Neural Representations of the Cocktail Party in Human Auditory Cortex

Jonathan Z. Simon

Department of Biology
Department of Electrical & Computer Engineering
Institute for Systems Research

University of Maryland

Acknowledgements

Grad Students

Francisco Cervantes
Alex Presacco
Krishna Puvvada

Past Grad Students

Nayef Ahmar
Claudia Bonin
Maria Chait
Marisel Villafane Delgado
Kim Drnec
Nai Ding
Victor Grau-Serrat
Ling Ma
Raul Rodriguez
Juanjuan Xiang
Kai Sum Li
Jiachen Zhuo

Undergraduate Students

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

Collaborators' Students

Murat Aytekin
Julian Jenkins
David Klein
Huan Luo

Past Postdocs

Dan Hertz
Yadong Wang

Collaborators

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

Funding

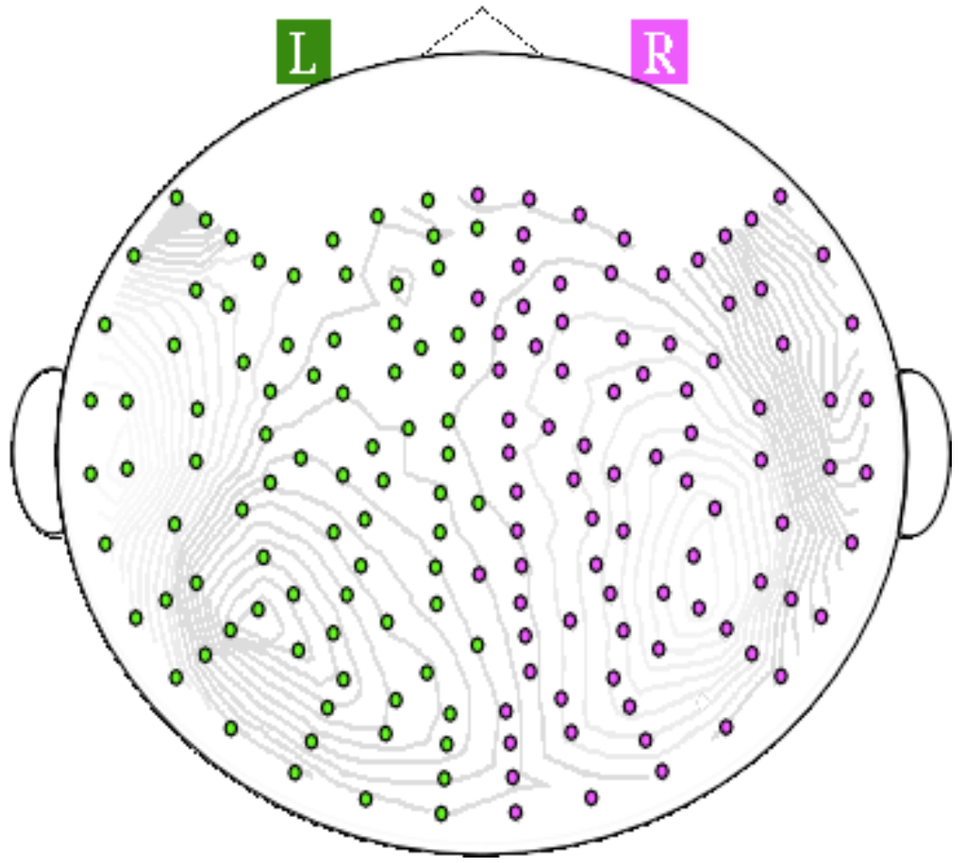
NIH R01 DC 008342
NIH R01 DC 007657
NIH R01 DC 005660
NIH R01 DC 000436
NIH R01 AG 036424
NIH R01 AG 027573
NIH R01 EB 004750
NIH R03 DC 004382
USDA 2009651200579l

Introduction

- Magnetoencephalography (MEG)
- Auditory Objects
- Neural Representations of Auditory Objects in Cortex: Decoding
- Neural Representations of Auditory Objects in Cortex: Encoding
- Neural Representations of Speech in Noise

Magnetoencephalography

- Non-invasive, Passive, Silent Neural Recordings
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity
  - high: ~100 fT (10^{-13} Tesla)
  - low: ~10^4 – ~10^6 neurons
- Temporal Resolution: ~1 ms
- Spatial Resolution
  - coarse: ~1 cm
  - ambiguous



Neural Signals & MEG

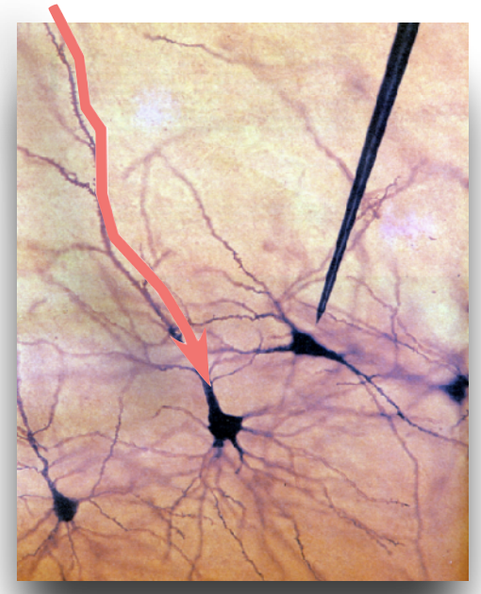
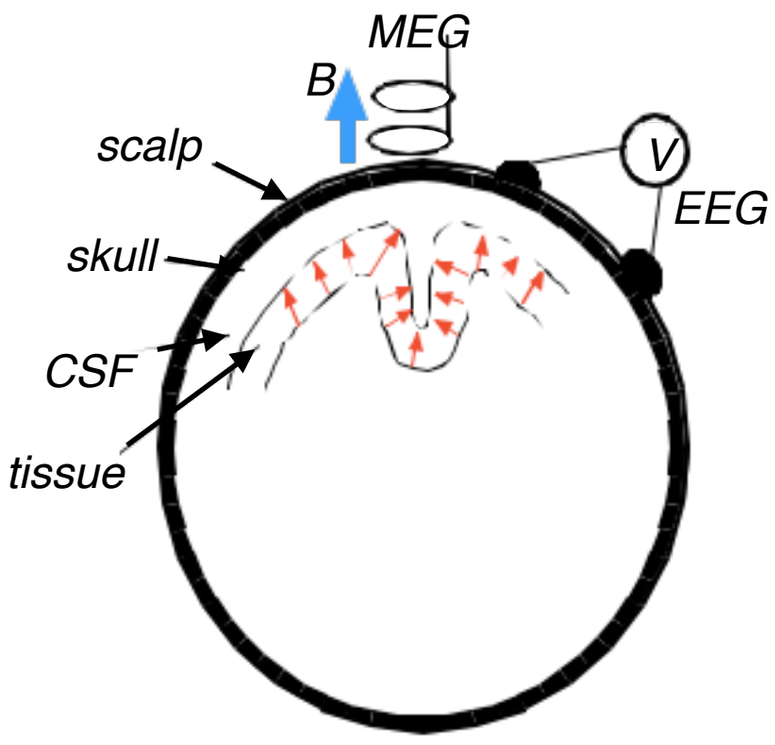
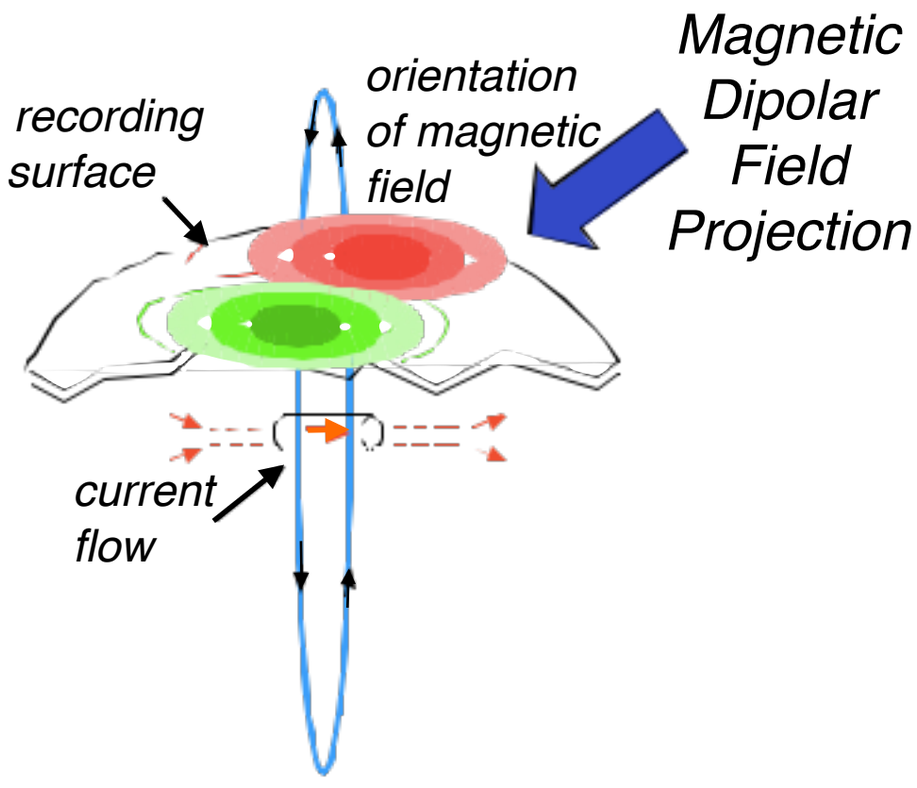


Photo by Fritz Goro





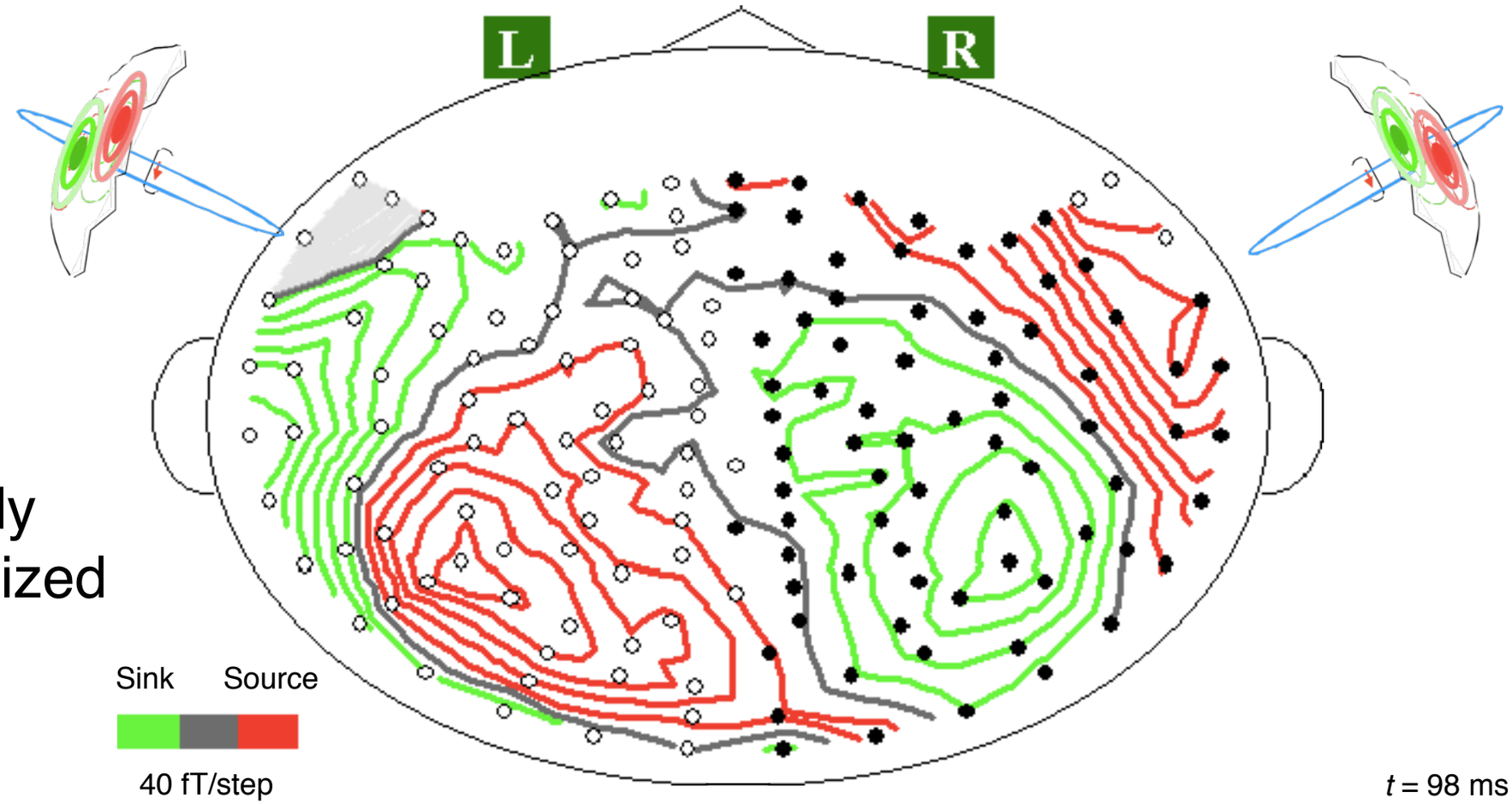
- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source

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

MEG Auditory Field

Flattened Isofield Contour Map

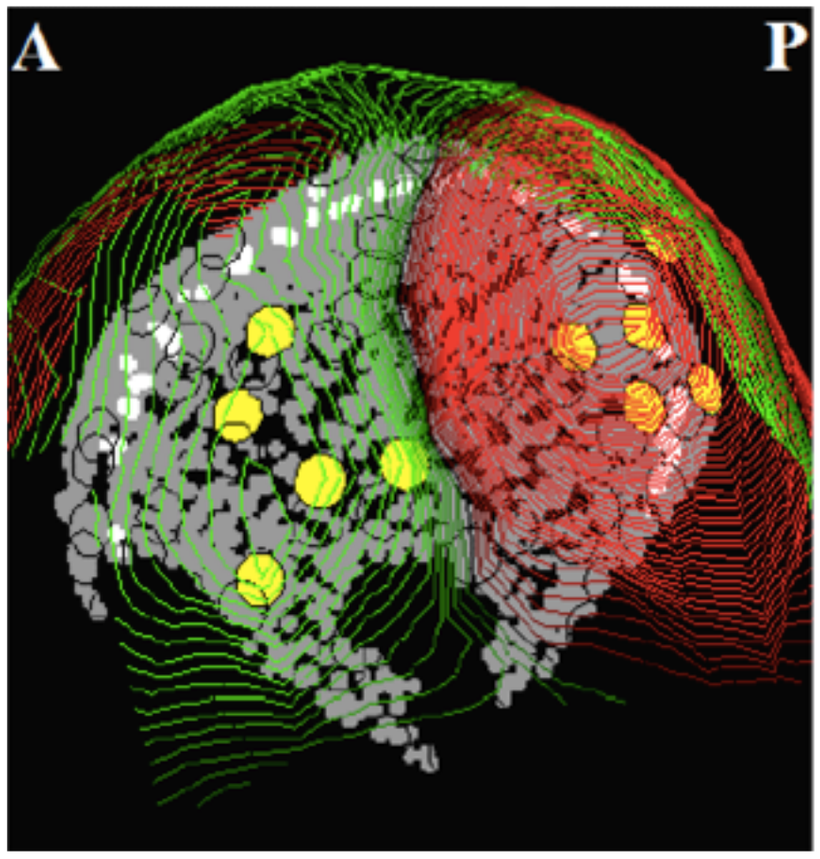
Instantaneous Magnetic Field



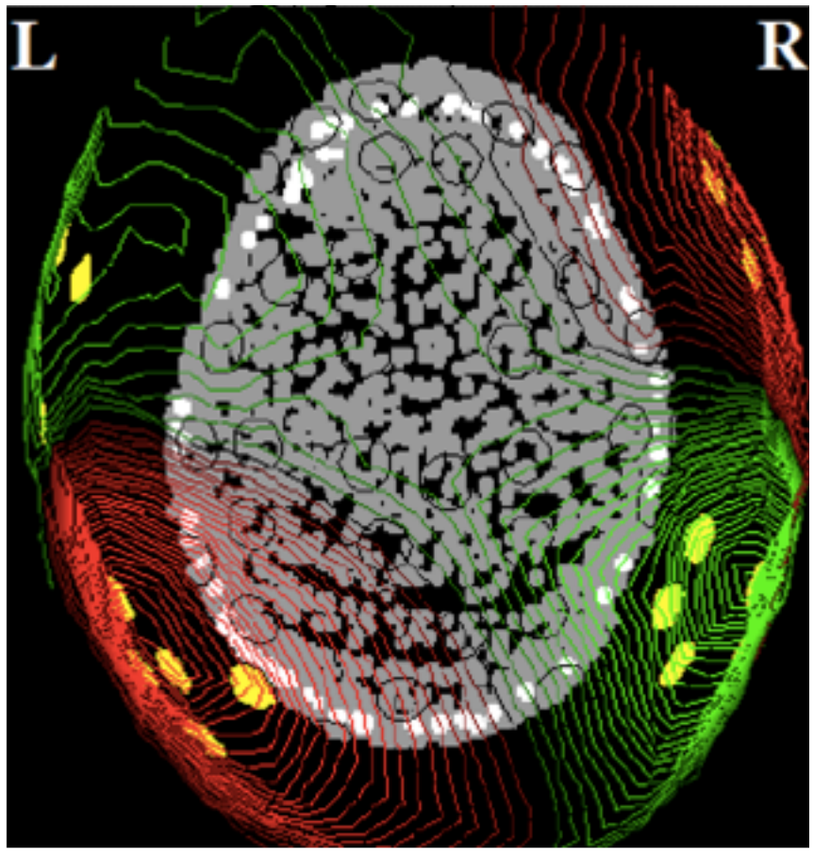
Strongly Lateralized

MEG Auditory Field

3-D Isofield Contour Map



Sagittal View



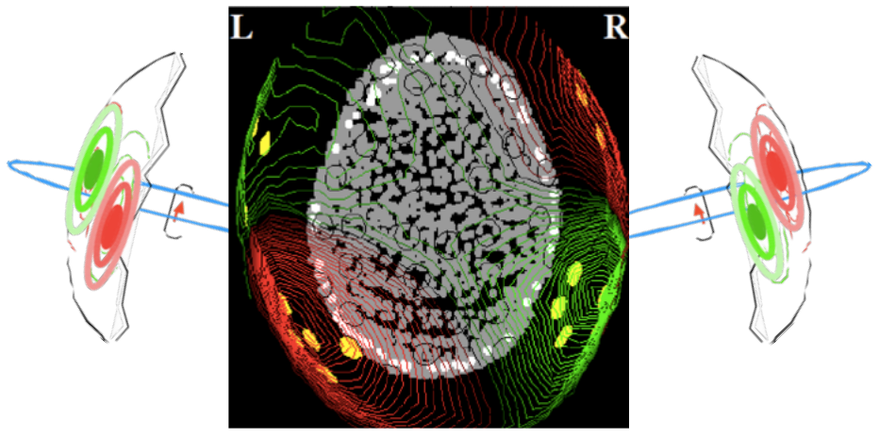
Axial View

Chait, Poeppel and Simon, Cerebral Cortex (2006)

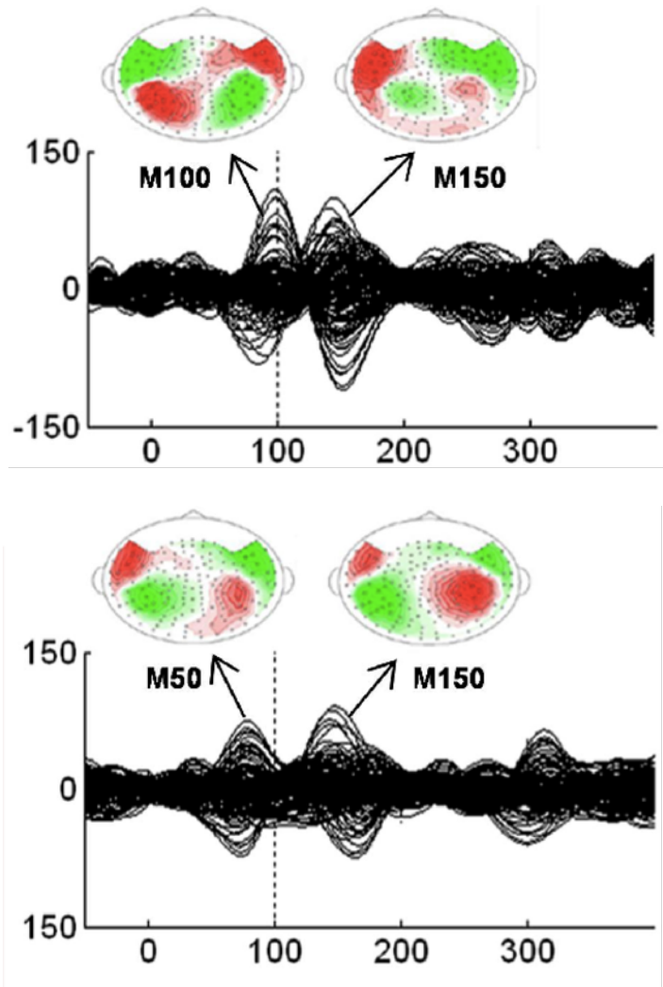
Time Course of MEG Responses

Auditory Evoked Responses

- MEG Response Patterns Time-Locked to Stimulus Events
- Robust
- Strongly Lateralized

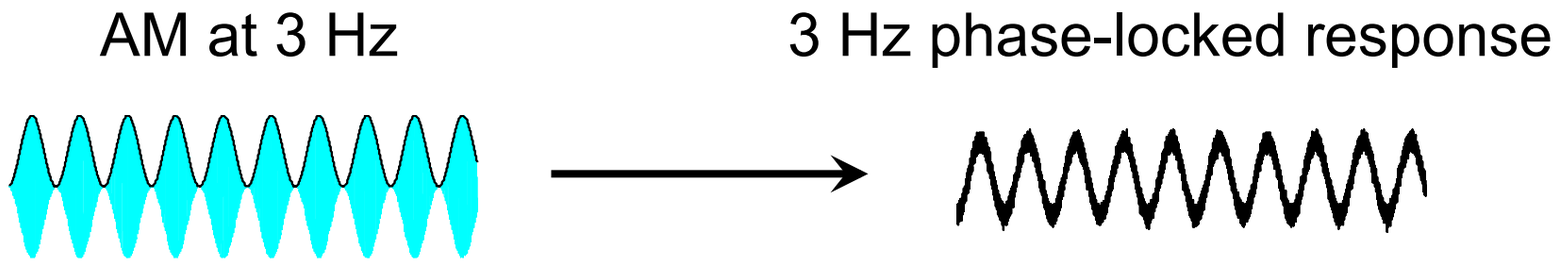


Pure Tone



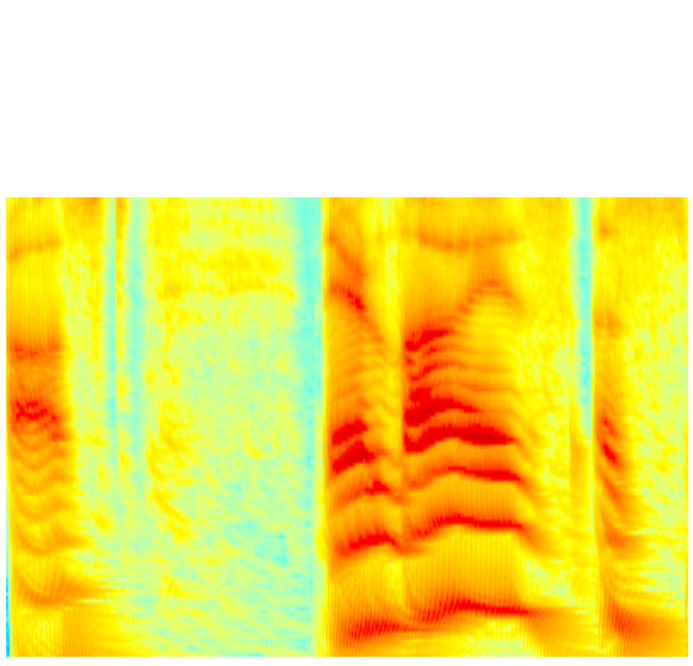
Broadband Noise

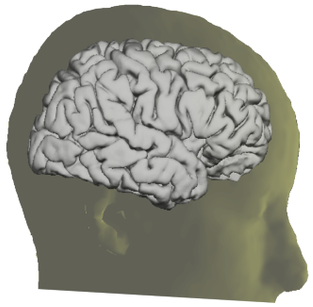
Phase-Locking in MEG to Slow Acoustic Modulations



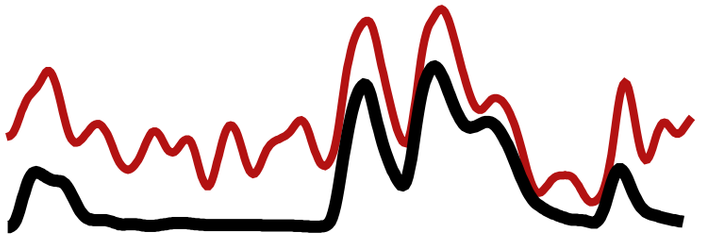
Ding & Simon, J Neurophysiol (2009)
Wang et al., J Neurophysiol (2012)

MEG Responses to Speech Modulations

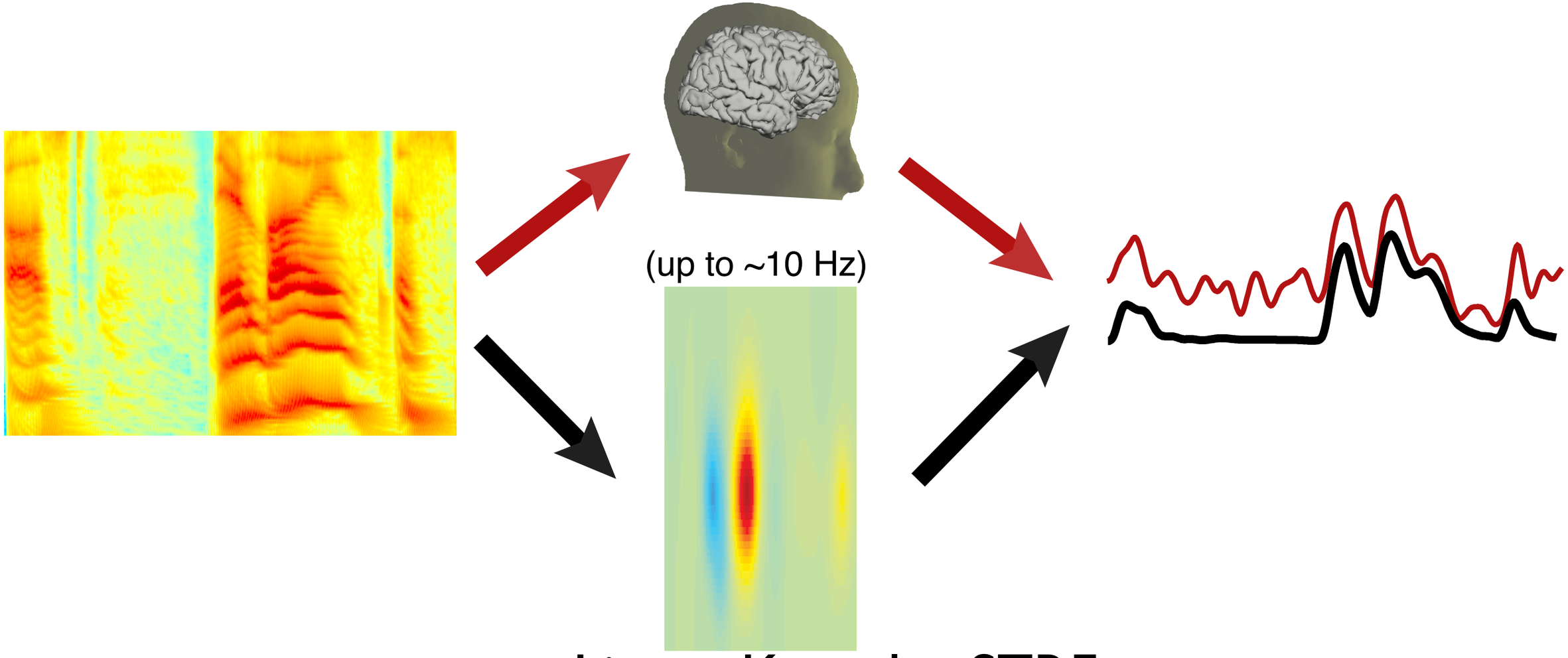




Auditory Model



MEG Responses Predicted by STRF Model

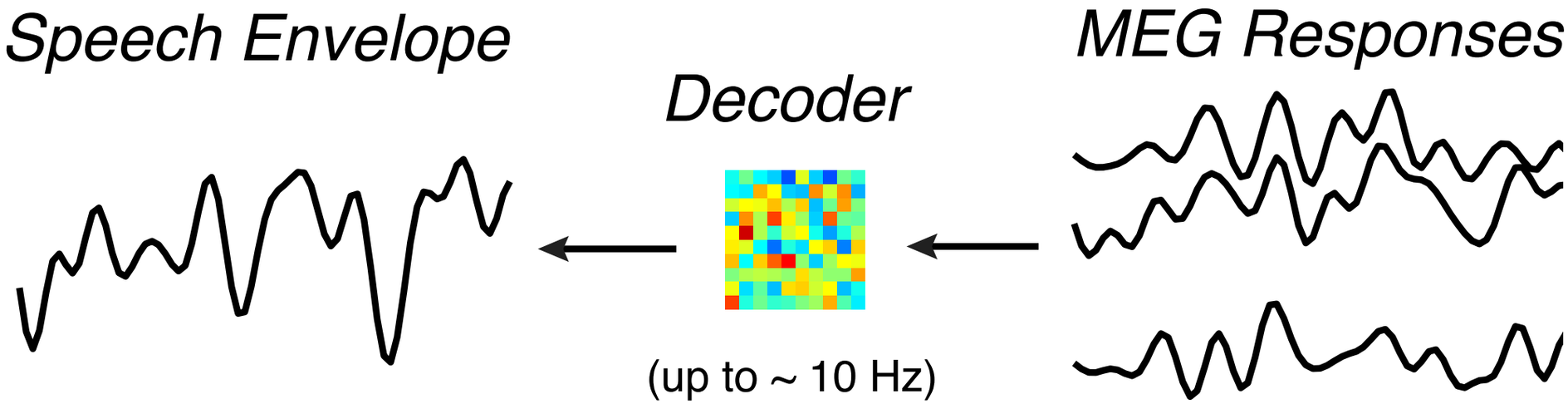


Linear Kernel = STRF

"Spectro-Temporal Response Function"

Ding & Simon, J Neurophysiol (2012)

Neural Reconstruction of Speech Envelope



Auditory Objects

- What is an auditory object?
  - perceptual construct (not neural, not acoustic)
  - commonalities with visual objects
  - several potential formal definitions

Auditory Object Definition

- Griffiths & Warren definition:
  - corresponds with *something* in the sensory world
  - object information *separate from* information of rest of sensory world
  - abstracted: object information *generalized over particular* sensory experiences

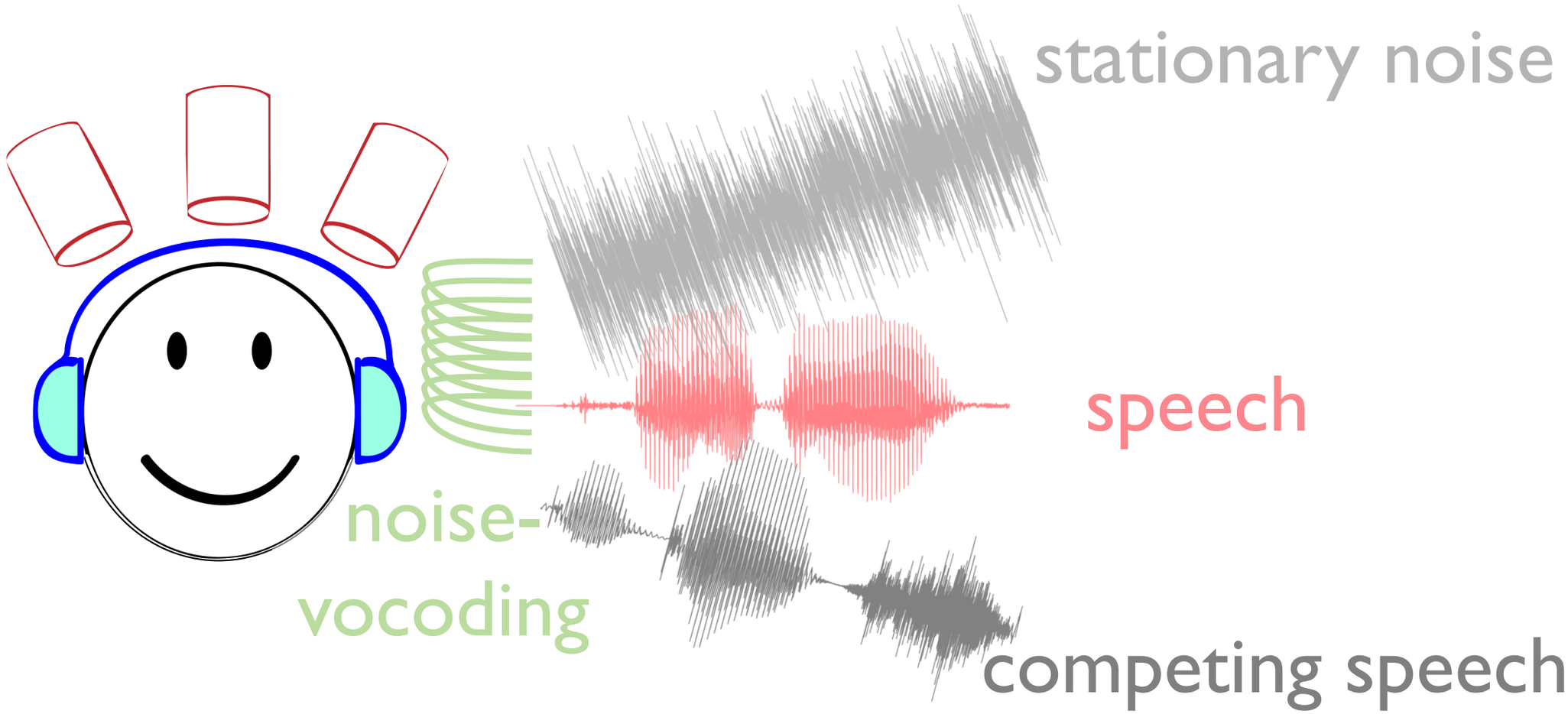
Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Auditory Objects at the Cocktail Party

Alex Katz,
The Cocktail Party

Experiments



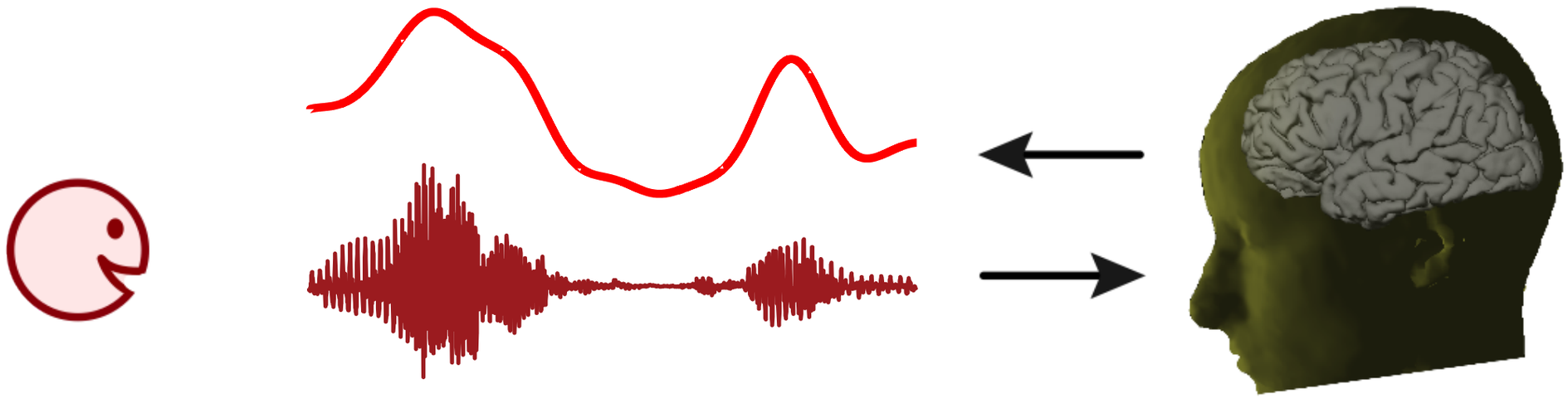
Speech Stream as an Auditory Object

- corresponds with something in the sensory world
- information *separate from* information of rest of sensory world
  e.g. other speech streams or noise
- abstracted: object information *generalized over particular* sensory experiences
  e.g. different sound mixtures

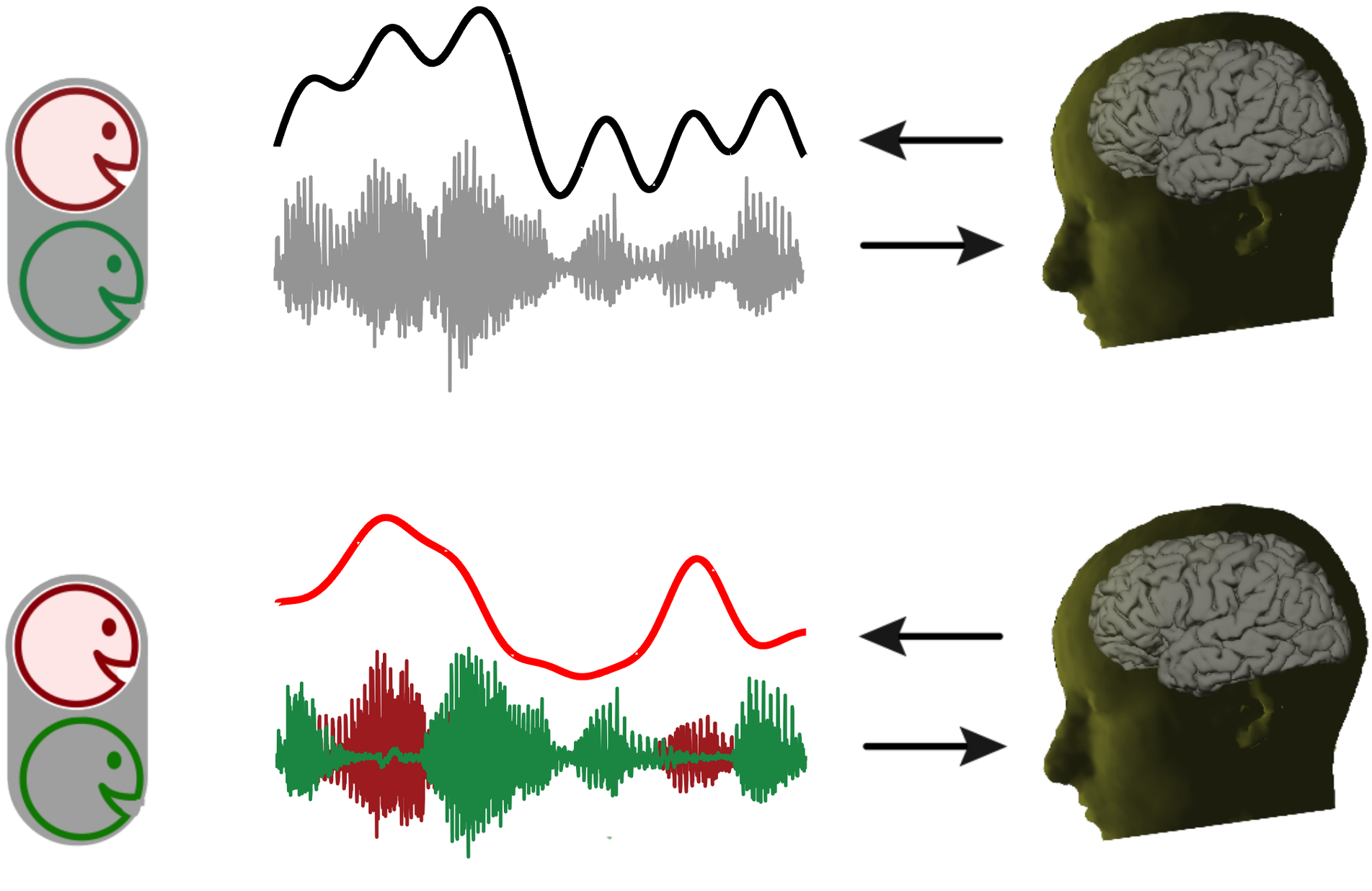
Neural Representation of an Auditory Object

- neural representation is of something in sensory world
- when other sounds mixed in,
  neural representation is of that auditory object, not entire acoustic scene
- neural representation invariant
  under broad changes in specific acoustics

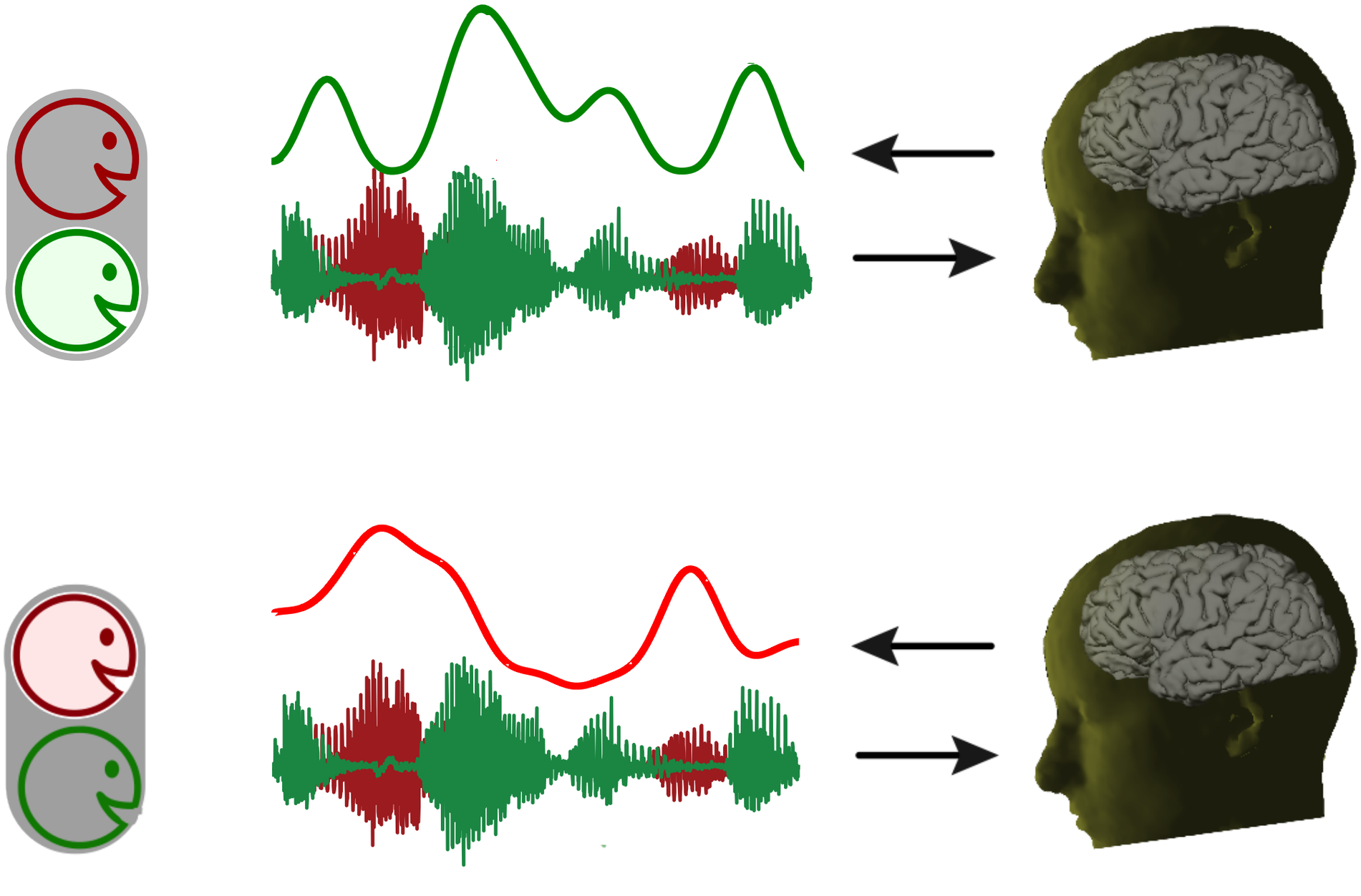
Selective Neural Encoding



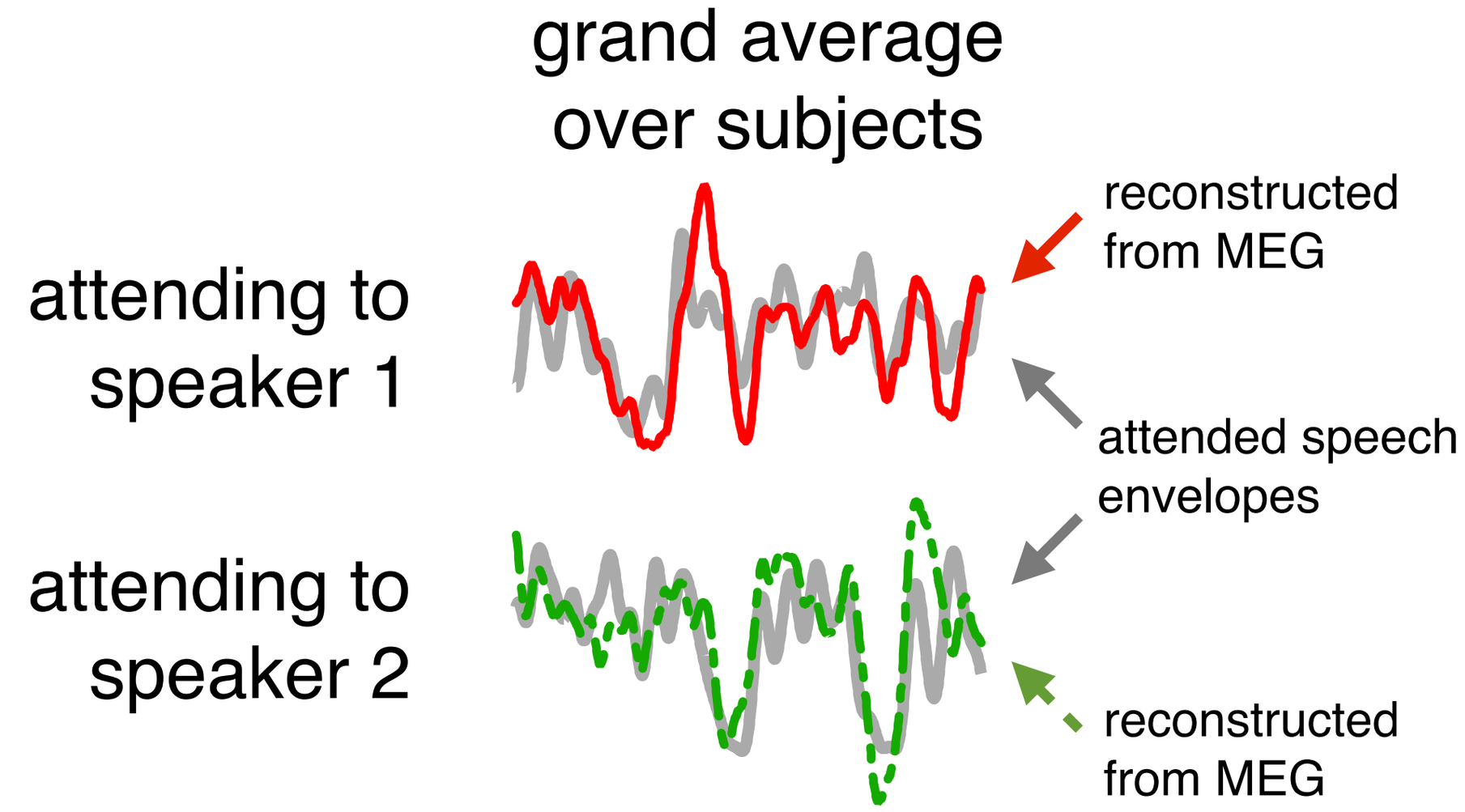
Unselective vs. Selective Neural Encoding



Selective Neural Encoding



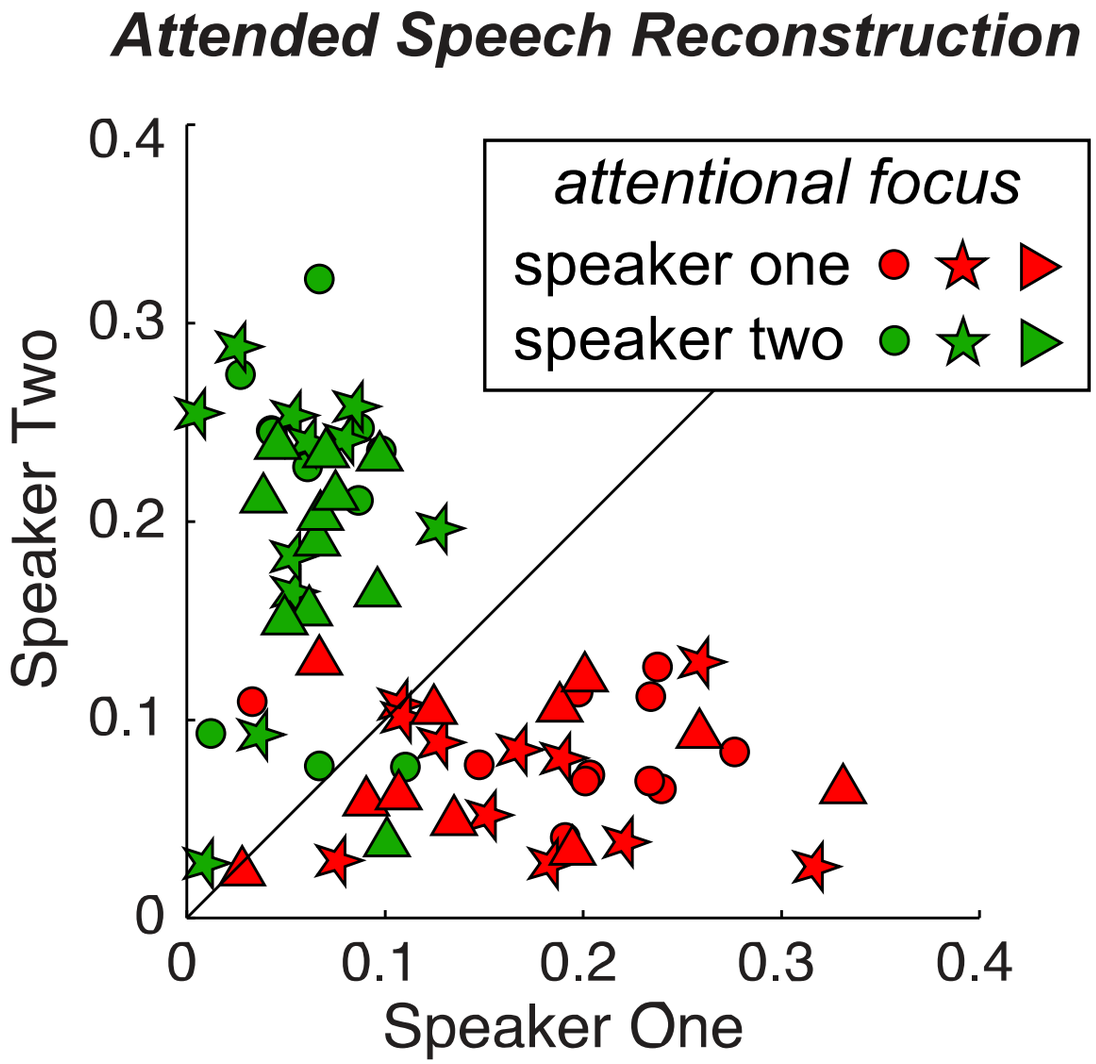
Stream-Specific Representation



Identical Stimuli!

Ding & Simon, PNAS (2012)

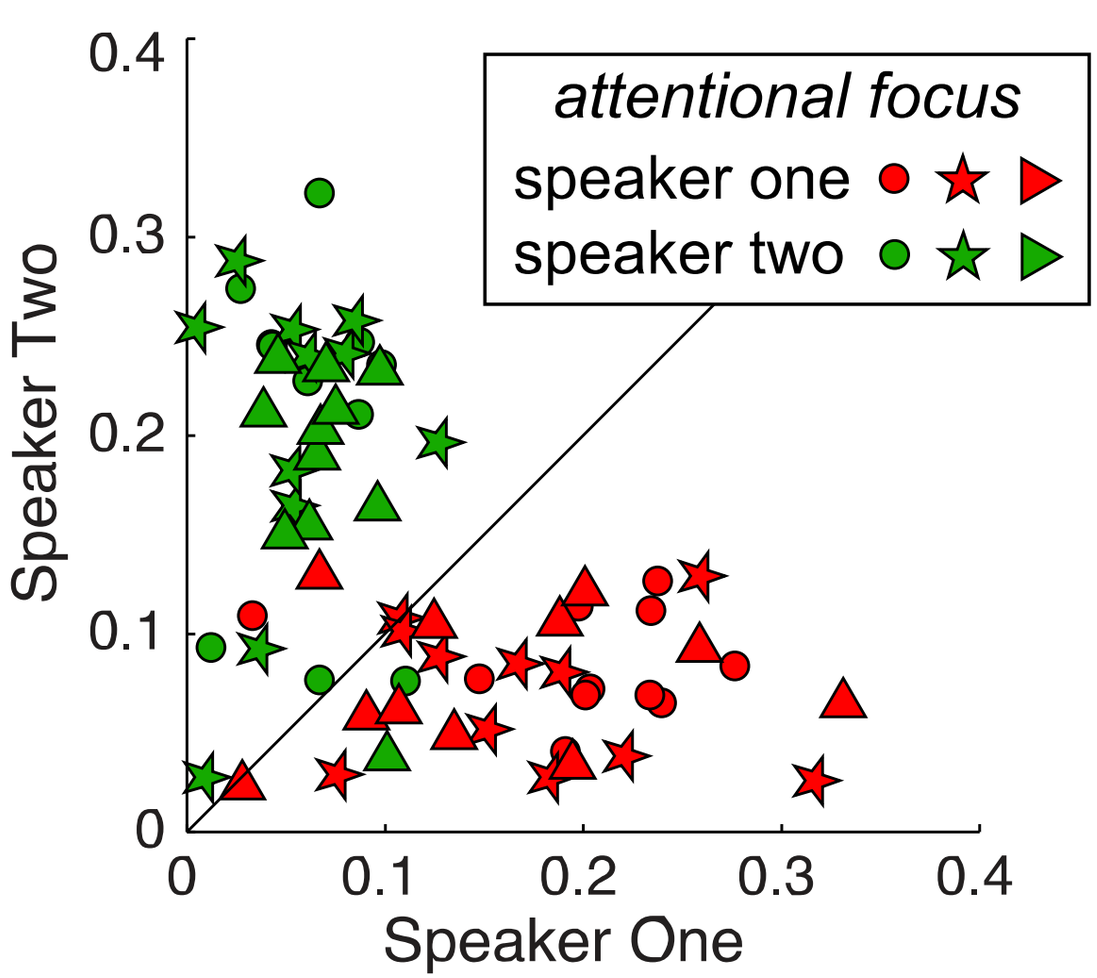
Single Trial Speech Reconstruction



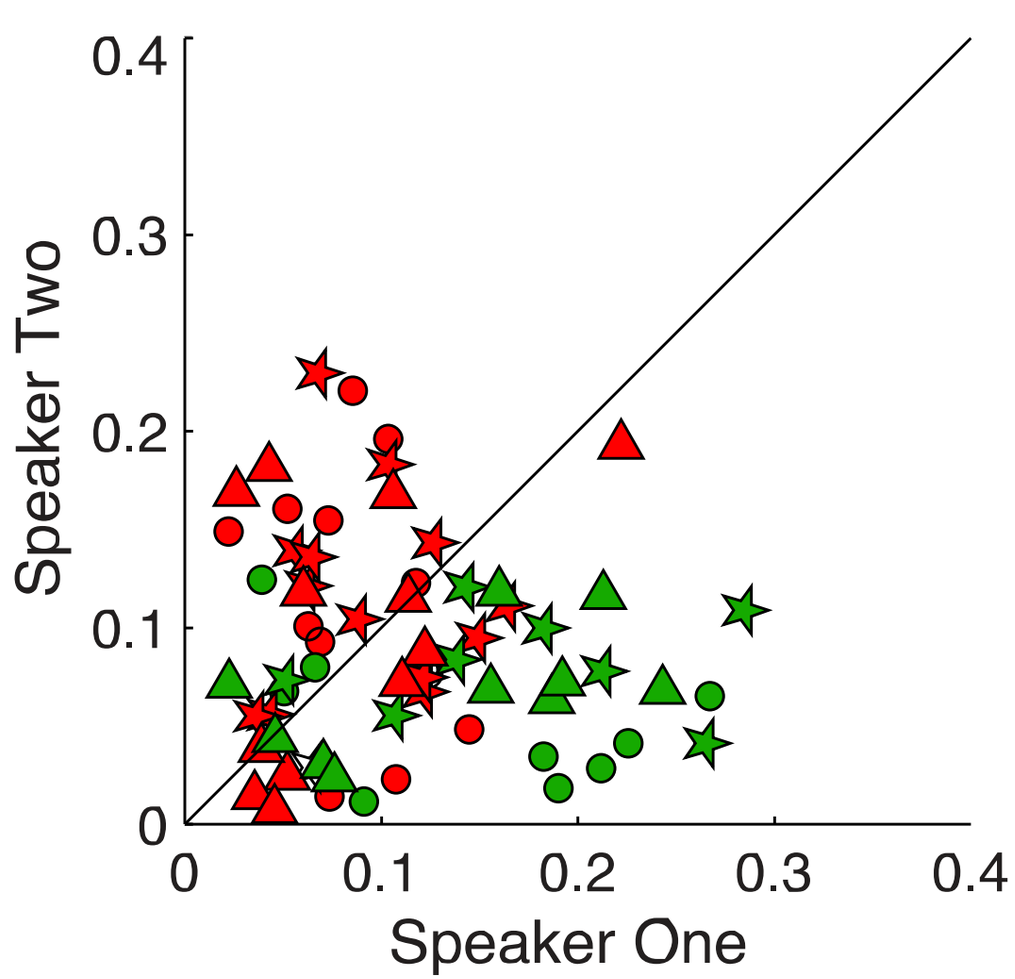
Ding & Simon, PNAS (2013)

Single Trial Speech Reconstruction

Attended Speech Reconstruction

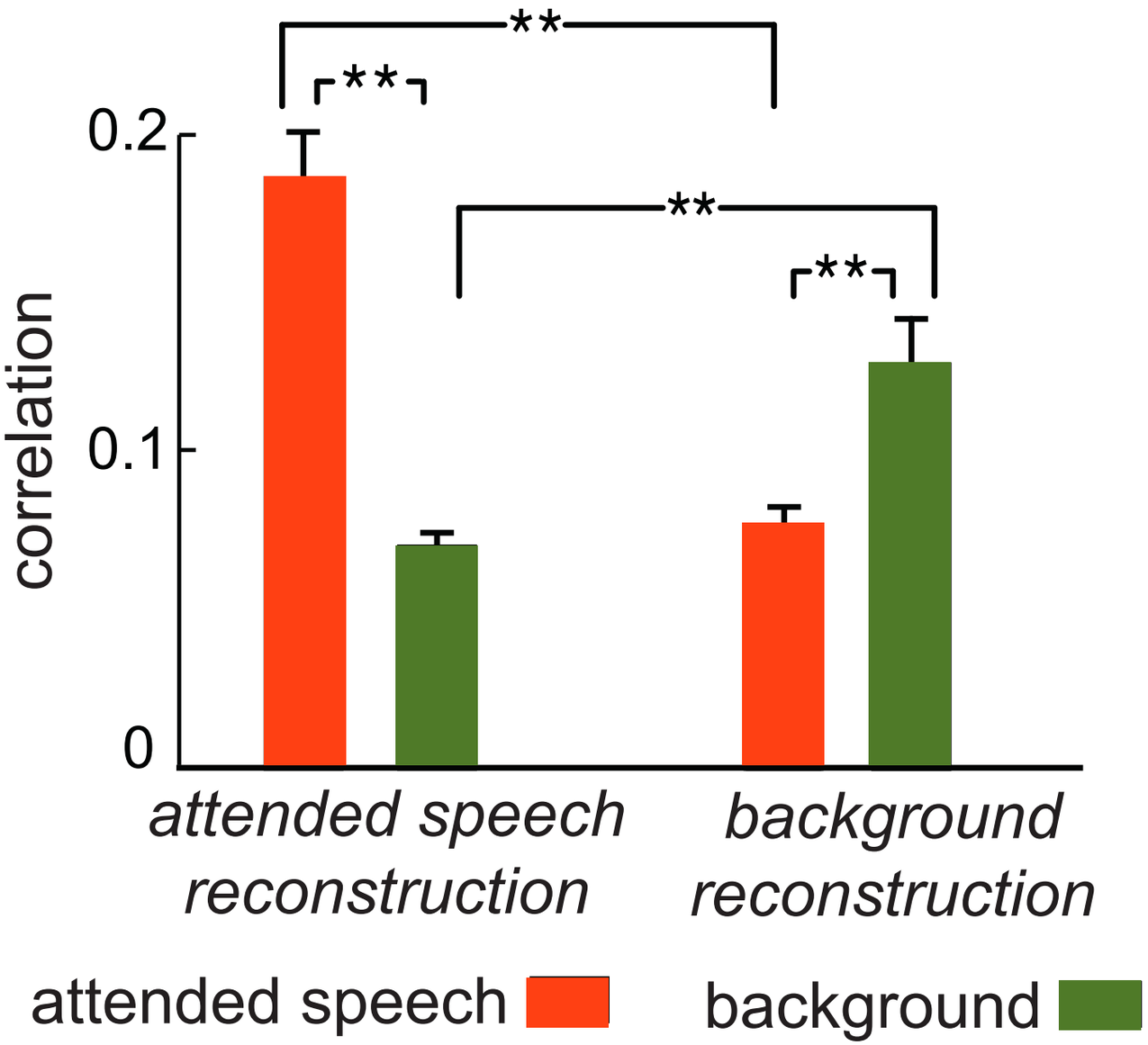


Background Speech Reconstruction



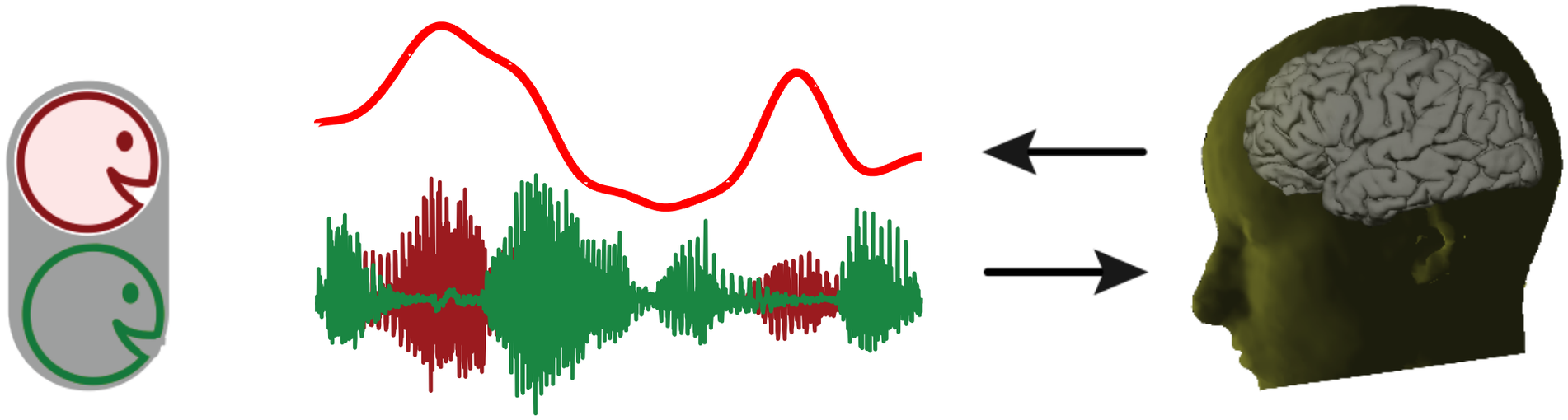
Ding & Simon, PNAS (2013)

Overall Speech Reconstruction

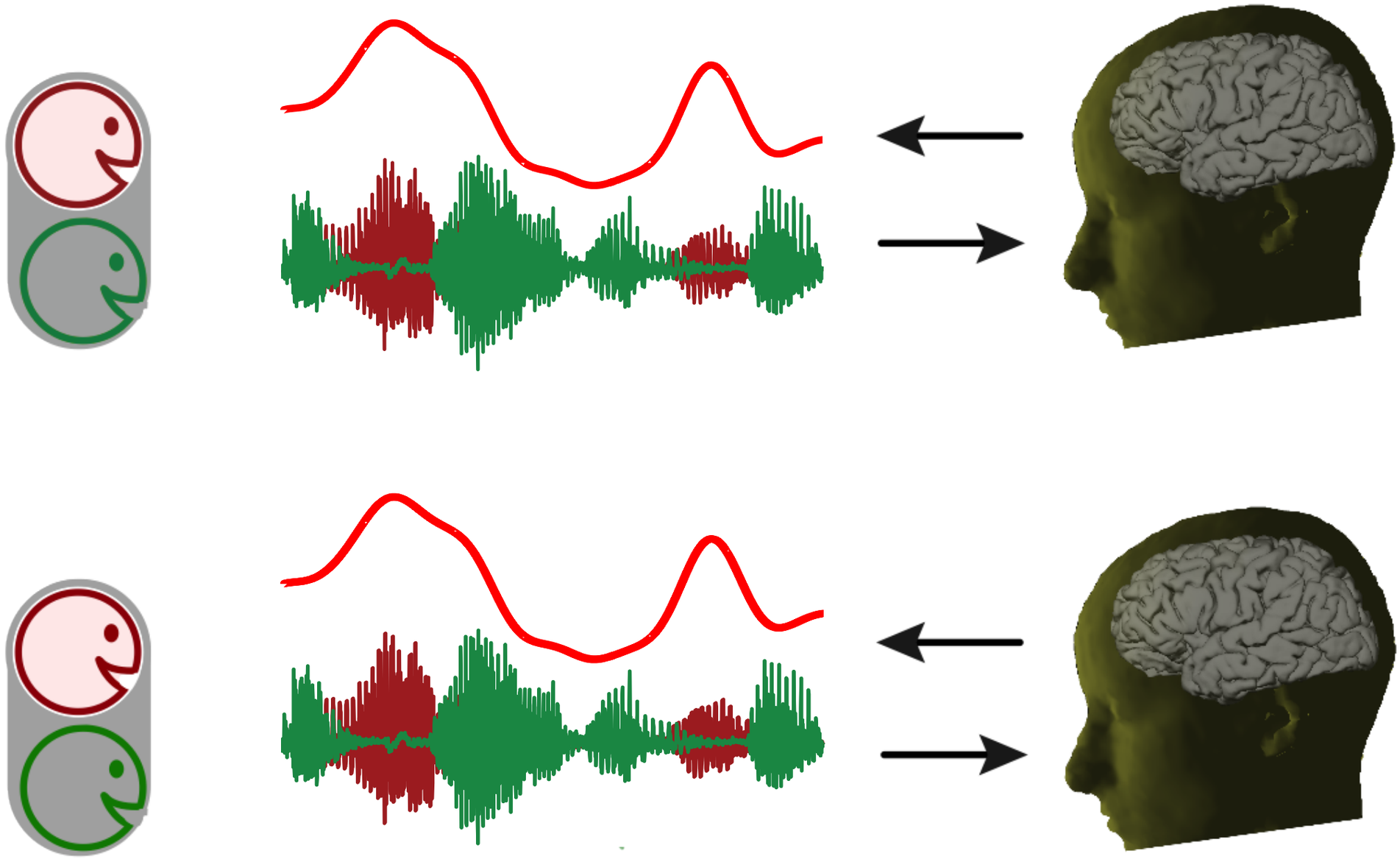


Distinct neural representations for different speech streams

Invariance Under Acoustic Changes



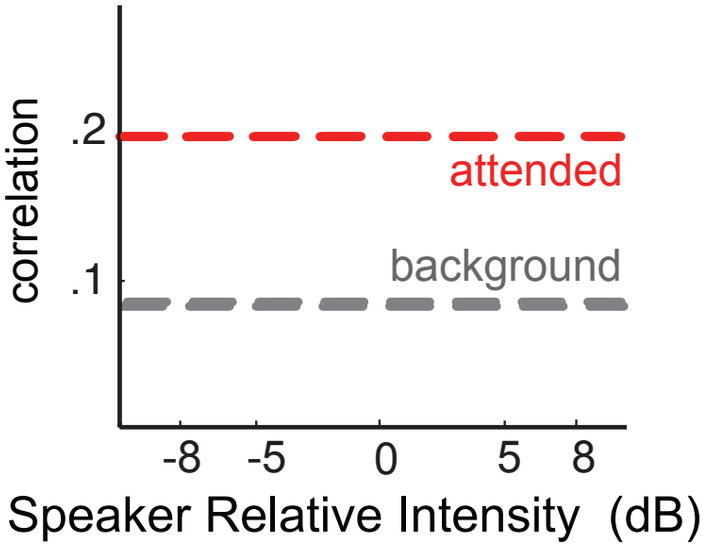
Invariance Under Acoustic Changes



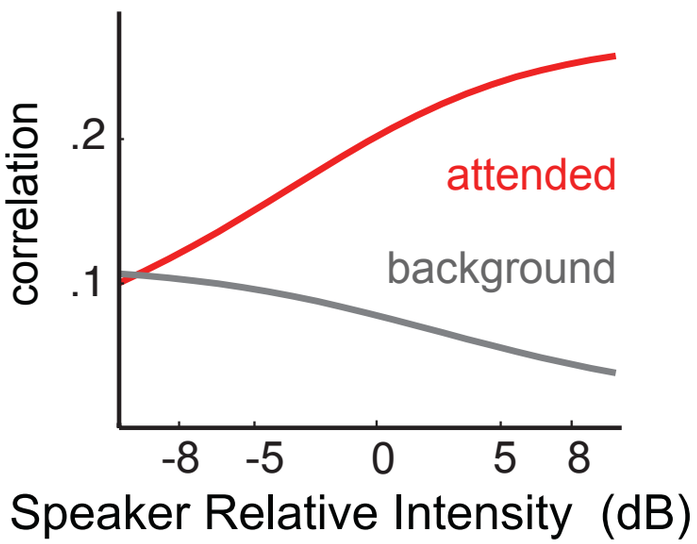
Stream-Based Gain Control?

Gain-Control Models

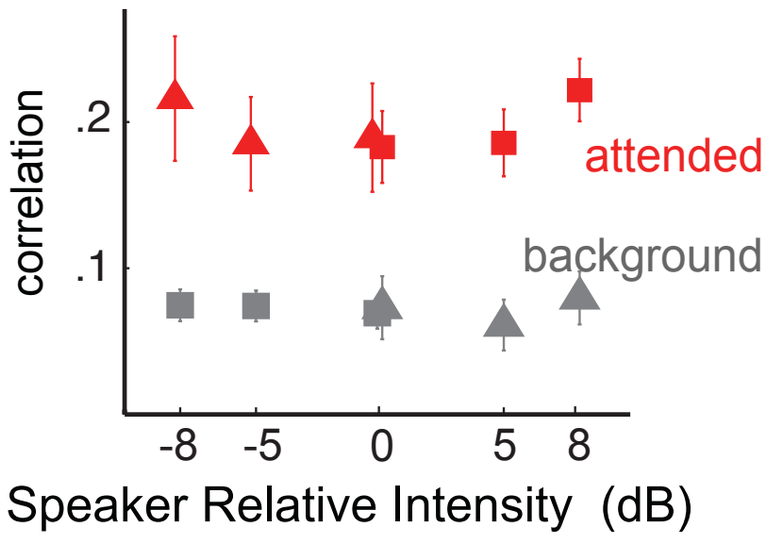
Object-Based



Stimulus- Based



Neural Results



- Stream-based not stimulus-based
- Neural representation is invariant to acoustic changes.

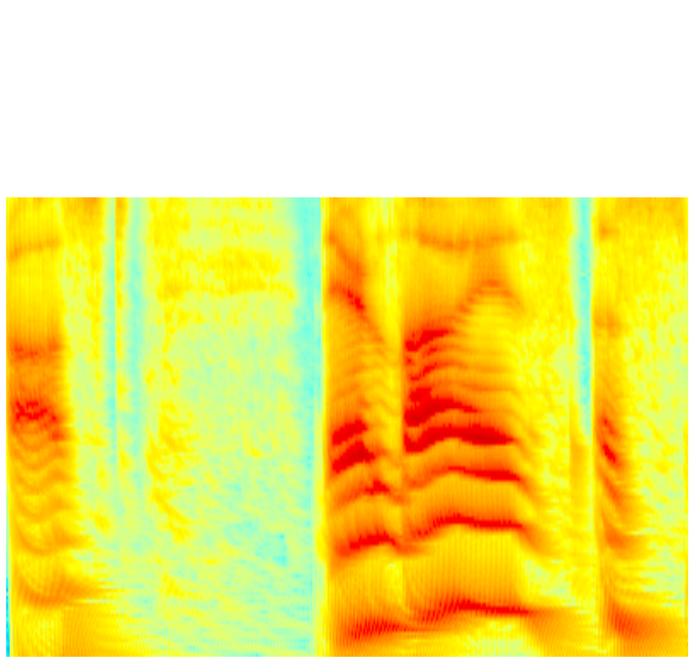
Neural Representation of an Auditory Object

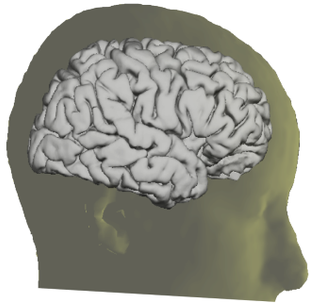
✓ neural representation is of something in sensory world

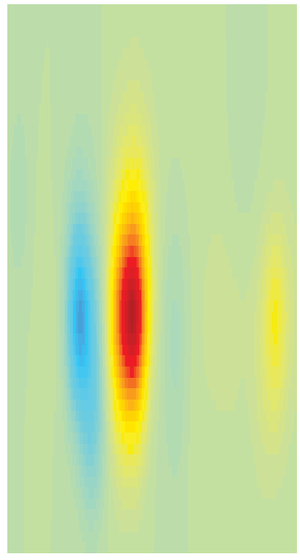
✓ when other sounds mixed in,
neural representation is of auditory object,
not entire acoustic scene

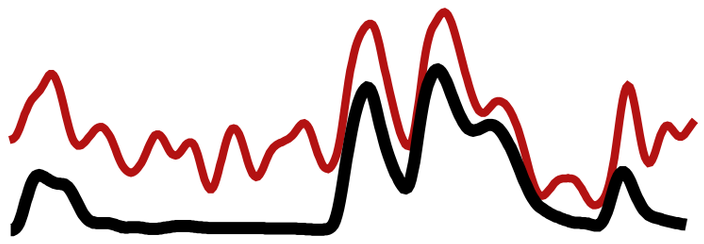
✓ neural representation invariant
under broad changes in specific acoustics

Forward STRF Model



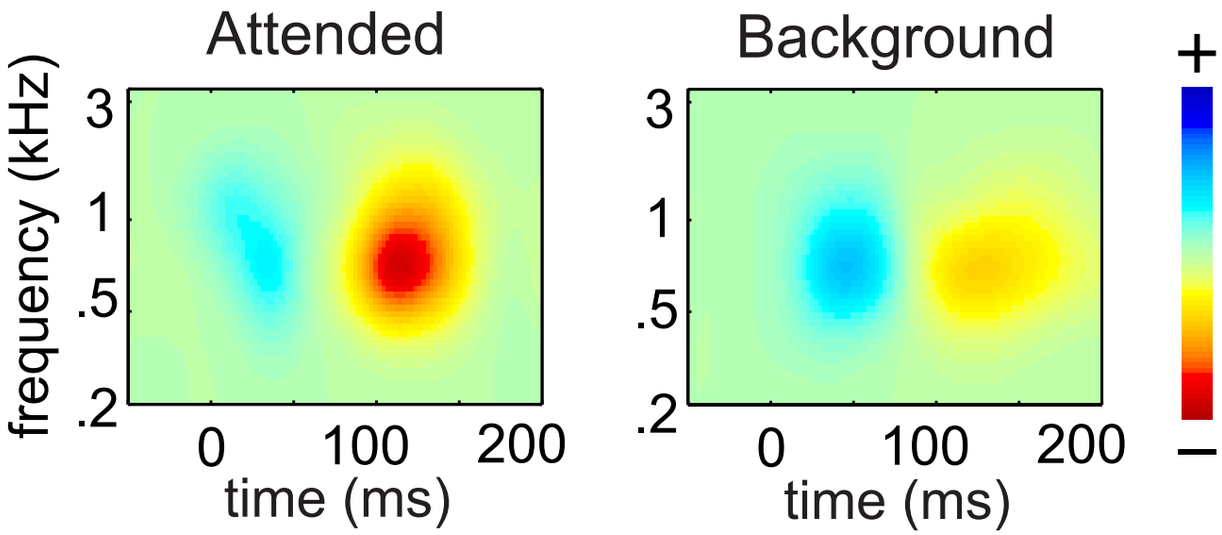






Spectro-Temporal Response Function (STRF)

STRF Results

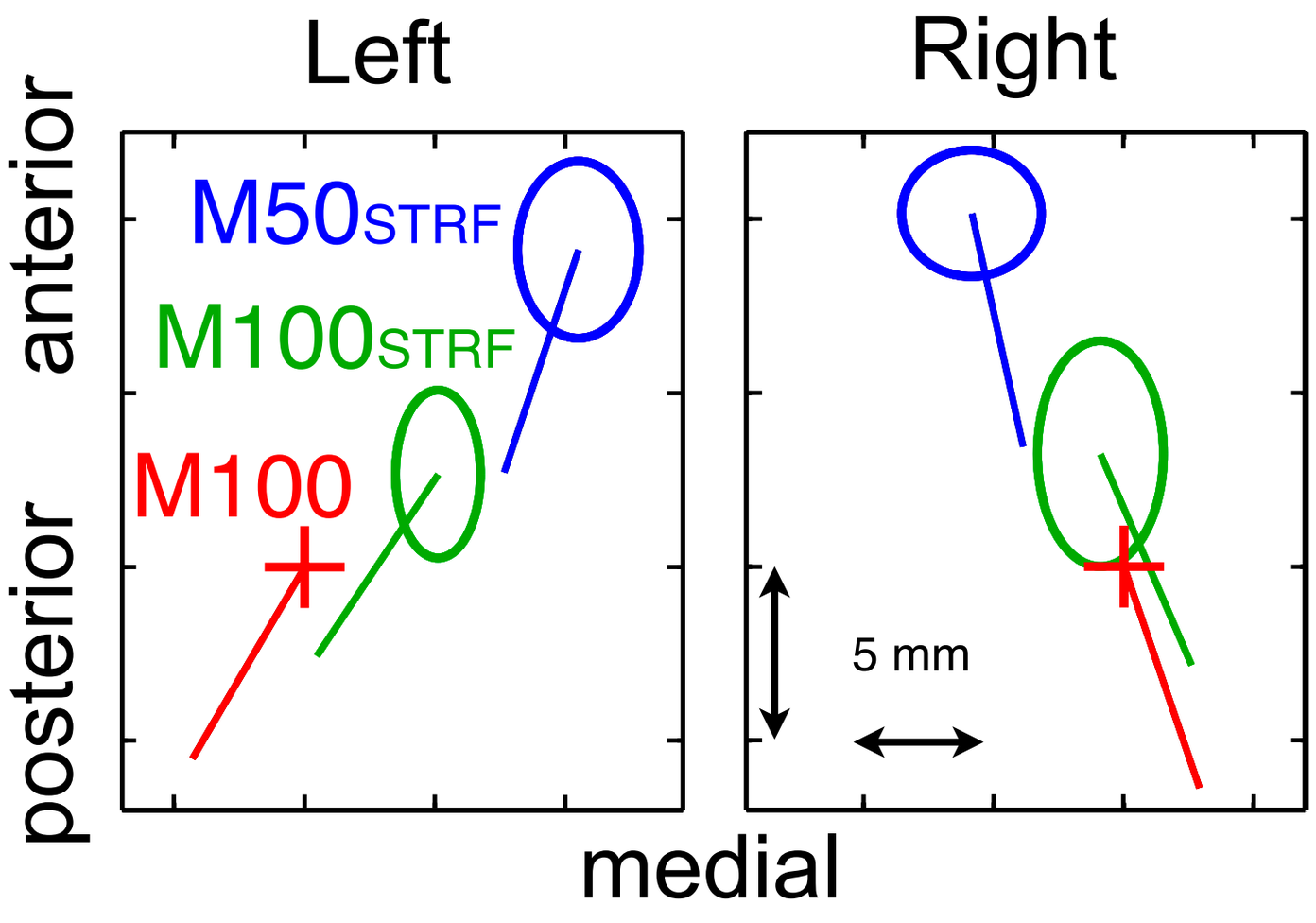


- STRF separable (time, frequency)
- 300 Hz - 2 kHz dominant carriers
- $M50_{STRF}$ positive peak
- $M100_{STRF}$ negative peak

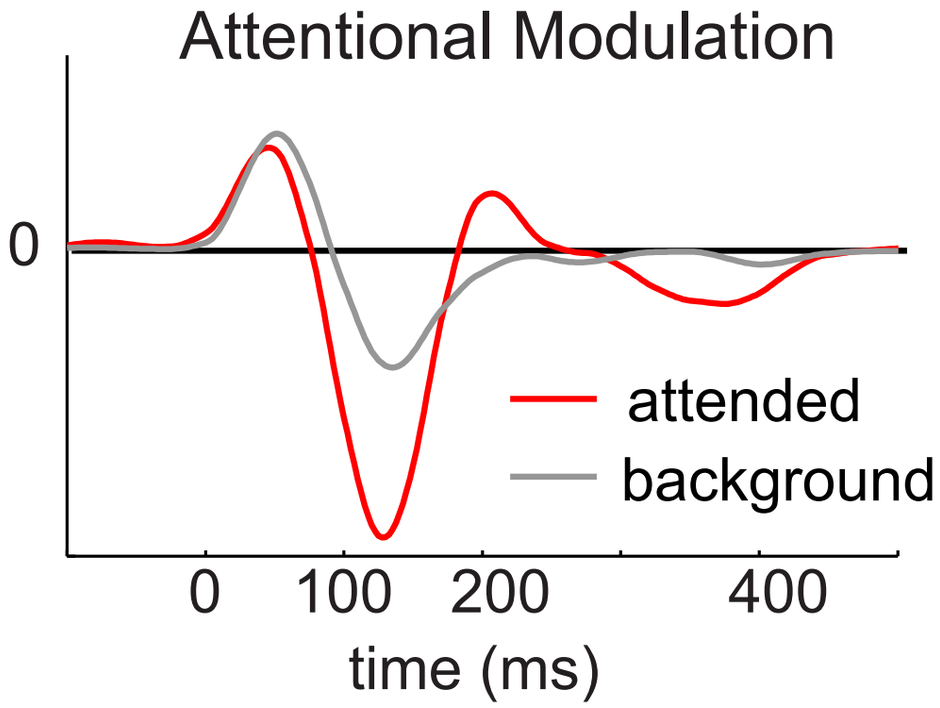
Neural Sources

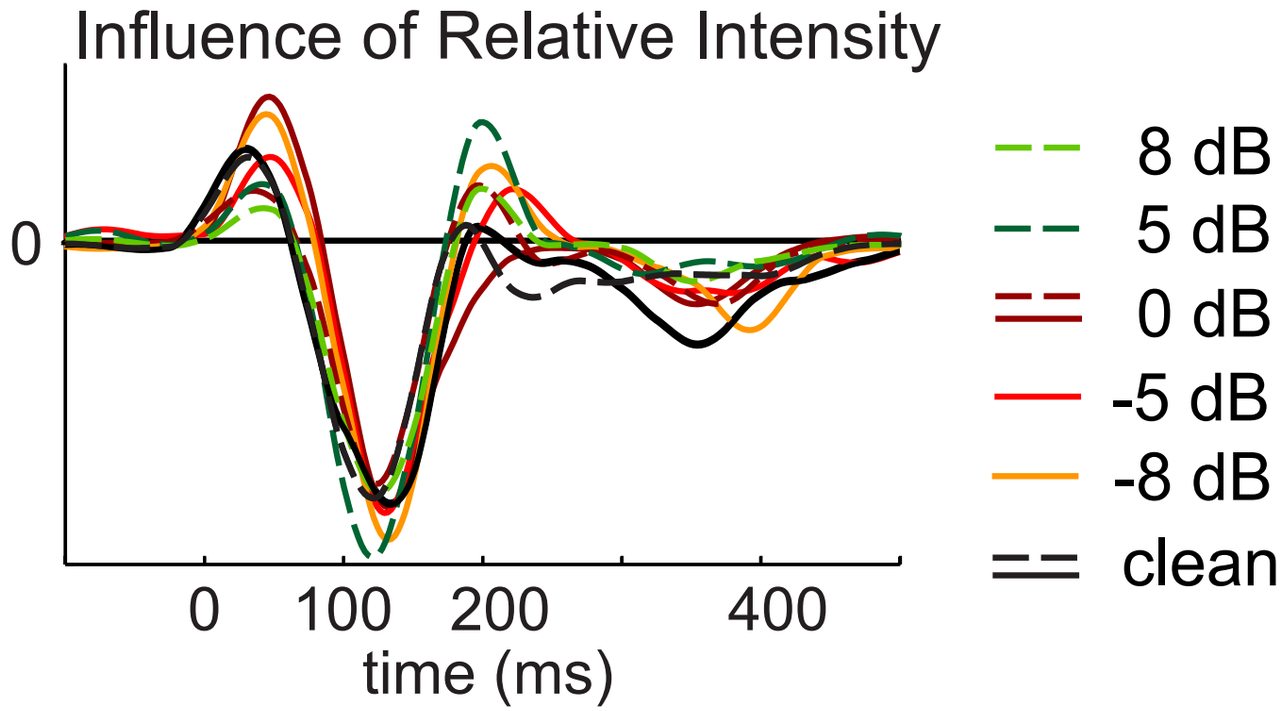
- M100$_{STRF}$ source near (same as?) M100 source: Planum Temporale

- M50$_{STRF}$ source is anterior and medial to M100 (same as M50?): Heschl's Gyrus



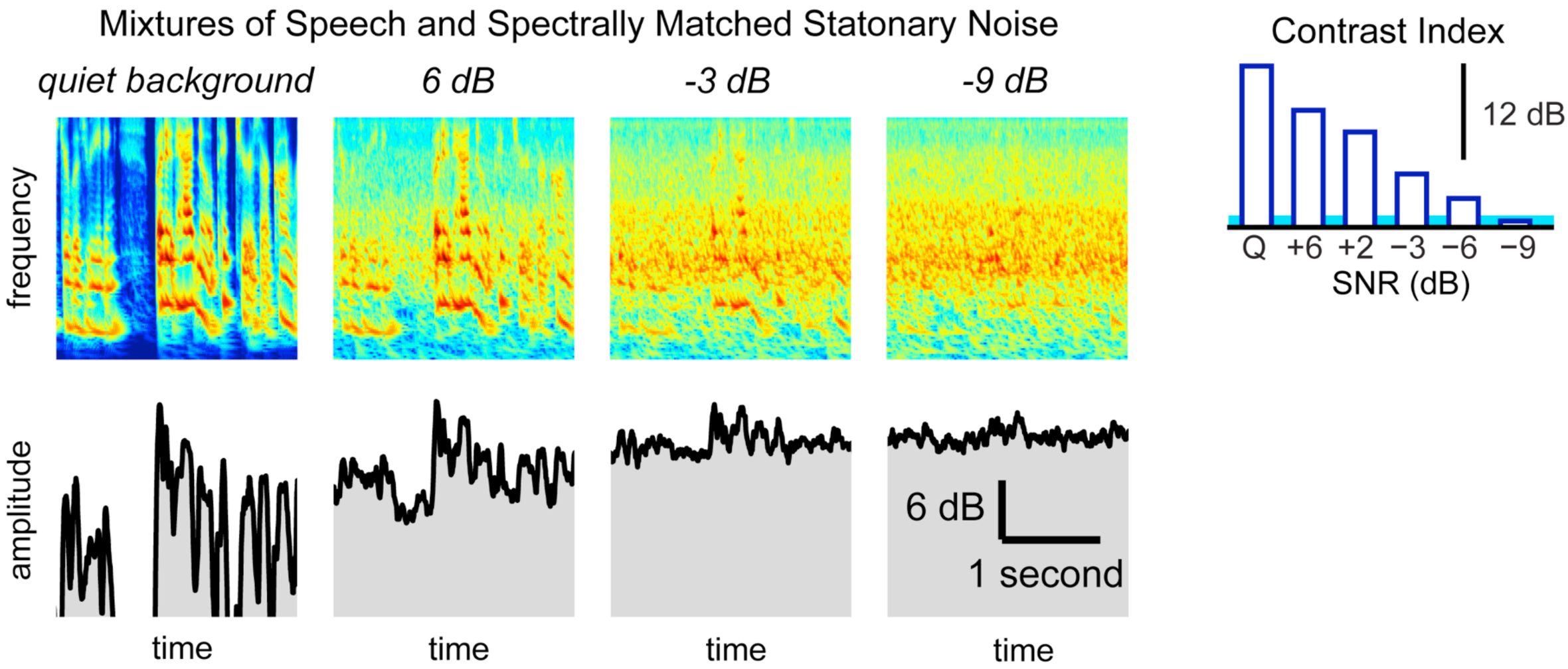
Cortical Object-Processing Hierarchy





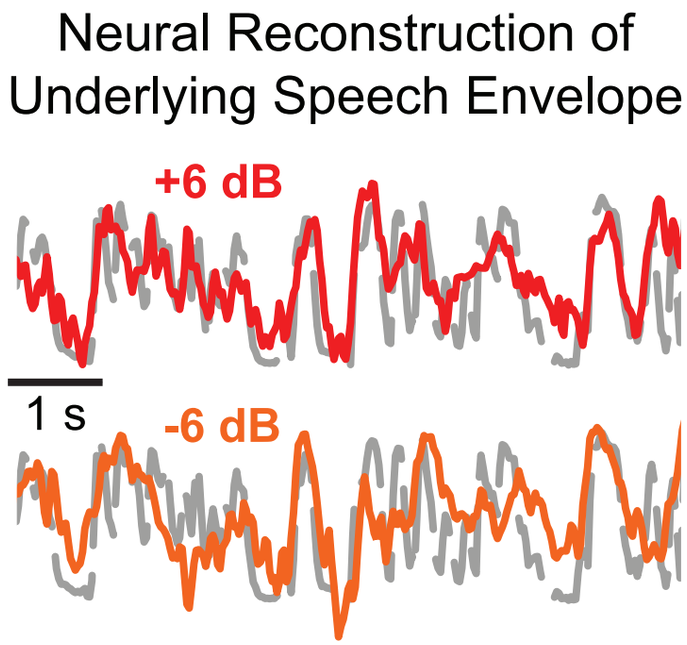
- $M100_{STRF}$ strongly modulated by attention, but not $M50_{STRF}$.
- $M100_{STRF}$ invariant against acoustic changes.
- Objects well-neurally represented at 100 ms, but not 50 ms.

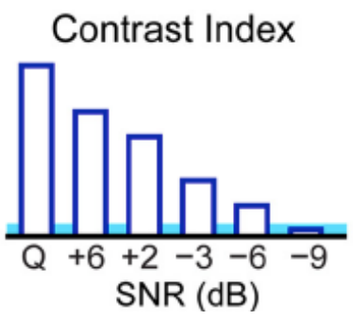
Speech in Noise

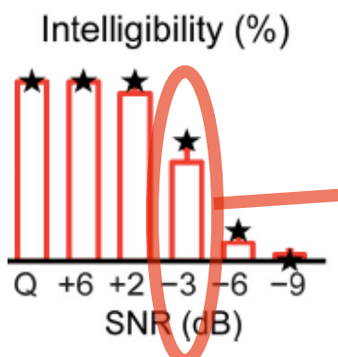


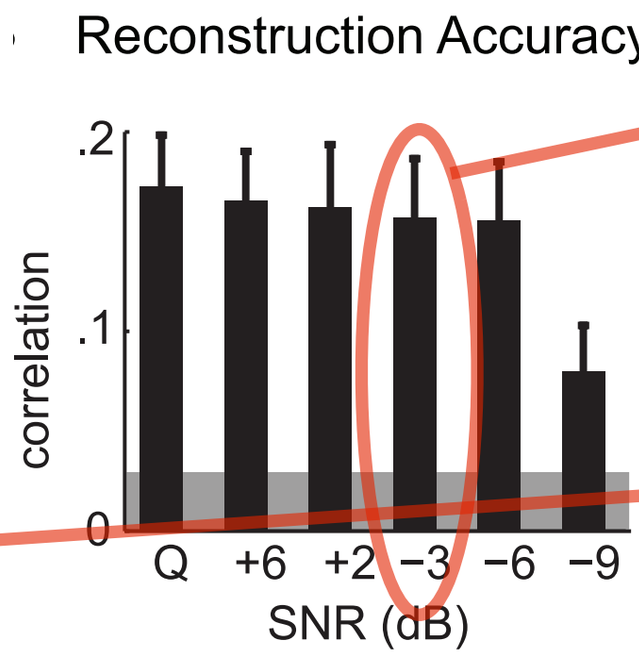
Ding & Simon, J Neuroscience (2013)

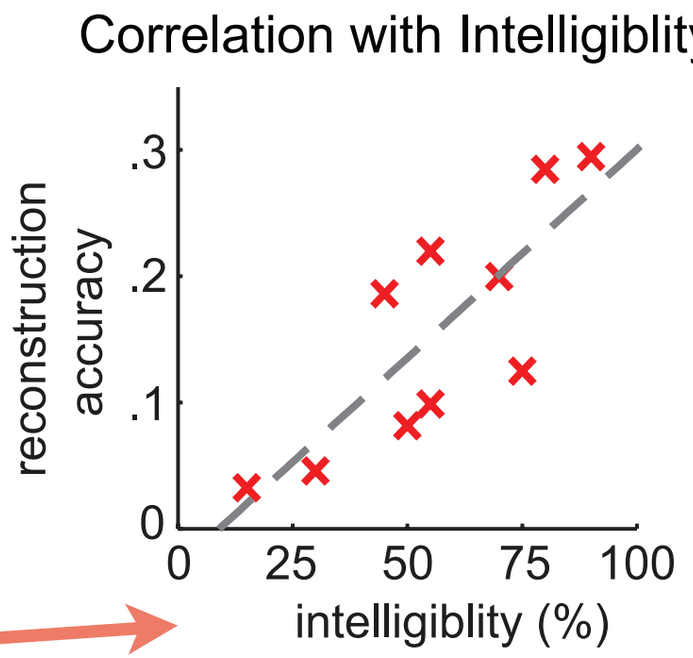
Speech in Noise: Results



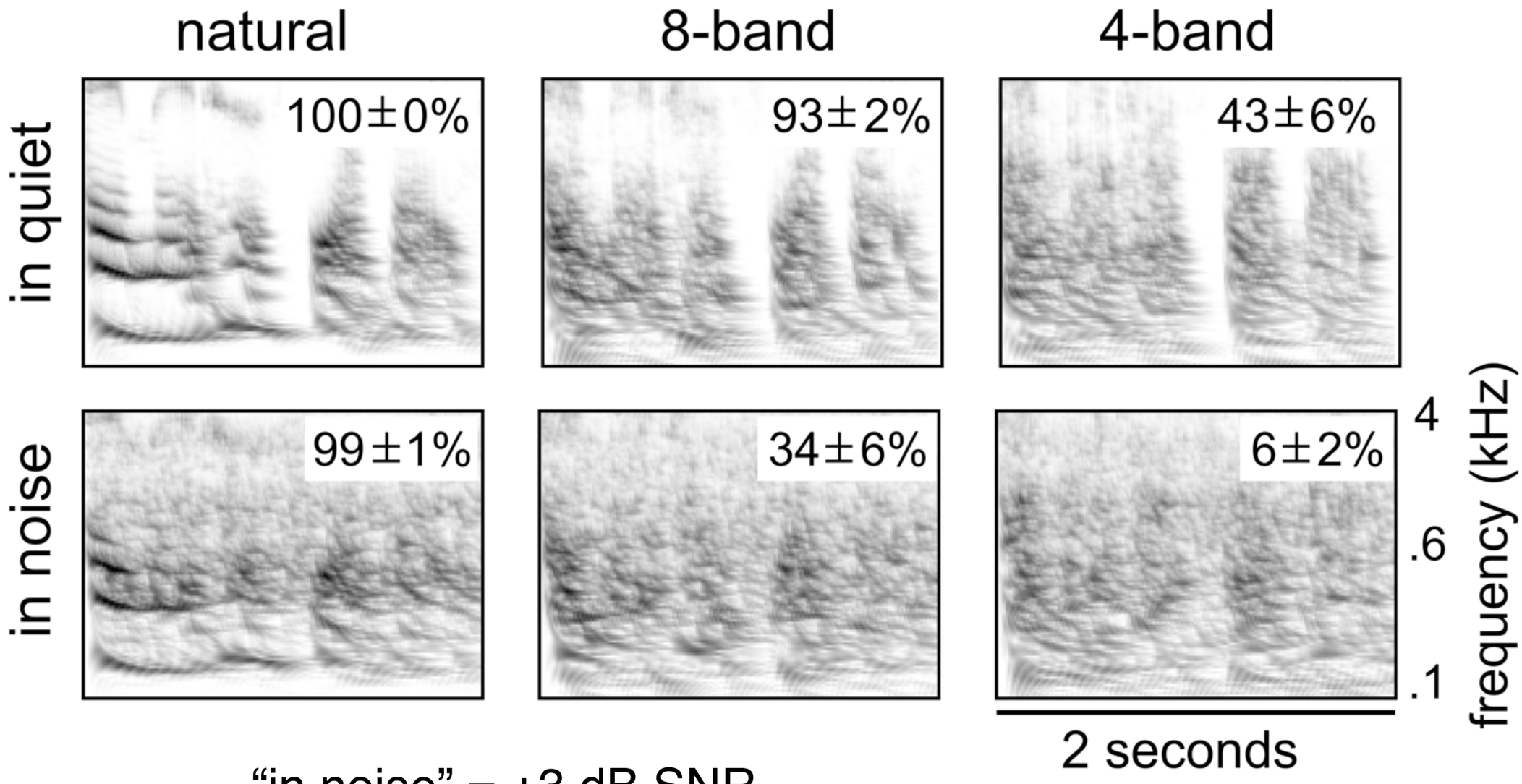








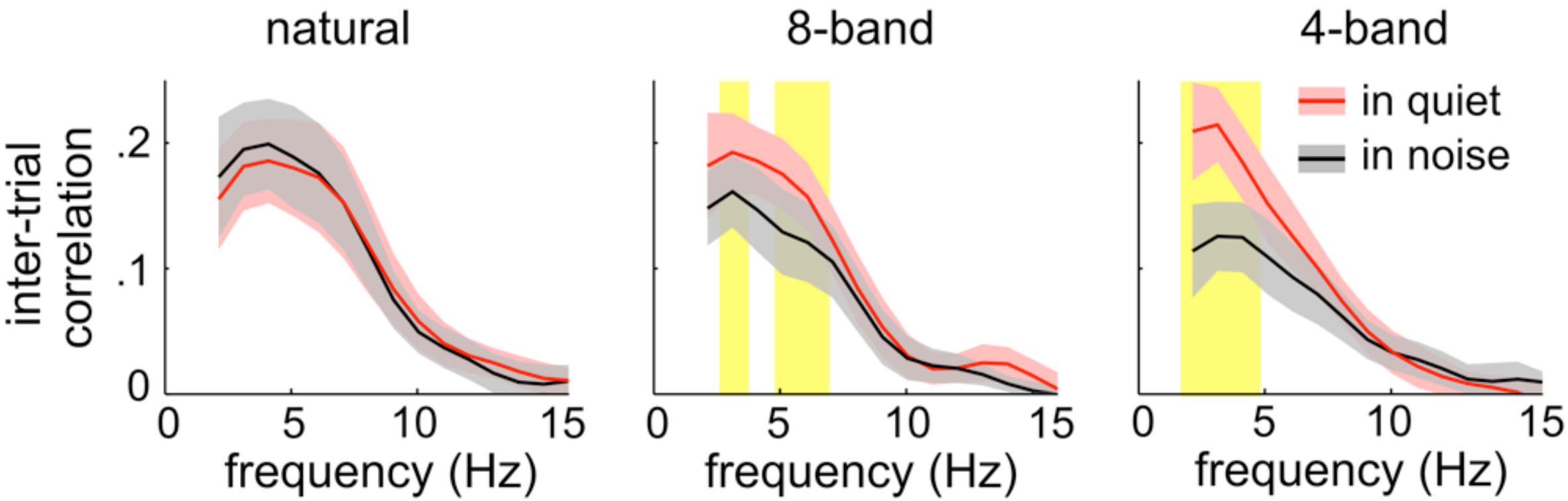
Noise-Vocoded Speech



"in noise" = +3 dB SNR

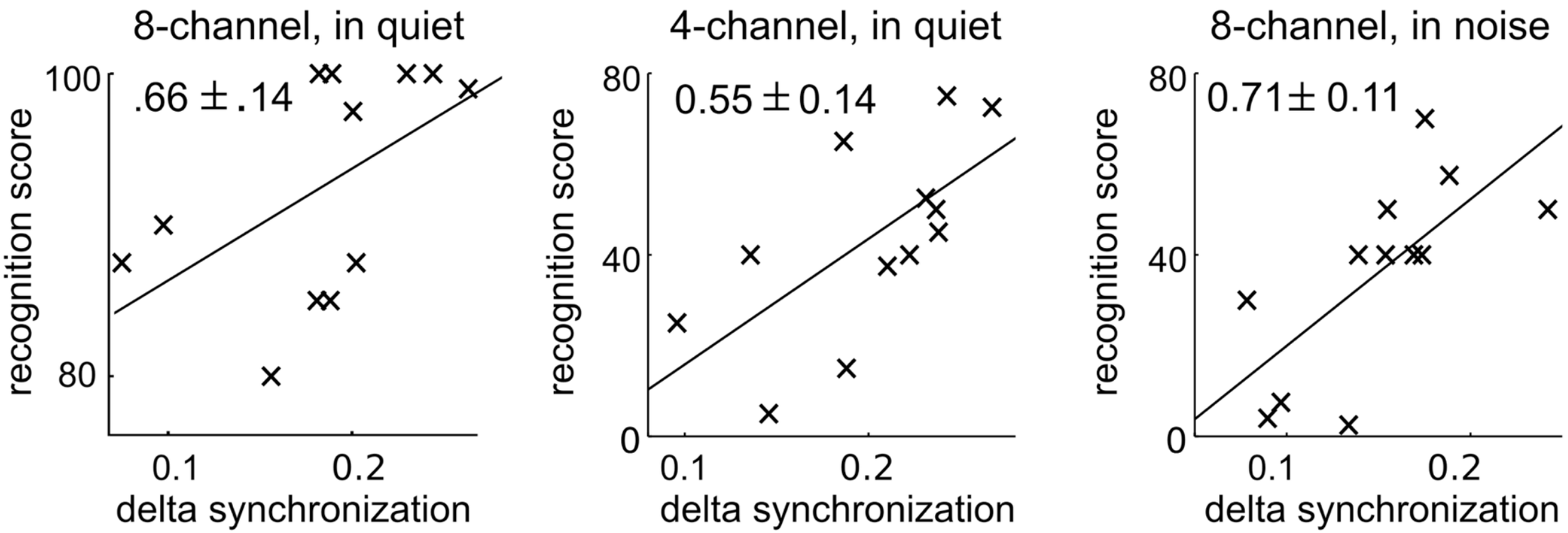
Ding, Chatterjee & Simon, NeuroImage (2014)

Noise-Vocoded Speech: Results



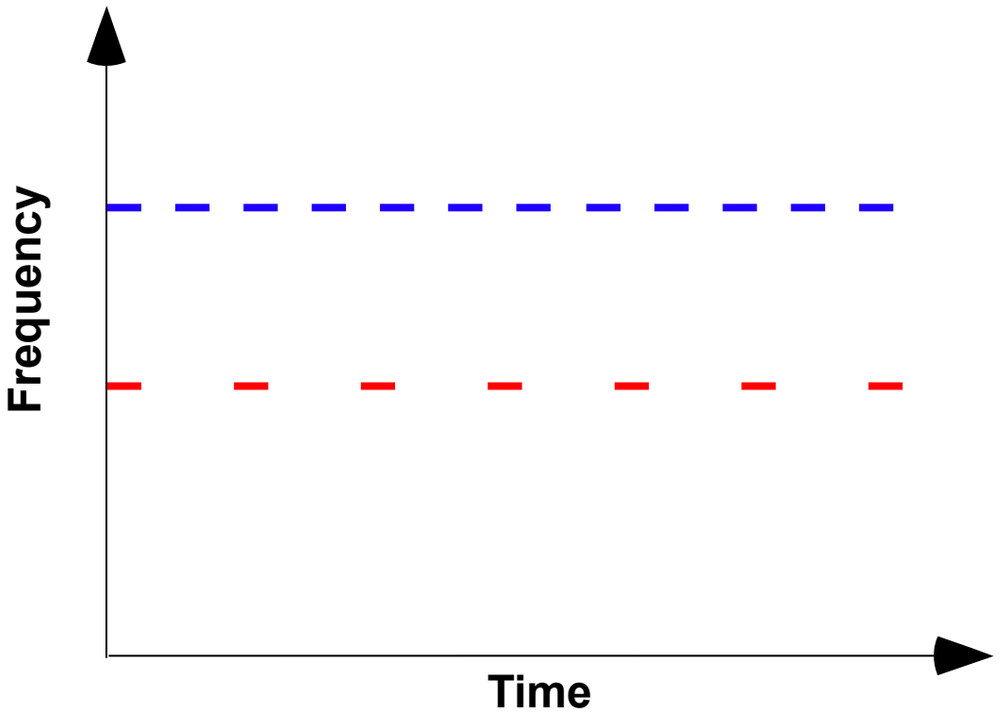
- Cortical entrainment to natural speech robust to noise
- Cortical entrainment to vocoded speech is not
- Not explainable by passive envelope tracking mechanisms
  - noise vocoding does not directly affect the stimulus envelope

Noise-Vocoded Speech: Results



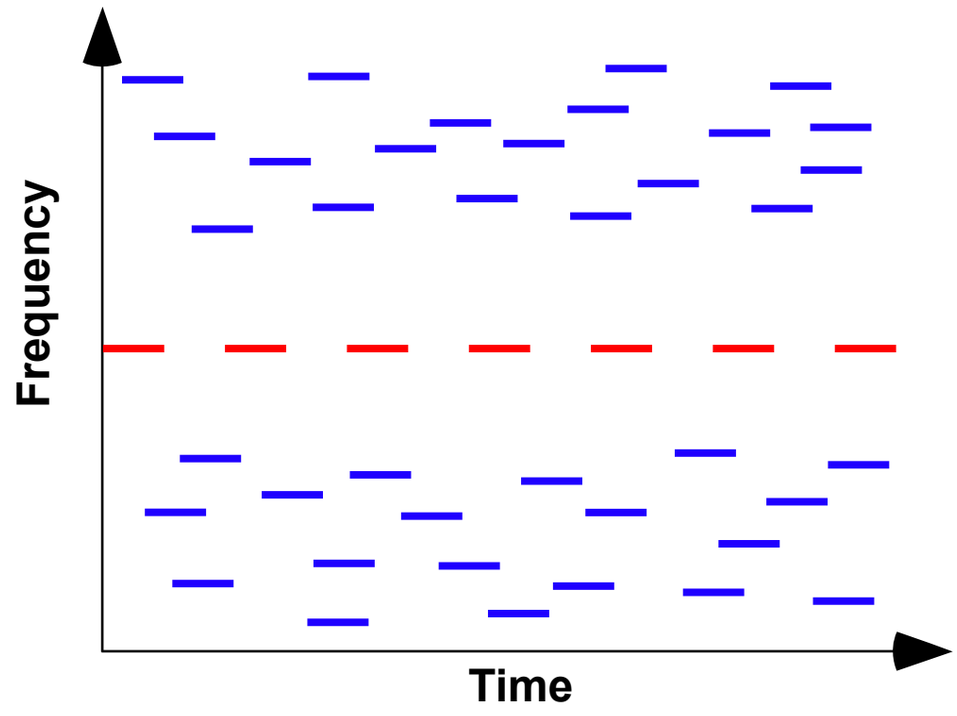
Not Just Speech

Competing Tone Streams



Xiang et al., J Neuroscience (2010)

Tone Stream in Masker Cloud



Elhilali et al., PLoS Biology (2009)

Summary

- Cortical representations of speech found here:
  - ✓ consistent with being *neural* representations of auditory *perceptual* objects
    - ✓ very robust to noise (~intelligibility)
    - ✓ relies on *spectro*-temporal fine structure
    - ✓ explicitly temporal representation
- Object representation at 100 ms latency (PT), but not by 50 ms (HG)

Thank You