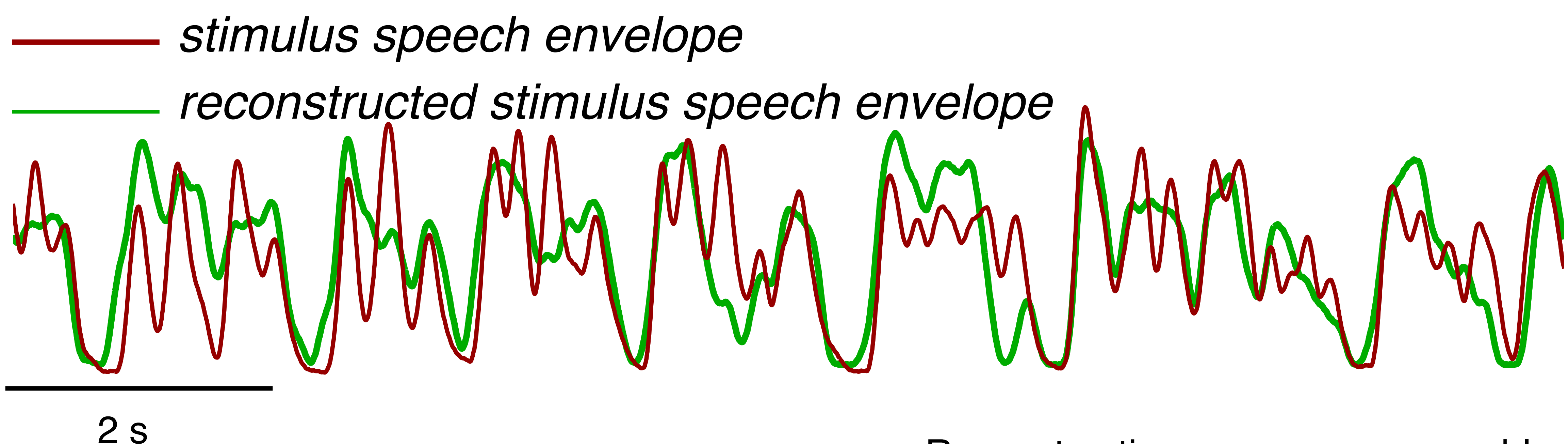
Spectro-Temporal Response Function (STRF)

Ding & Simon, J Neurophysiol (2012)

(up to ~ 10 Hz)

Neural Reconstruction of Speech Envelope





Reconstruction accuracy comparable to single unit recordings & ECoG

Ding & Simon, J Neurophysiol (2012)

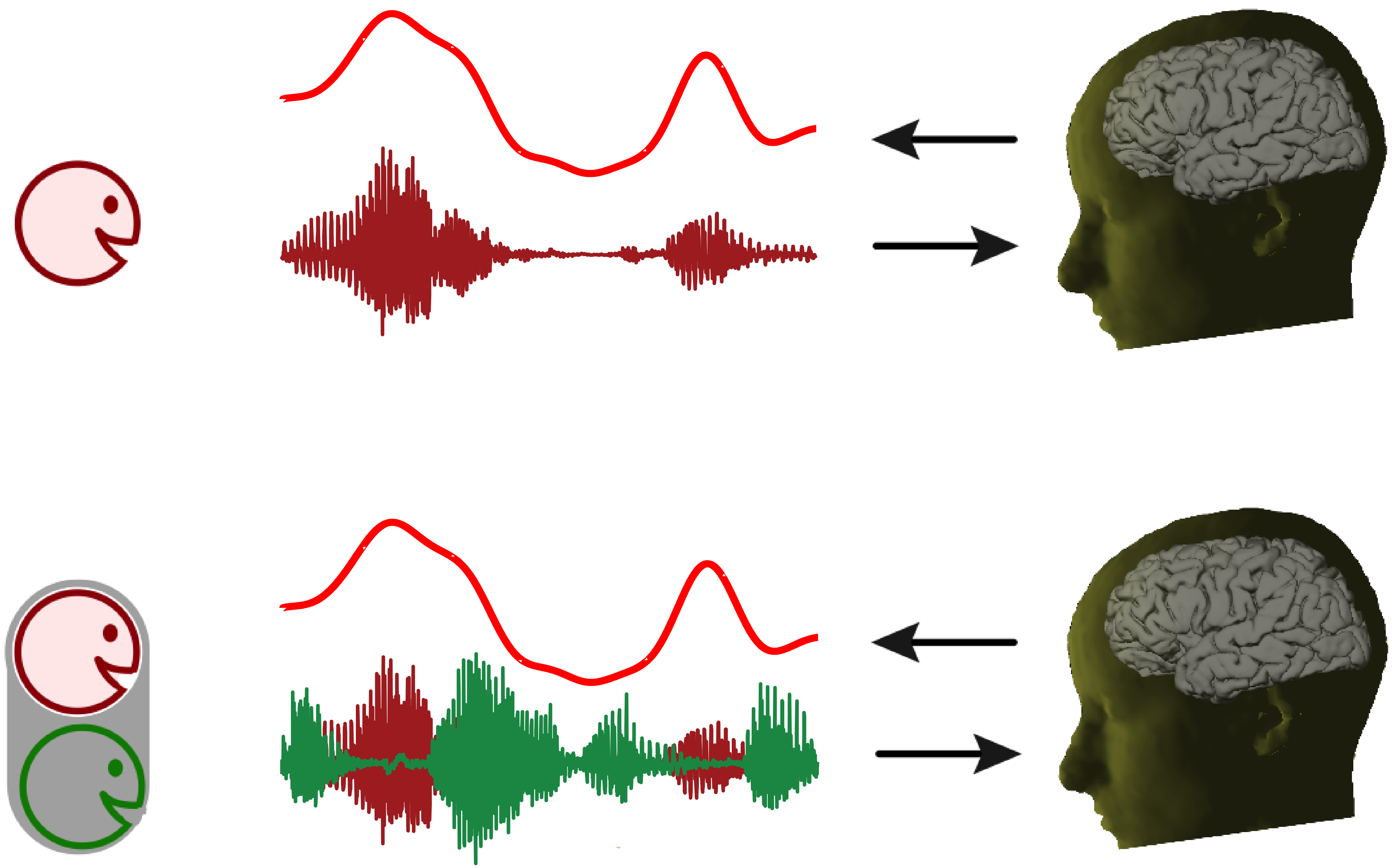
Speech Stream as an Auditory Object

- a speech stream corresponds with something in the sensory world
- information related to a speech stream is separate from information related to the rest of the sensory world, e.g. other speech streams or noise
- a speech stream is abstracted: it is generalized among different sensory experiences, e.g. different sound mixtures

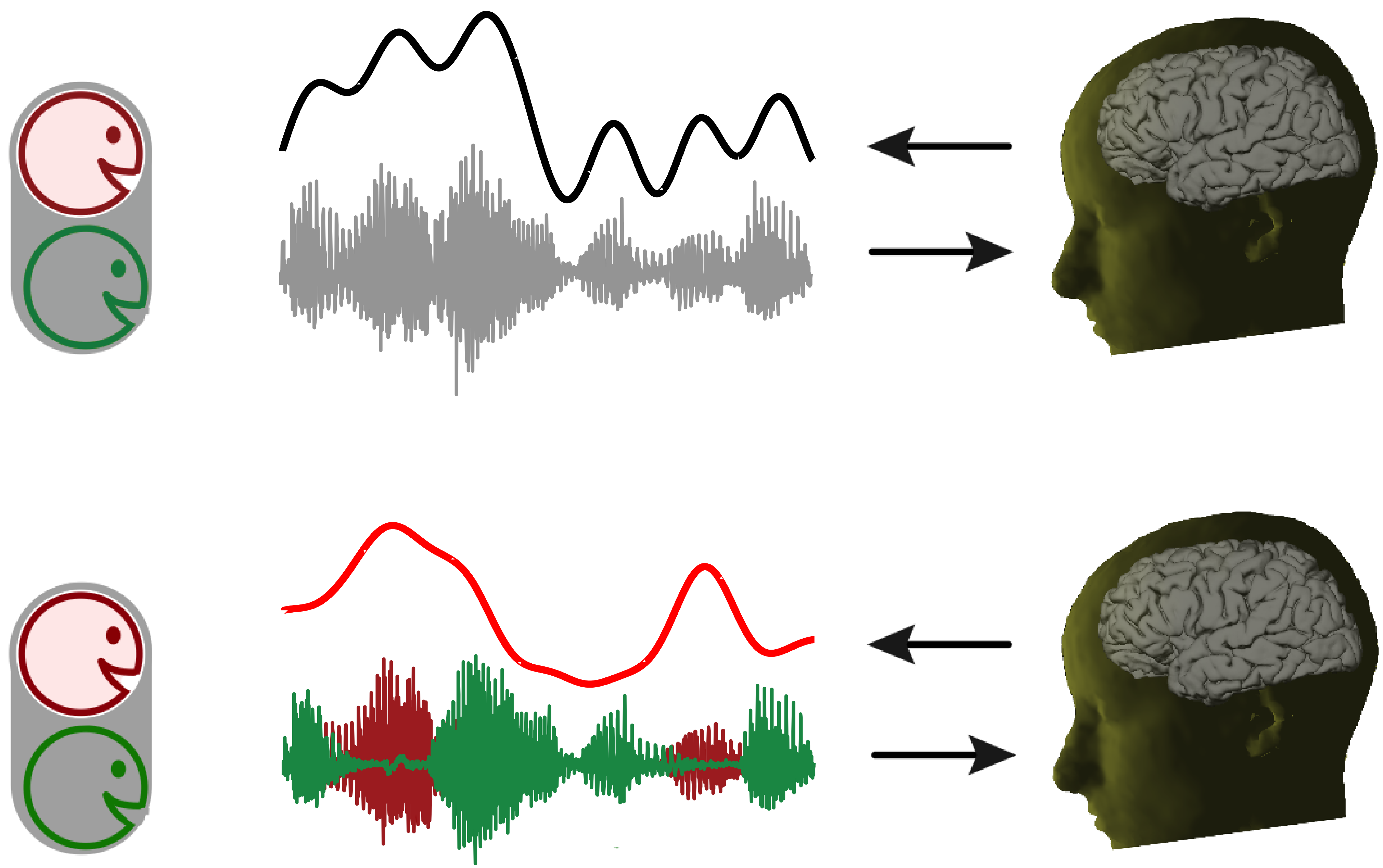
Neural Representation of an Auditory Object

- neural representation is of auditory object, something in sensory world
- when auditory object is with other sounds, the neural representation is of the auditory object, not the entire acoustic scene
- neural representation remains invariant under broad changes in acoustic representation of auditory object

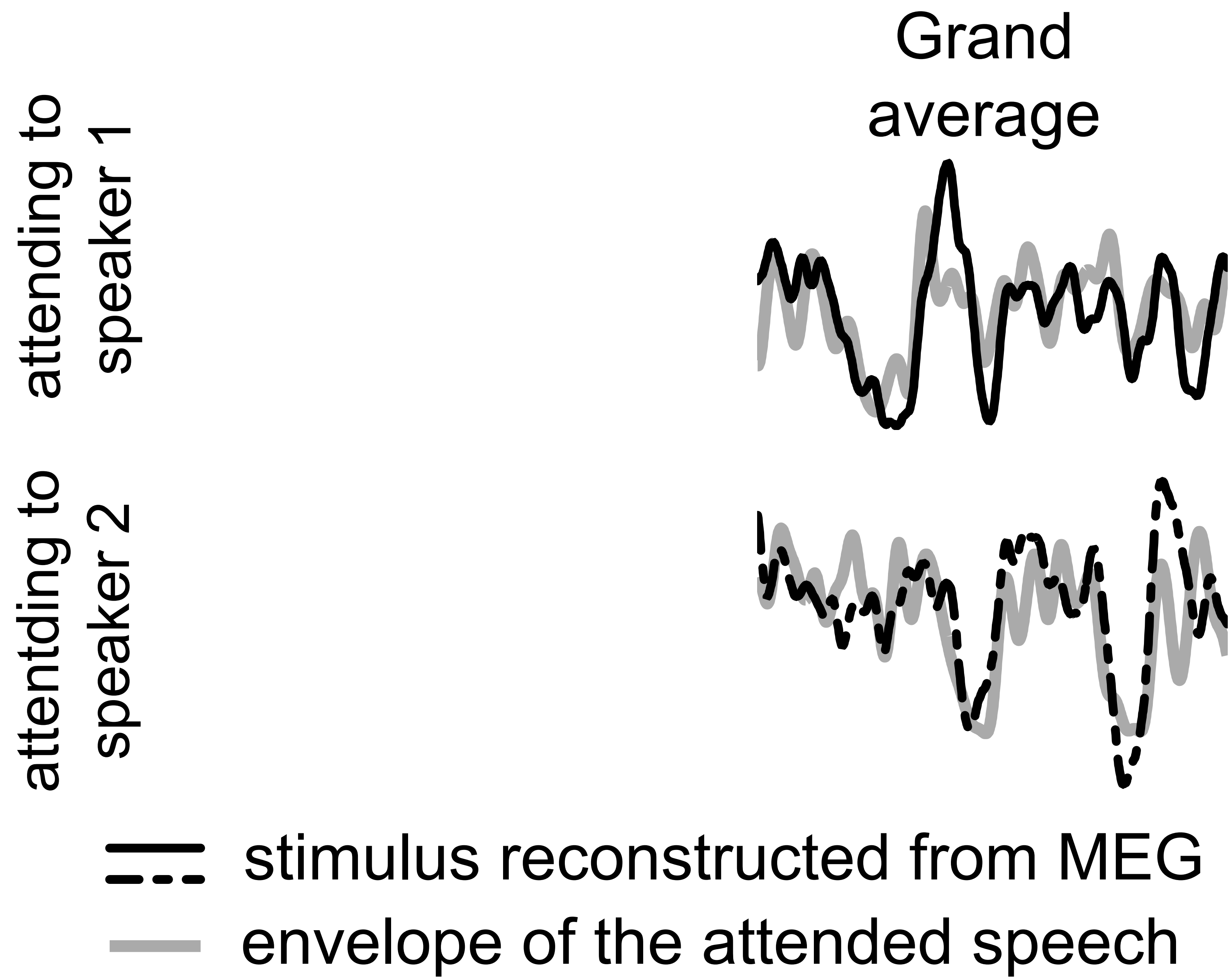
Selective Neural Encoding



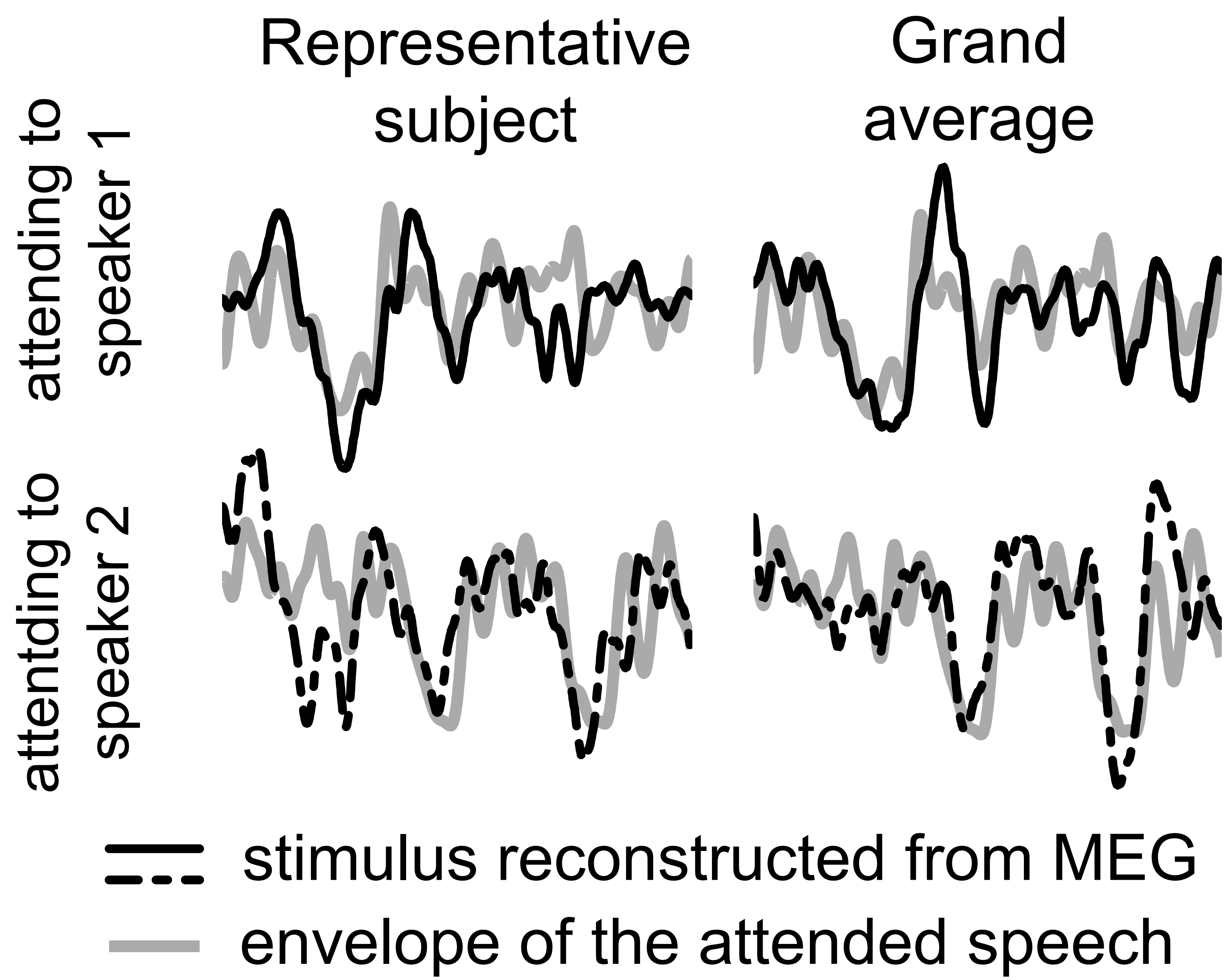
Unselective vs. Selective Neural Encoding



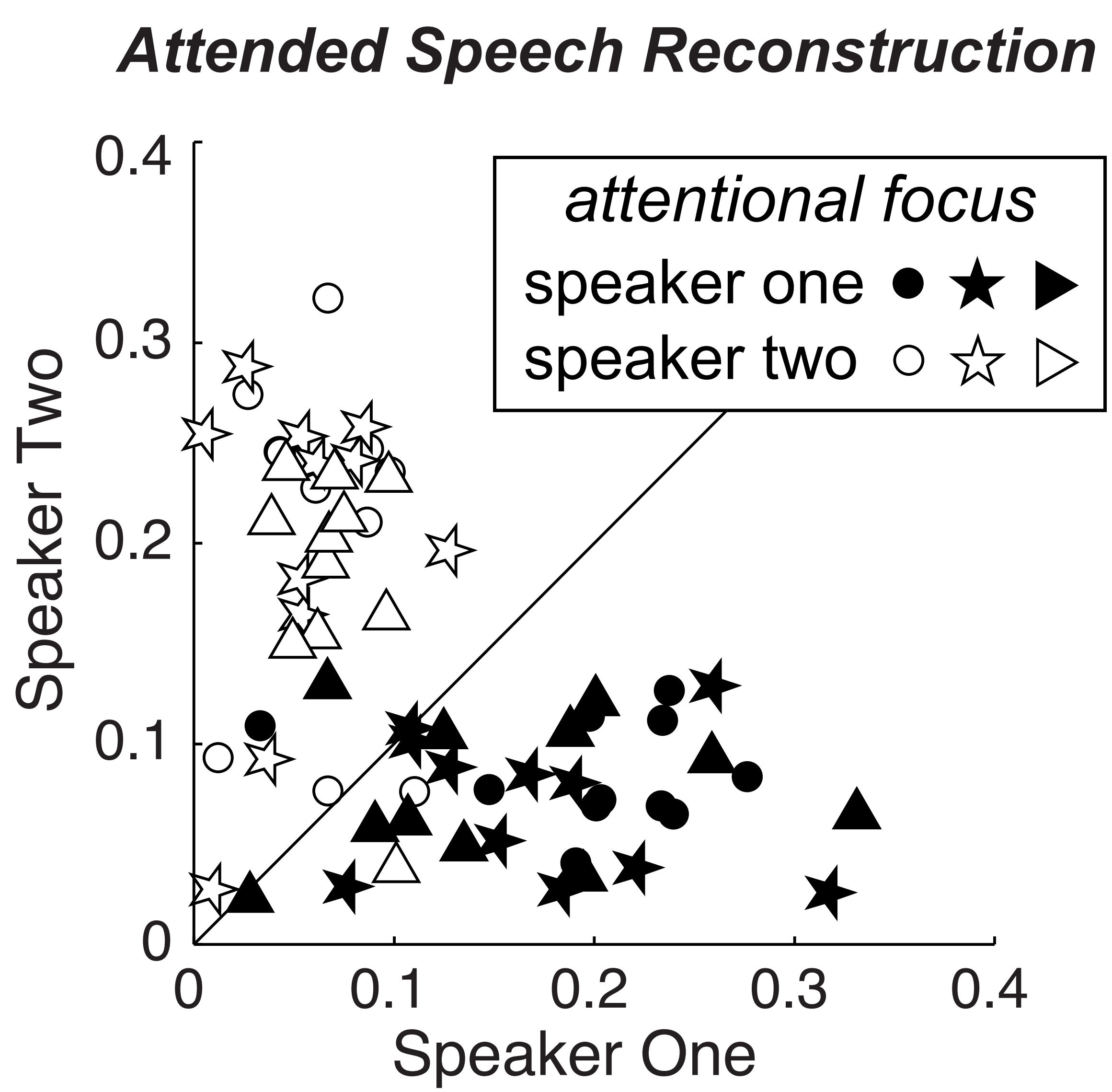
Auditory Object-Specific Representation



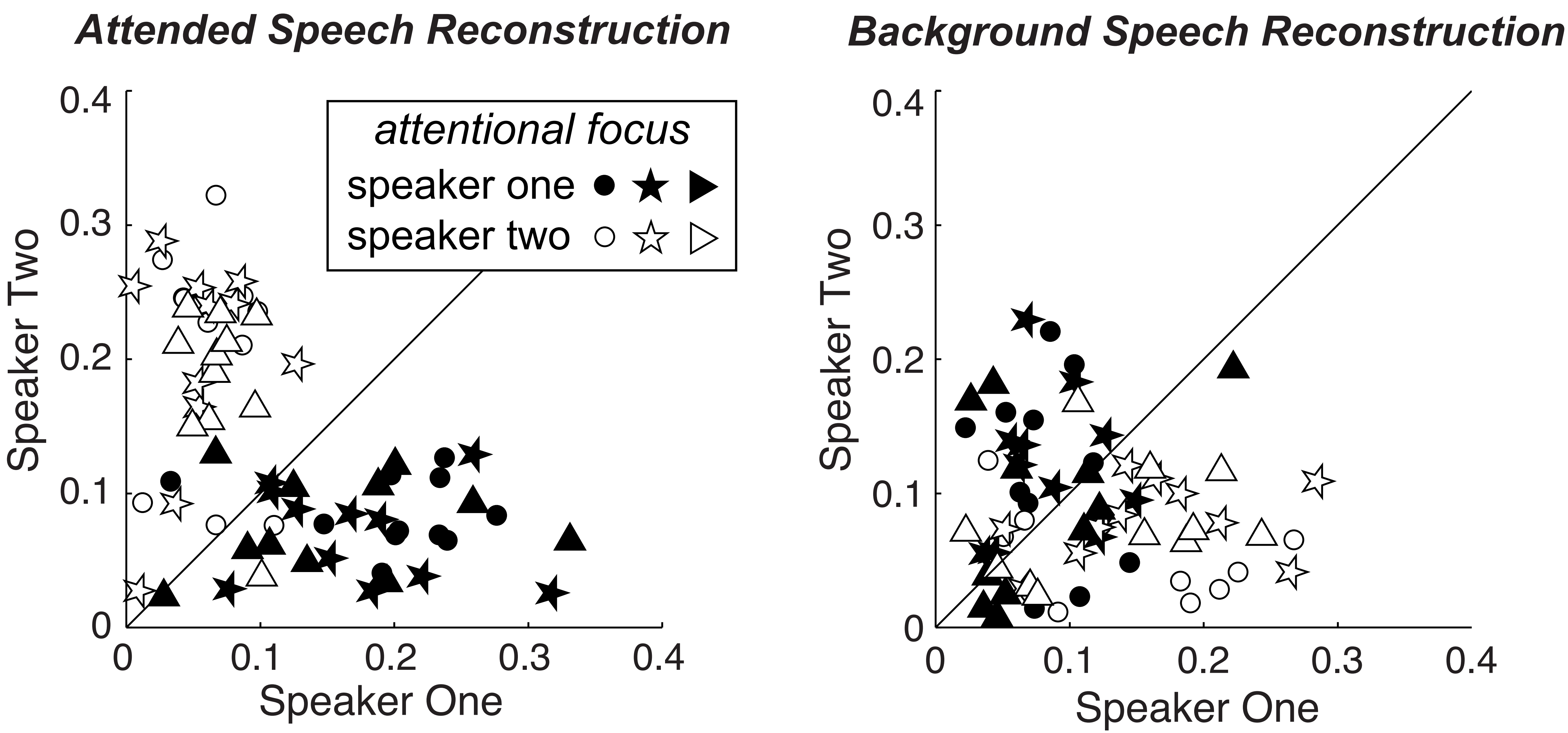
Auditory Object-Specific Representation



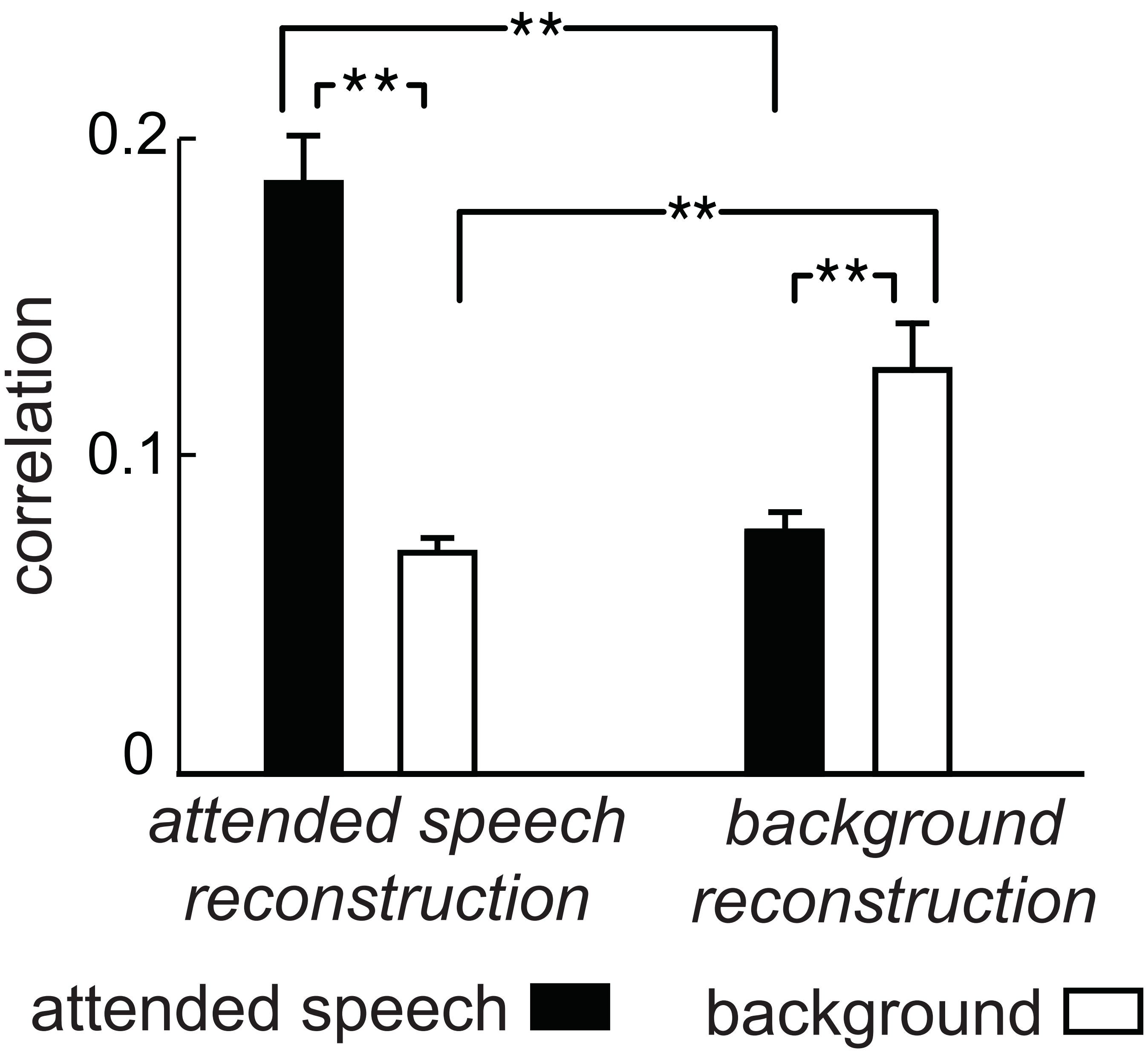
Single Trial Speech Reconstruction



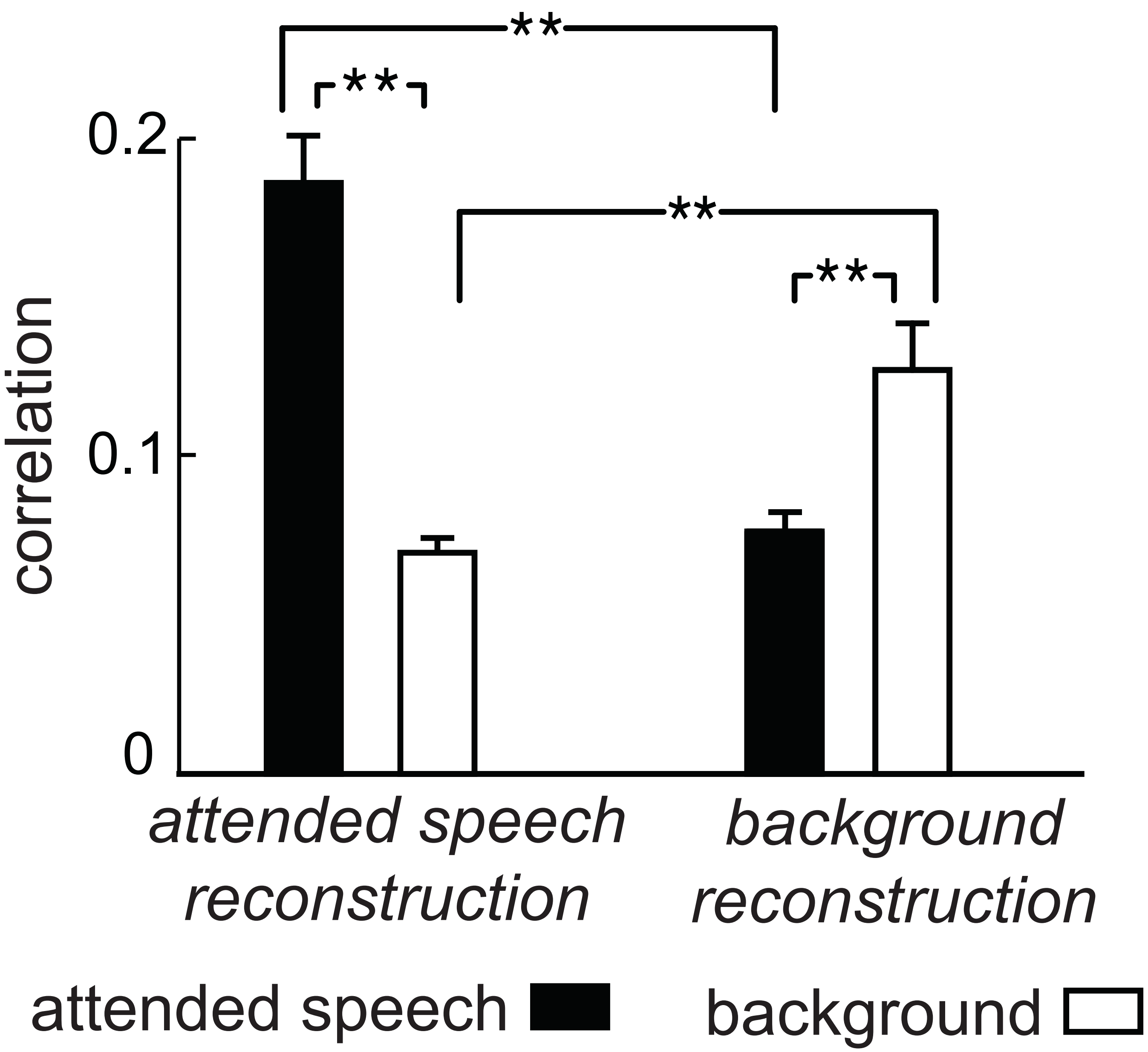
Single Trial Speech Reconstruction



Overall Speech Reconstruction

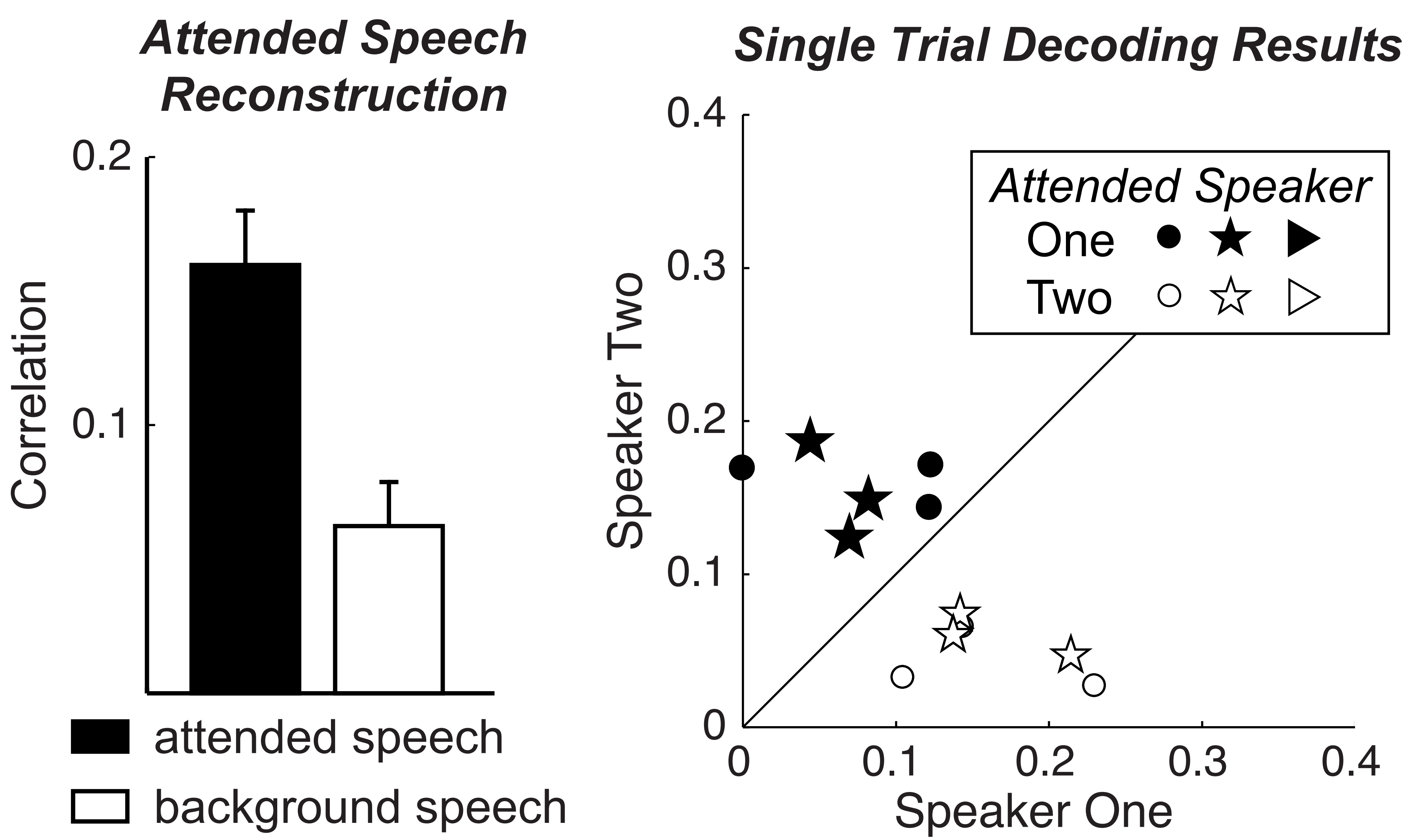


Overall Speech Reconstruction

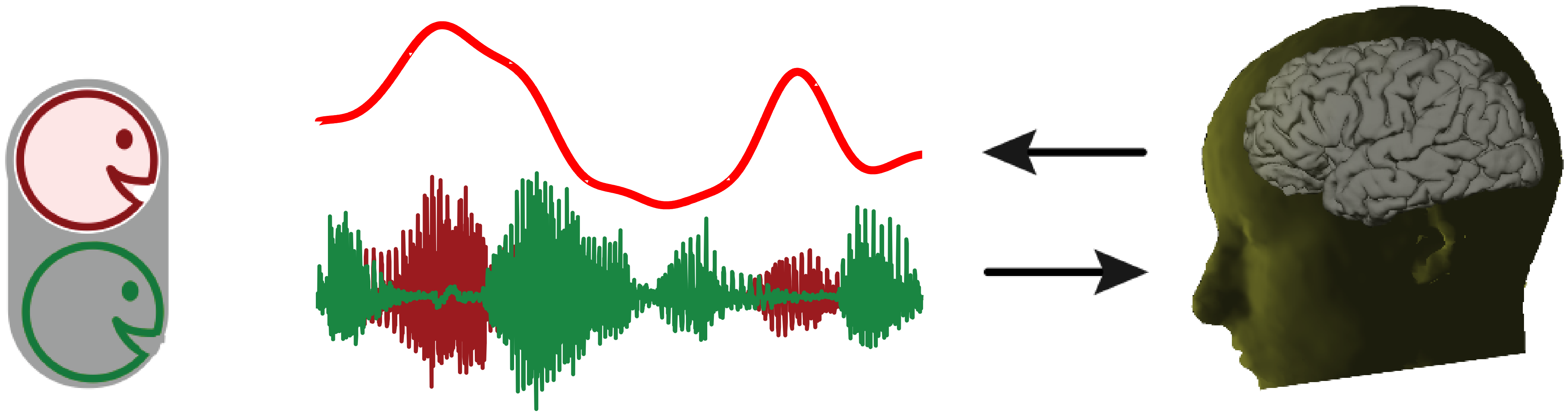


Distinct neural representations for different speech streams

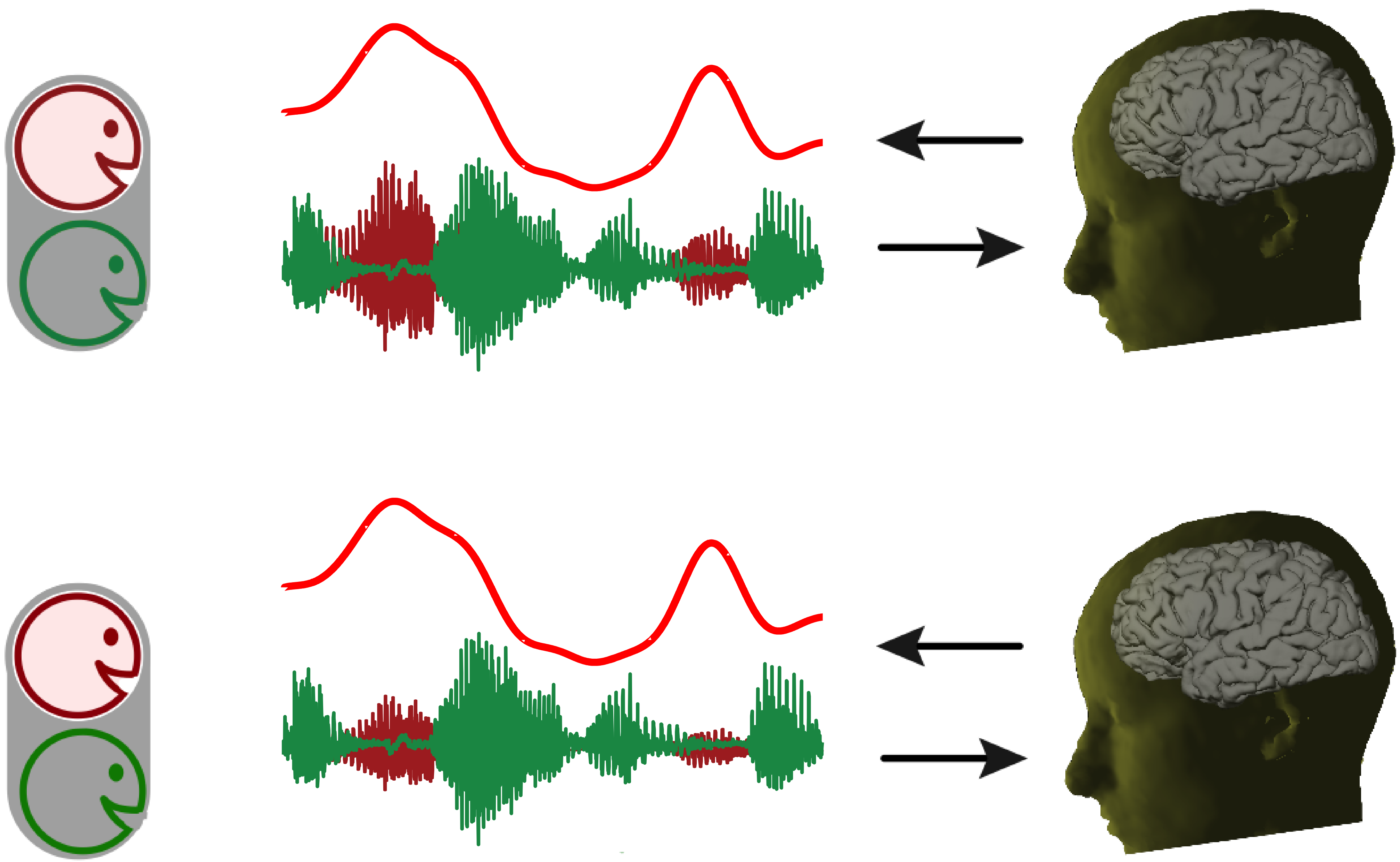
Reconstruction of Same-Sex Speech



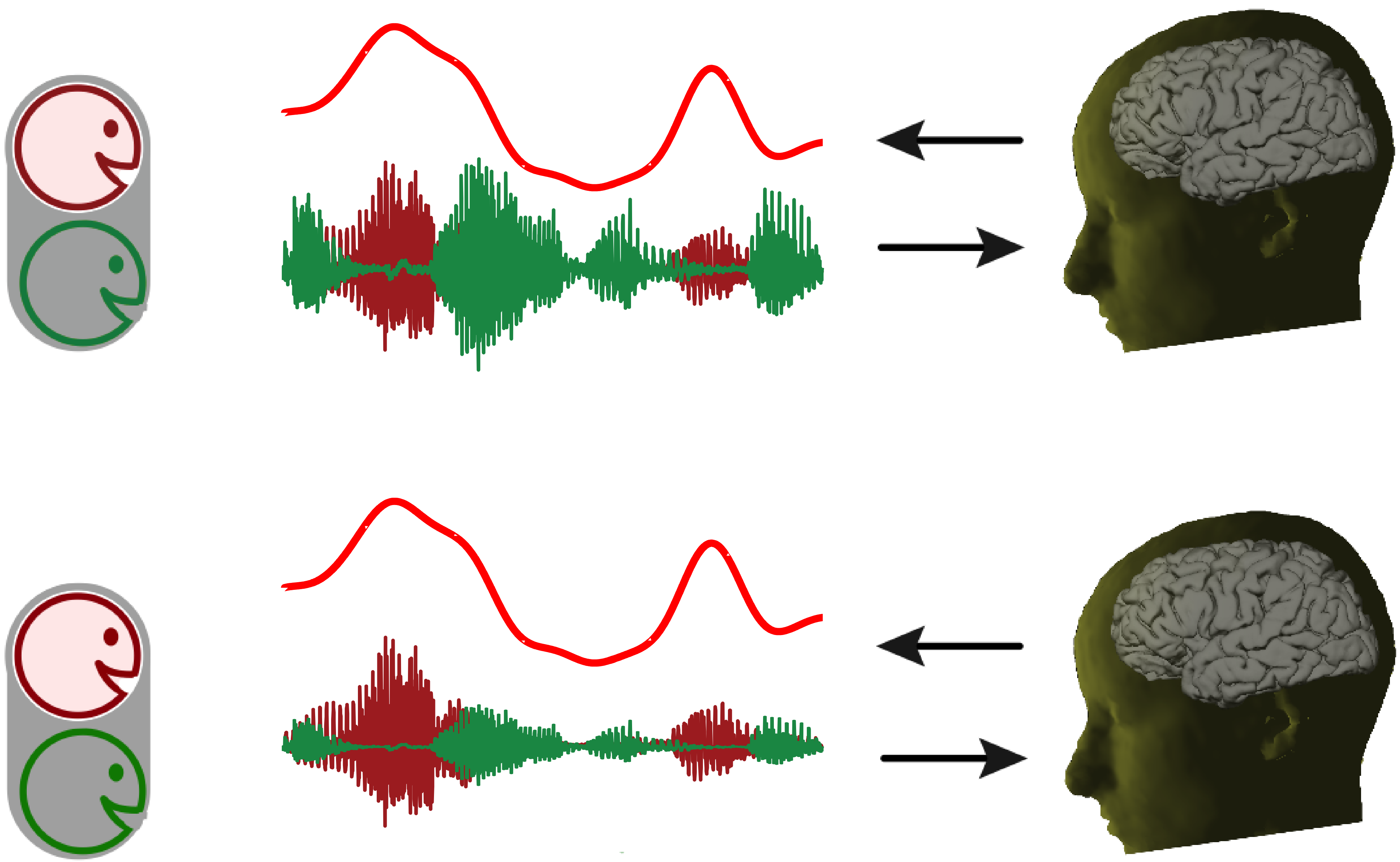
Invariance Under Acoustic Changes



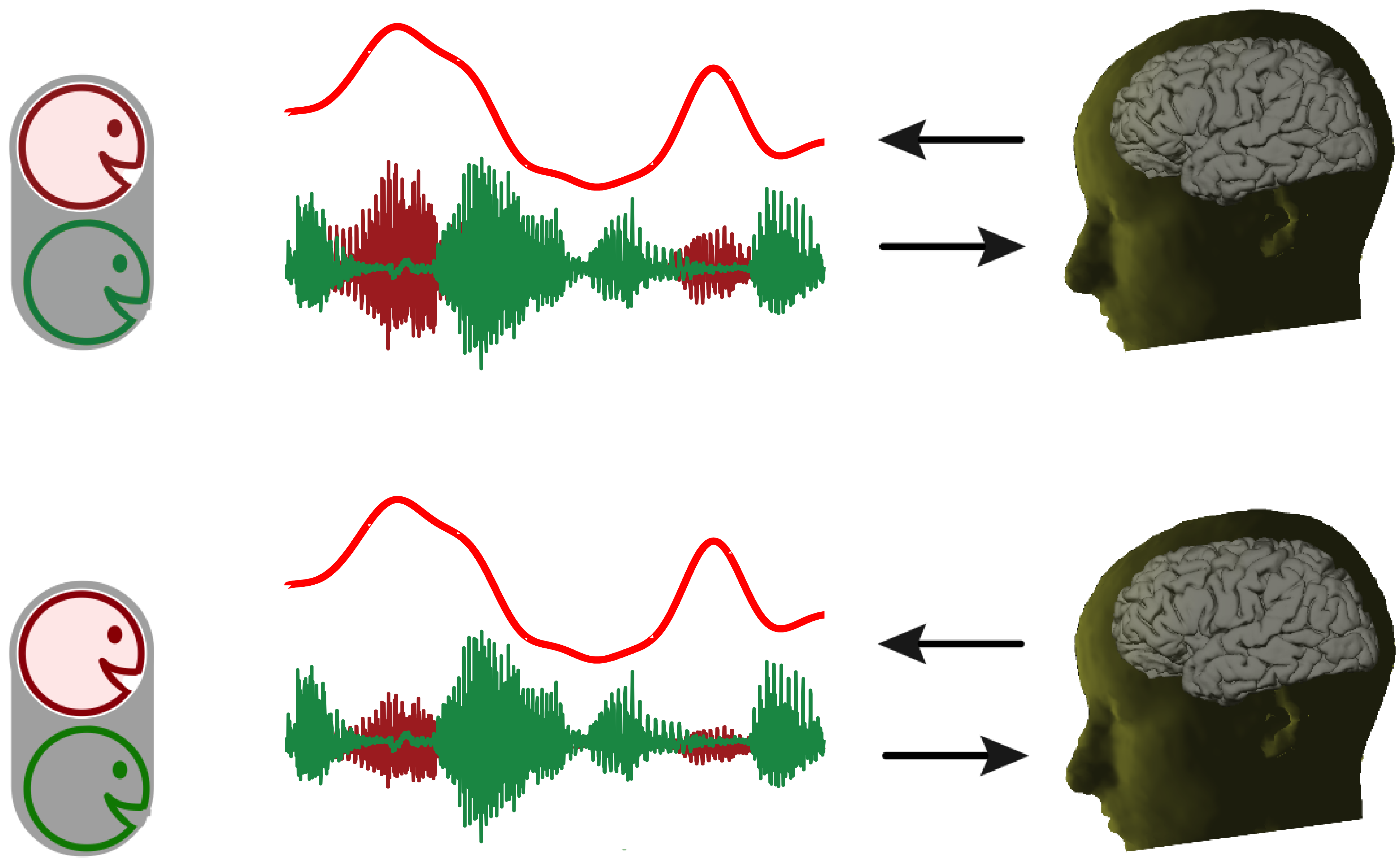
Invariance Under Acoustic Changes



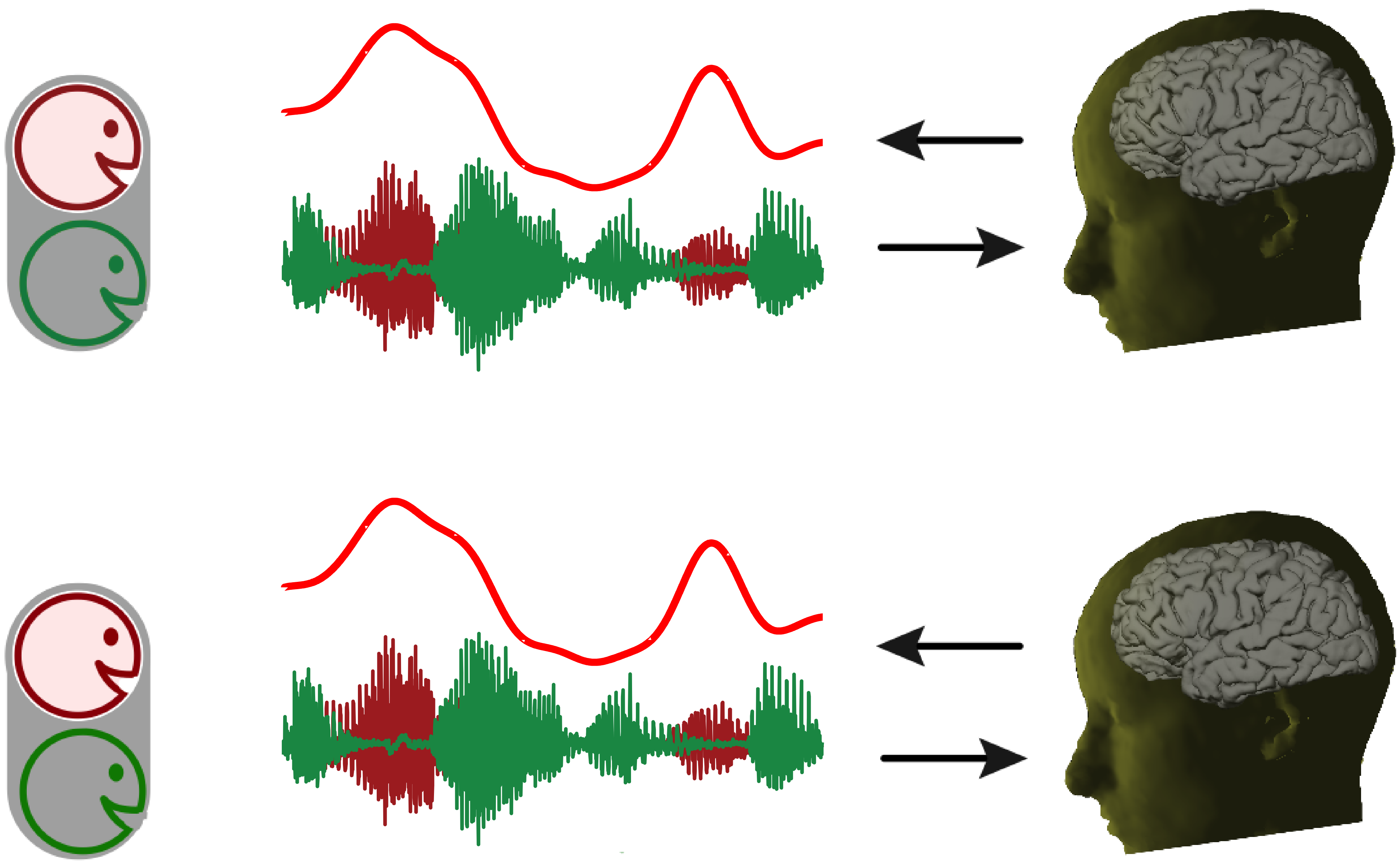
Invariance Under Acoustic Changes



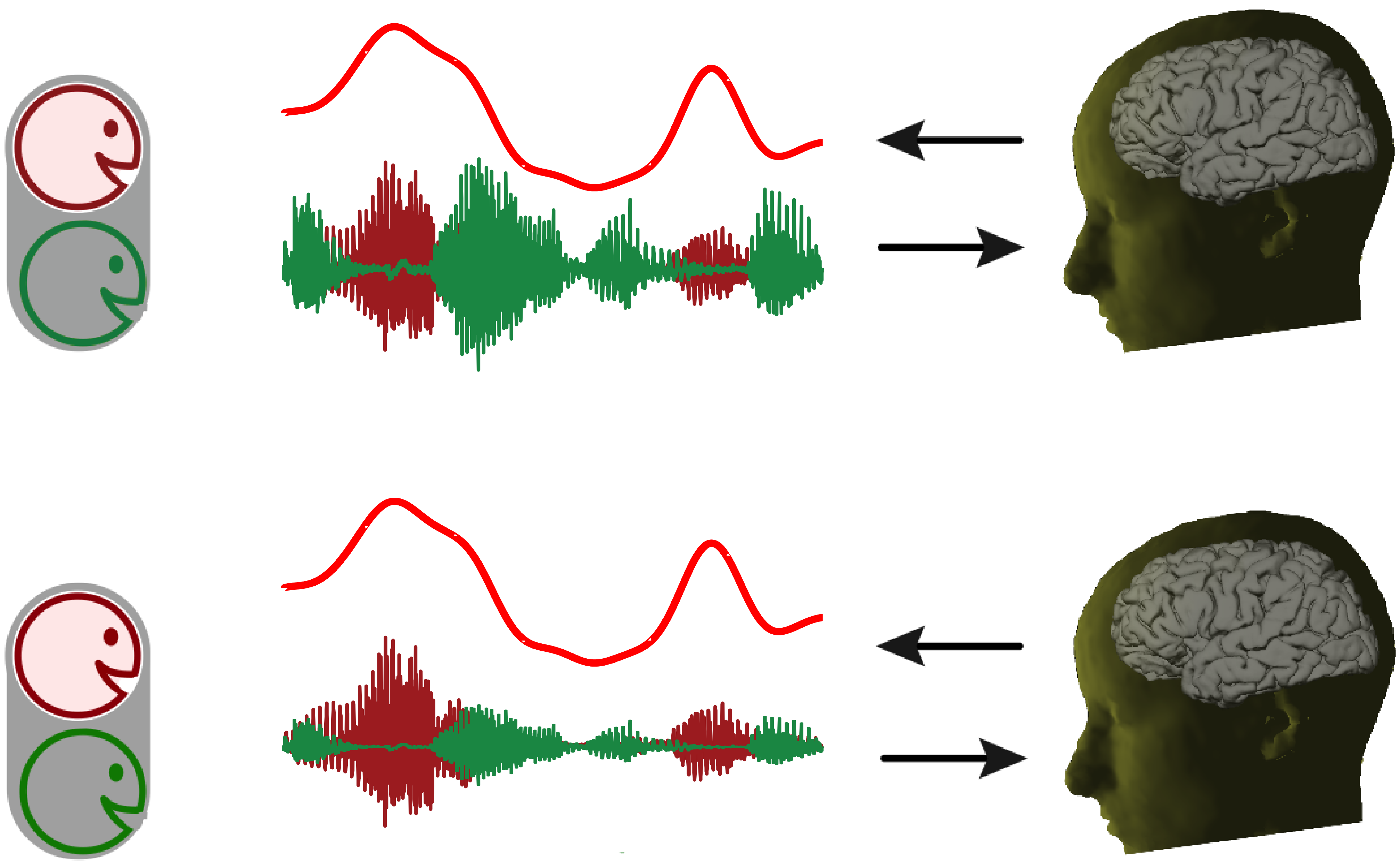
Invariance Under Acoustic Changes



Invariance Under Acoustic Changes

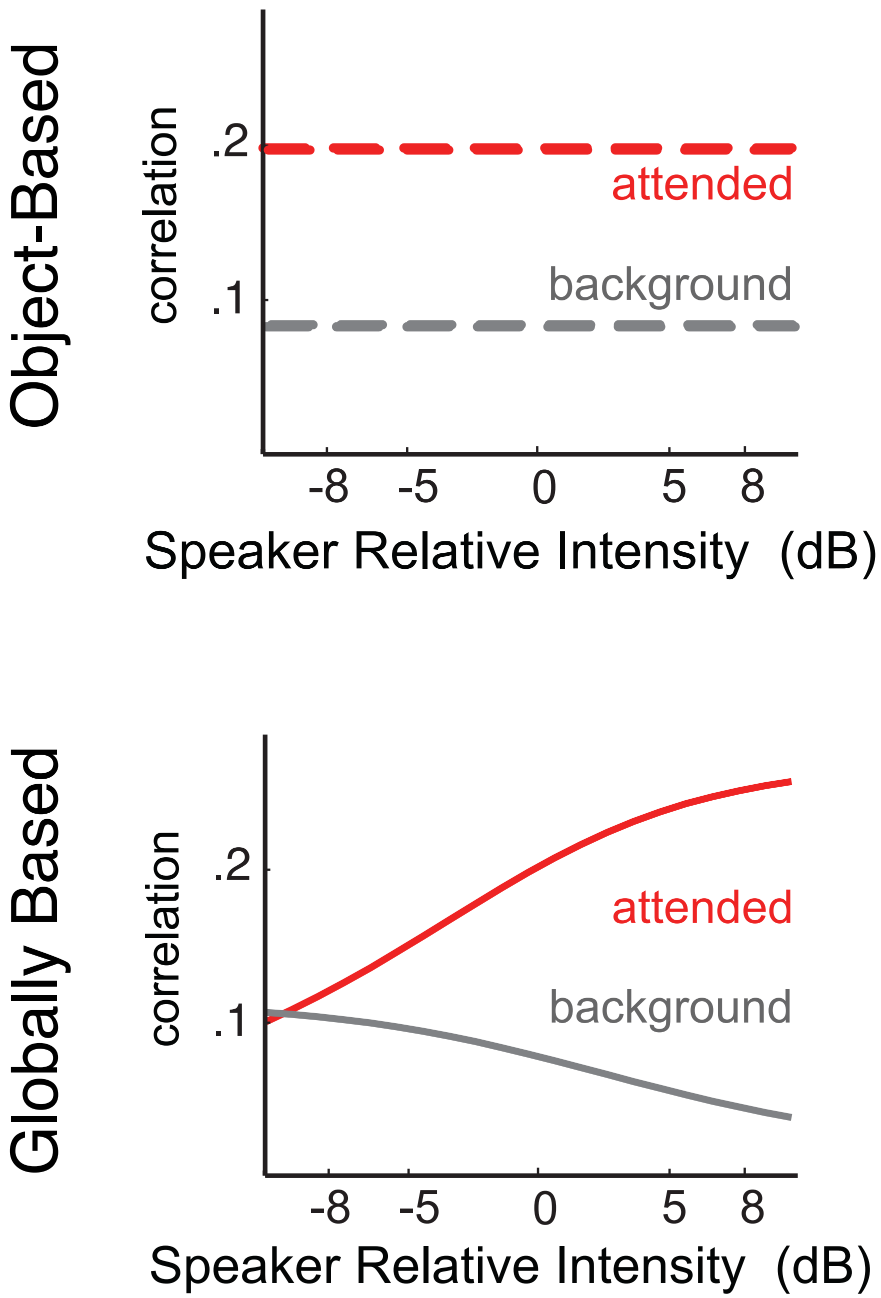


Invariance Under Acoustic Changes



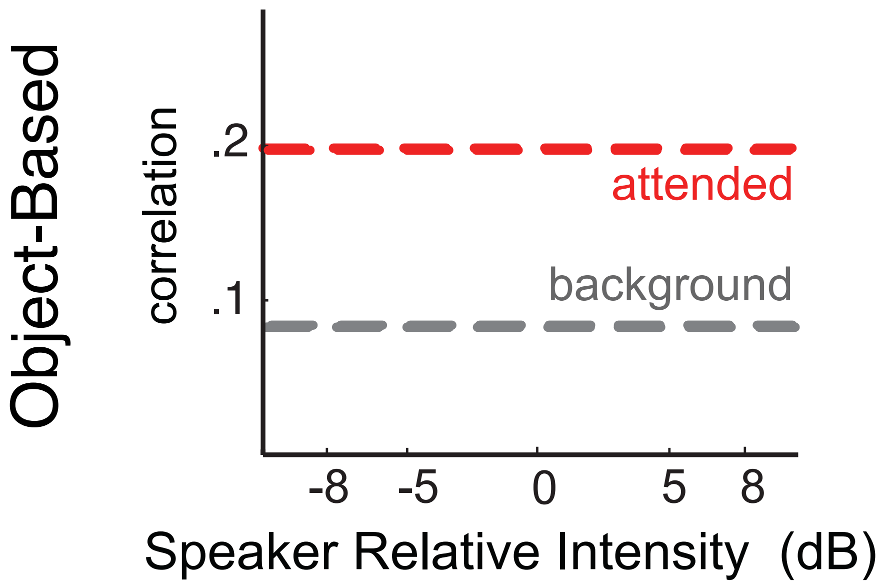
Object-Based Gain Control?

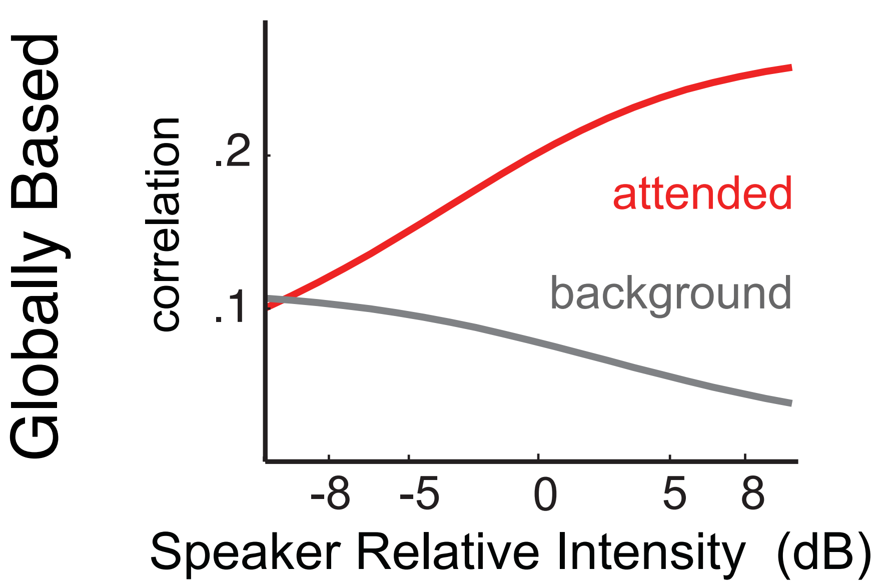
Gain-Control Models



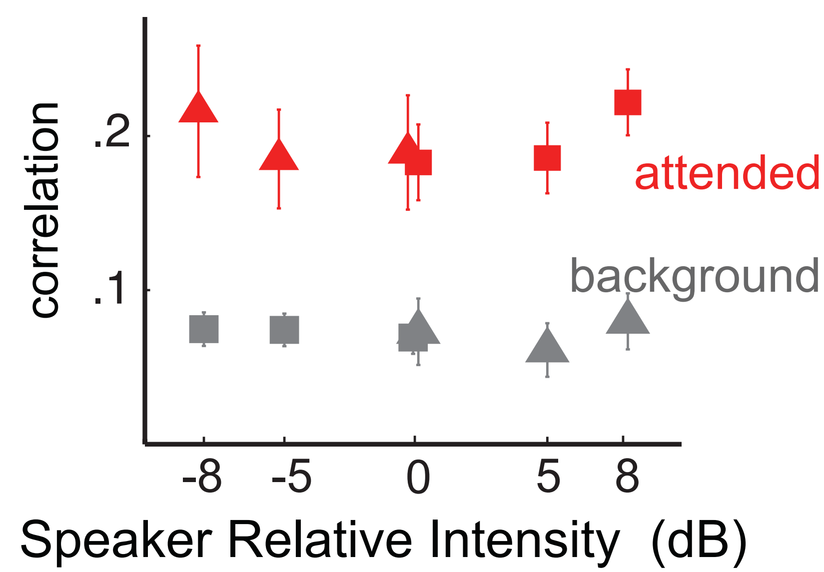
Object-Based Gain Control?

Gain-Control Models



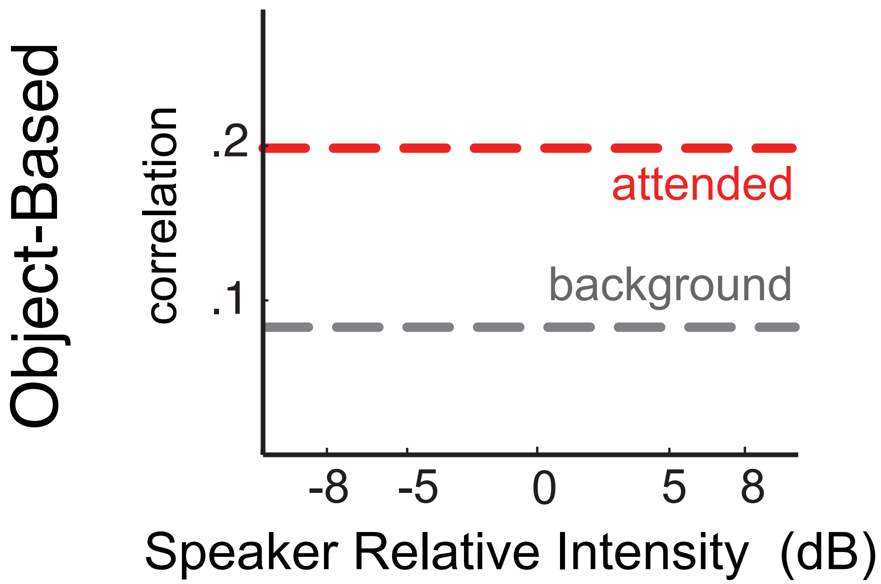


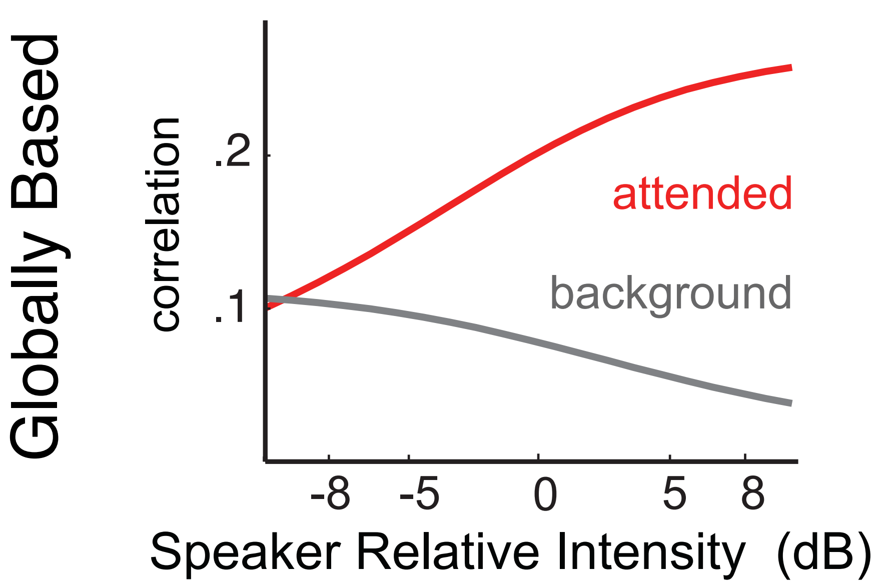
Neural Results



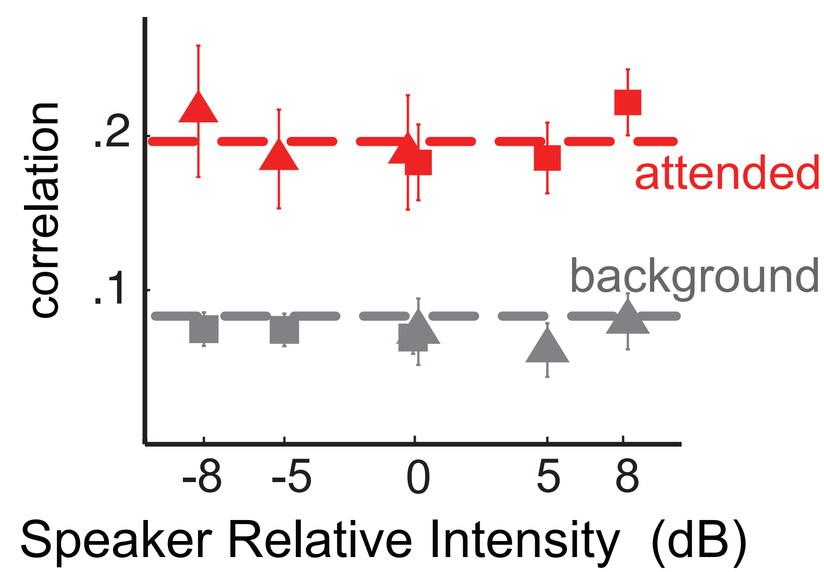
Object-Based Gain Control?

Gain-Control Models





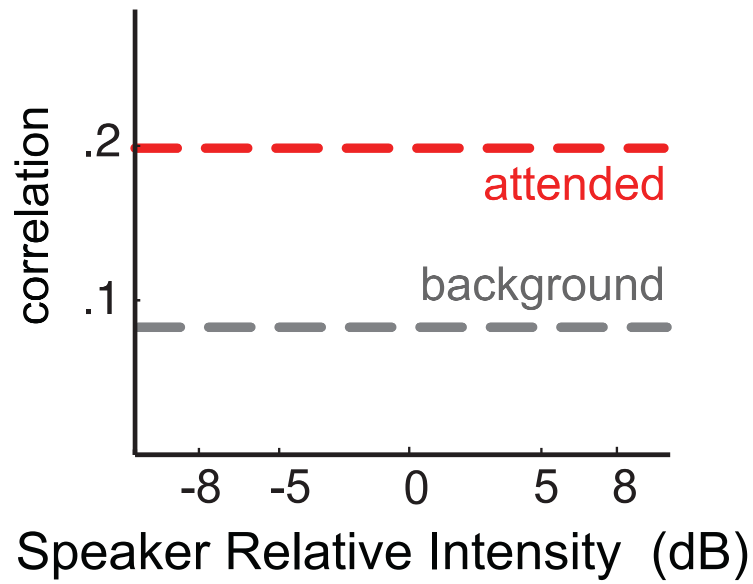
Neural Results



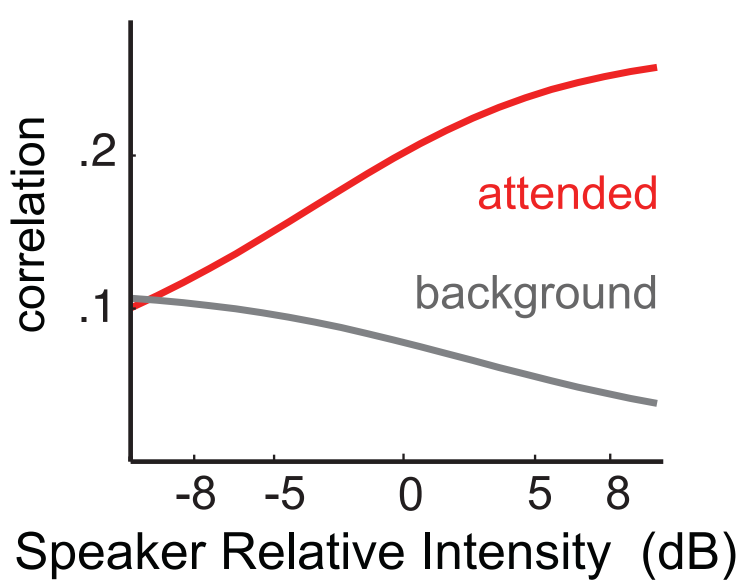
Object-Based Gain Control?

Gain-Control Models

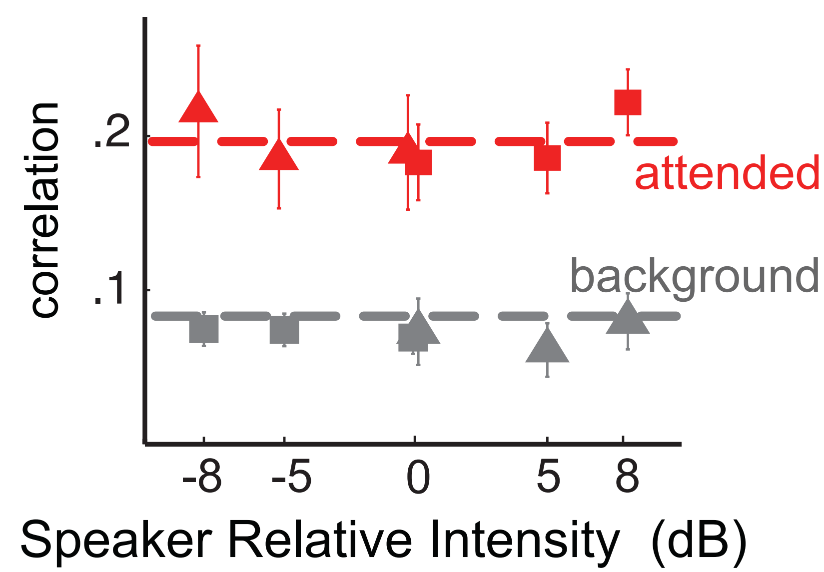
Object-Based



Globally Based

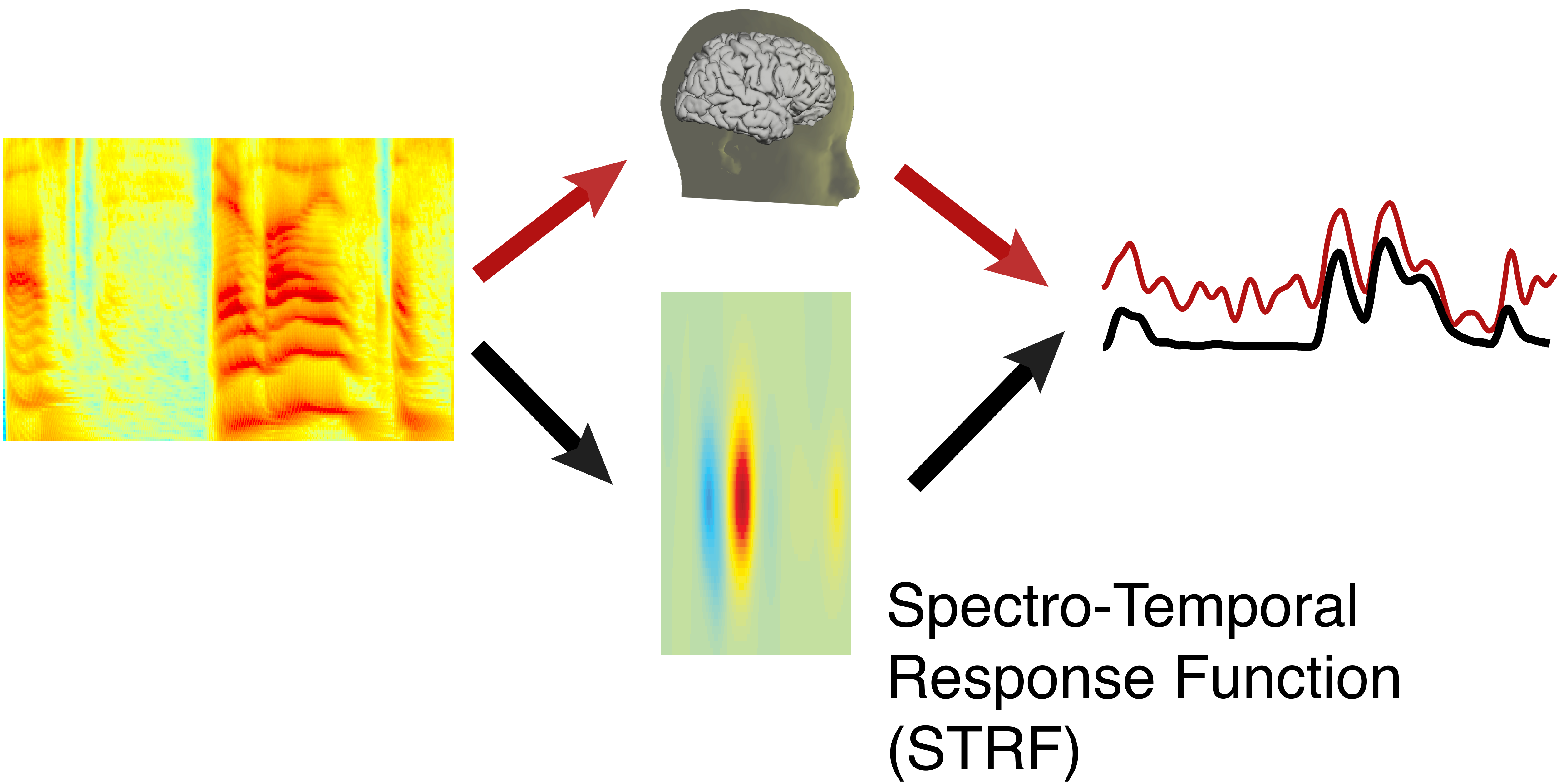


Neural Results

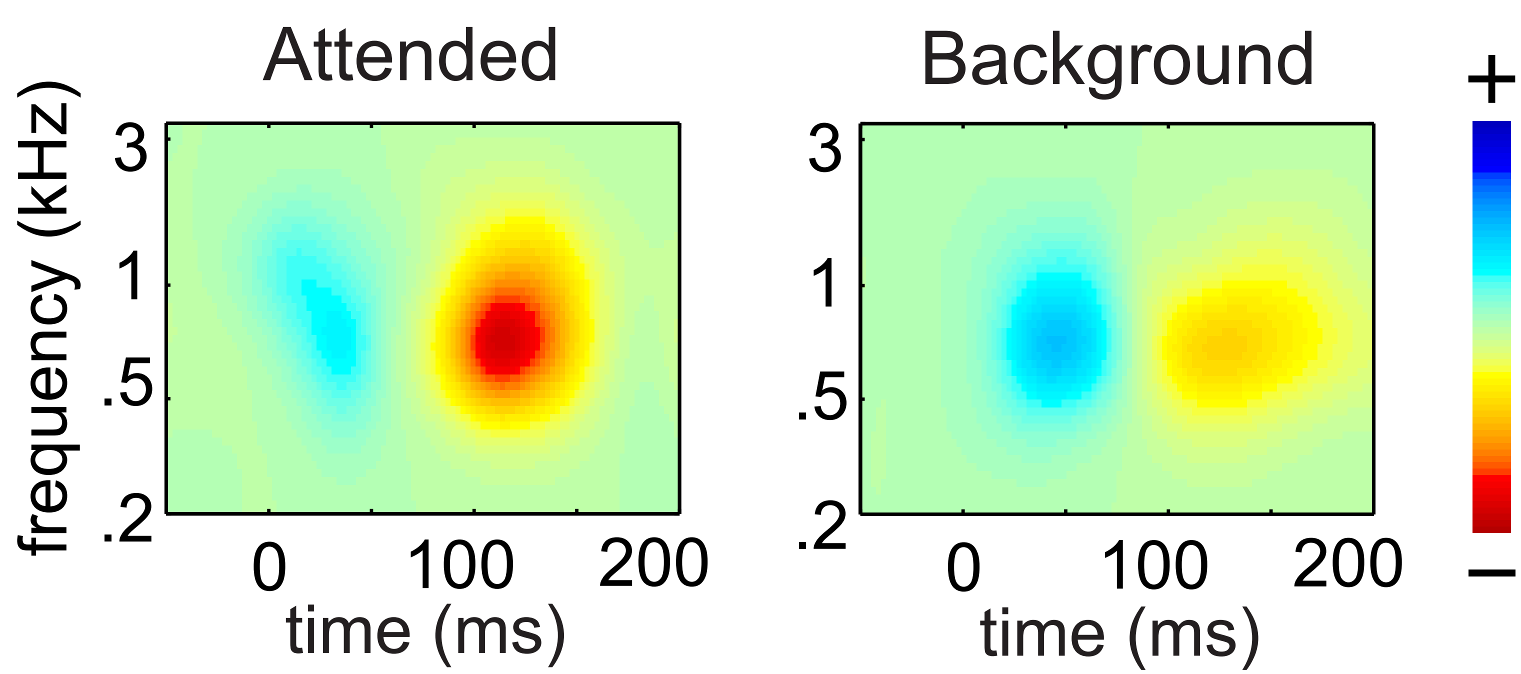


- Gain Control is Object-Based
- Neural representation is invariant to acoustic changes.

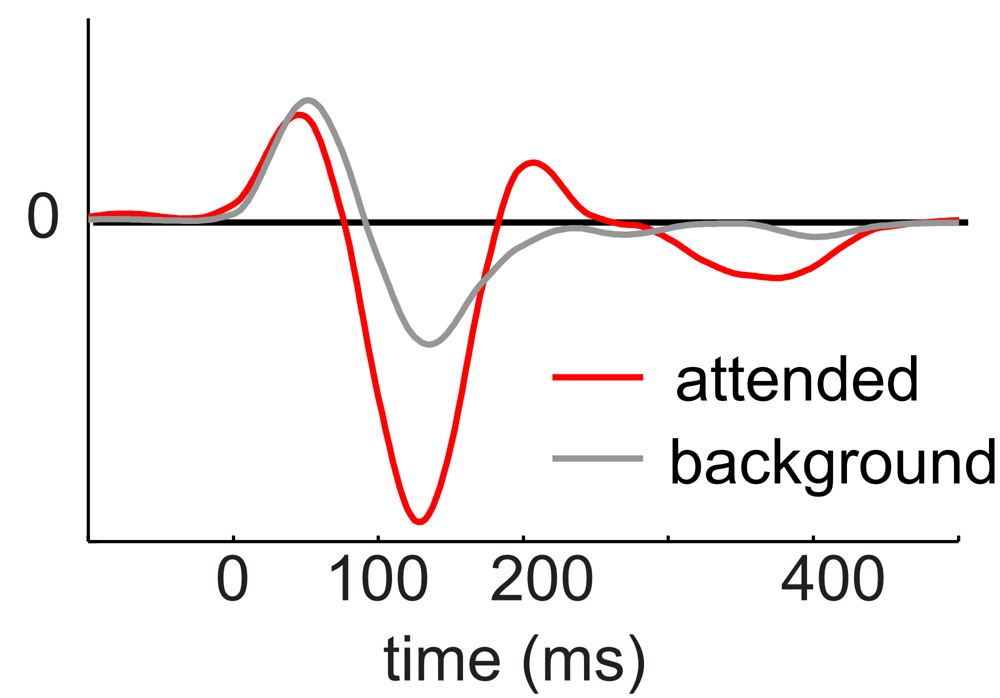
STRF model



STRF Results

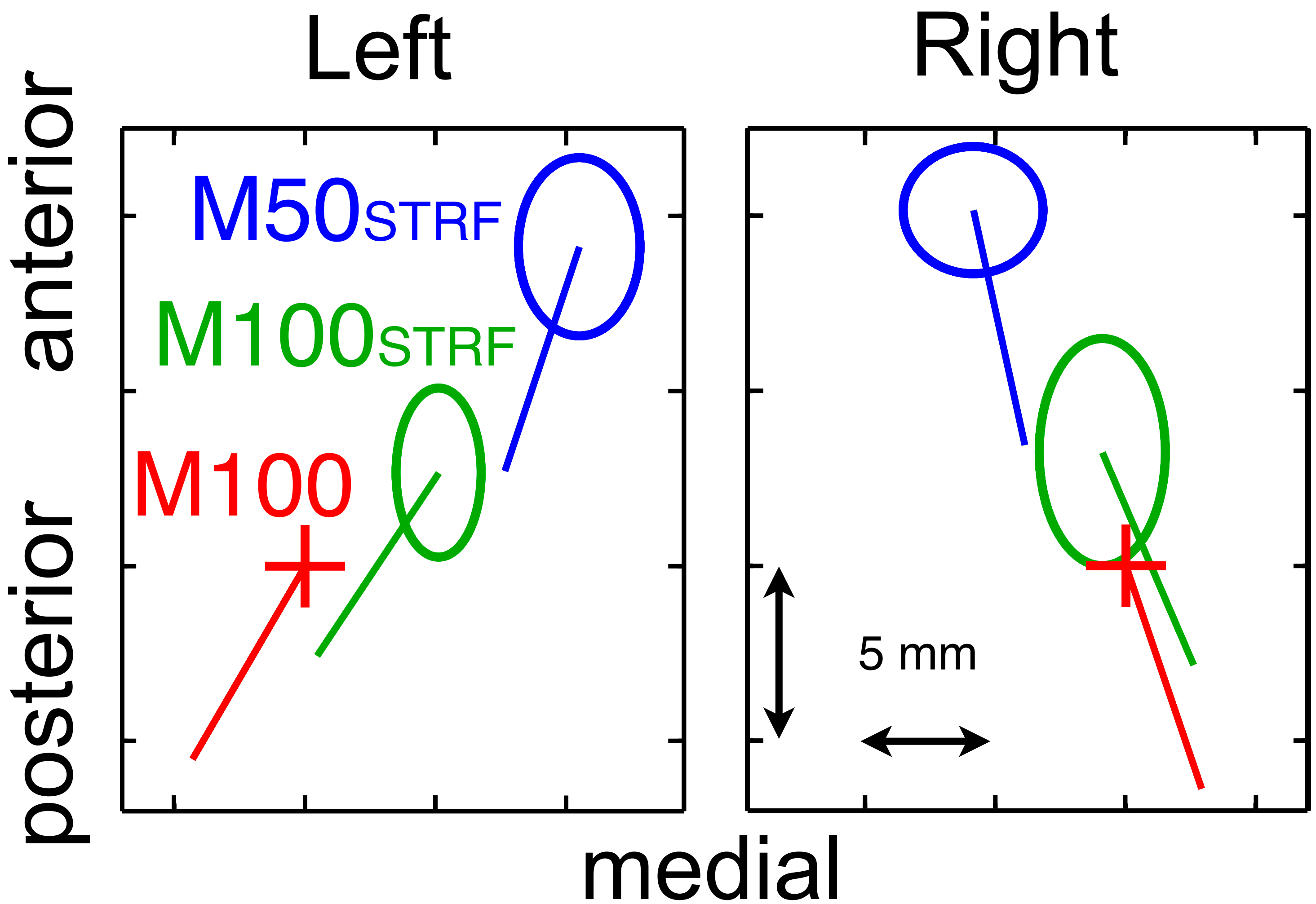


- STRF separable (time, frequency)
- 300 Hz - 2 kHz dominant carrier
- $M50_{STRF}$ positive peak
- $M100_{STRF}$ negative peak
- $M100_{STRF}$ strongly modulated, but not $M50_{STRF}$

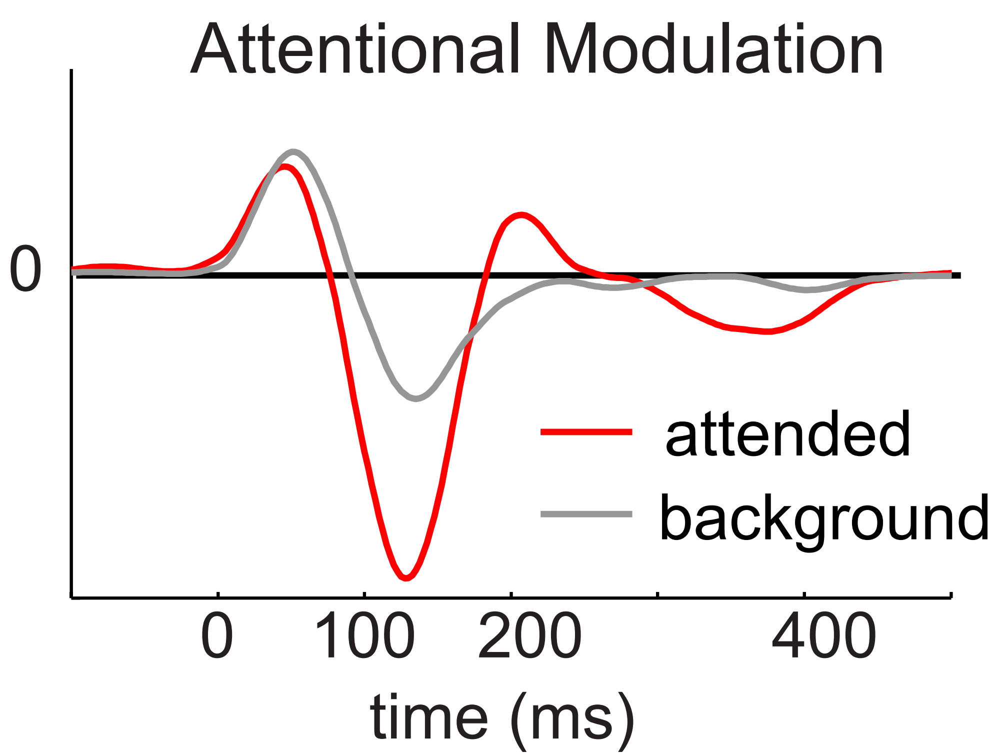


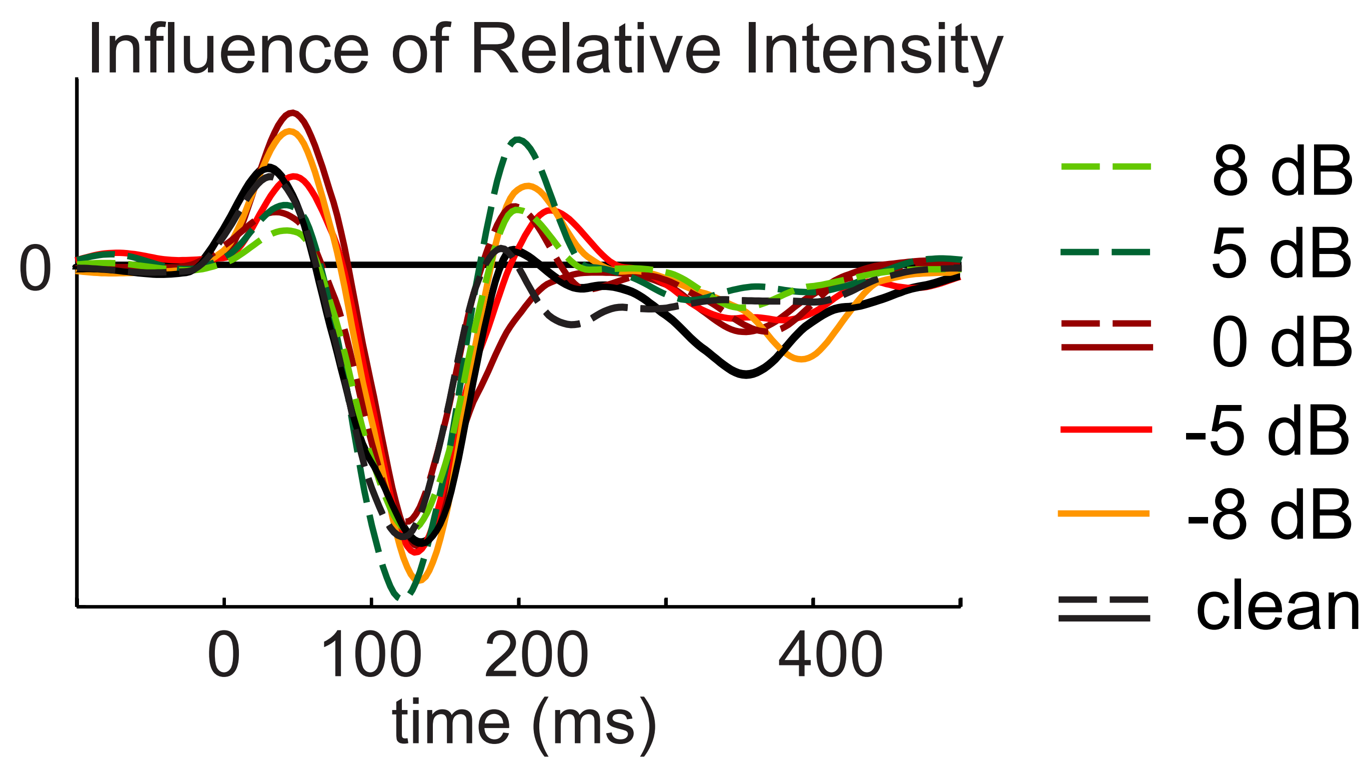
Neural Sources

- M100$_{STRF}$ source near (same as?) M100 source: STG/PT
- M50$_{STRF}$ source is anterior and medial to M100 (same as M50?): HG



Cortical Object-Processing Hierarchy





- $M100_{STRF}$ strongly modulated by attention, but not $M50_{STRF}$.
- $M100_{STRF}$ invariant against acoustic changes (but not $M50_{STRF}$?).
- Objects well-neurally represented at 100 ms, but not 50 ms.

Summary

- Cortical representations of speech show properties consistent with being neural representations of auditory objects
  - Meet three formal criteria
- Object representation well-formed at 100 ms latency (STG, PT), but not at 50 ms (HG)

Acknowledgements

Collaborators
- Catherine Carr
- Alain de Cheveigné
- Didier Depireux
- Mounya Elhilali
- Jonathan Fritz
- Cindy Moss
- David Poeppel
- Shihab Shamma

Past Postdocs
- Dan Hertz
- Yadong Wang

Past Grad Students
- Nayef Ahmar
- Claudia Bonin
- Maria Chait
- Victor Grau-Serrat
- Ling Ma
- Raul Rodriguez
- Juanjuan Xiang
- Kai Sum Li
- Jiachen Zhuo

Current Grad Students
- Francisco Cervantes
- Marisel Villafane Delgado
- Nai Ding
- Kim Drnec
- Krishna Puvvada

Collaborators' Students
- Murat Aytekin
- Julian Jenkins
- David Klein
- Huan Luo

Undergraduate Students
- Abdulaziz Al-Turki
- Nicholas Asendorf
- Sonja Bohr
- Elizabeth Camenga
- Corinne Cameron
- Julien Dagenais
- Katya Dombrowski
- Kevin Kahn
- Andrea Shome
- Ben Walsh

Funding
- NIH R03 DC 004382
- NIH R01 EB 004750
- NIH R01 AG 027573
- NIH R01 DC 007657
- NIH R01 DC 000436
- NIH R01 DC 008342
- NIH R01 DC 005660
- NIH F31 NS 055589
- USDA 20096512005791