Cortical Encoding of Auditory Objects at the Cocktail Party

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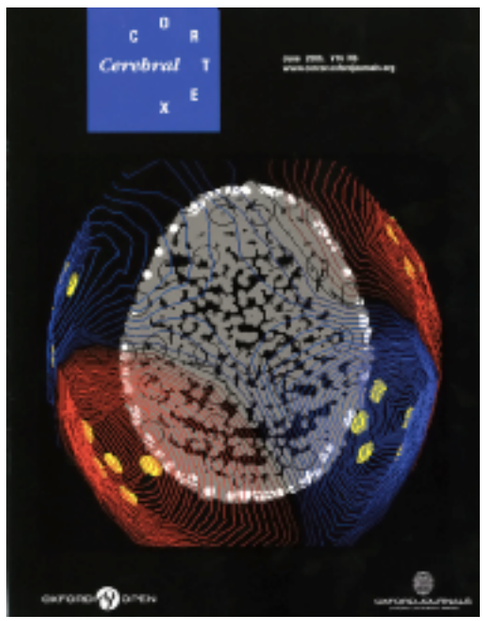
Biology Department Seminar September 20, 2013

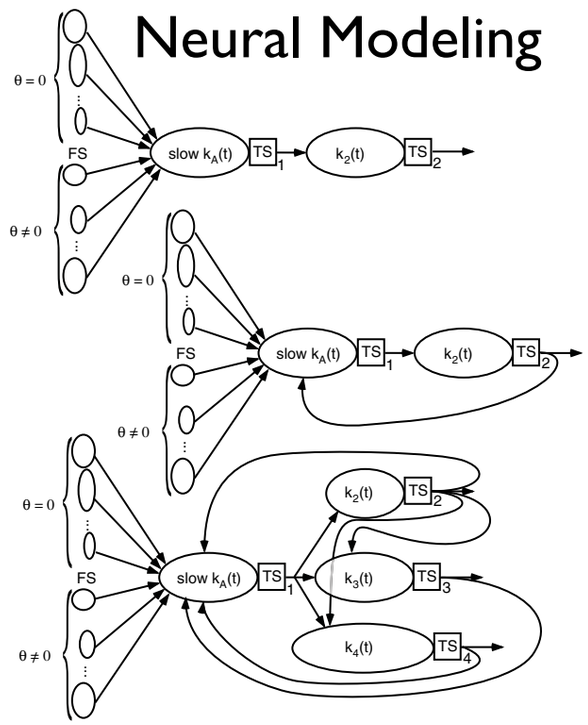
Jonathan Z. Simon

Neural processing of speech and complex auditory streams

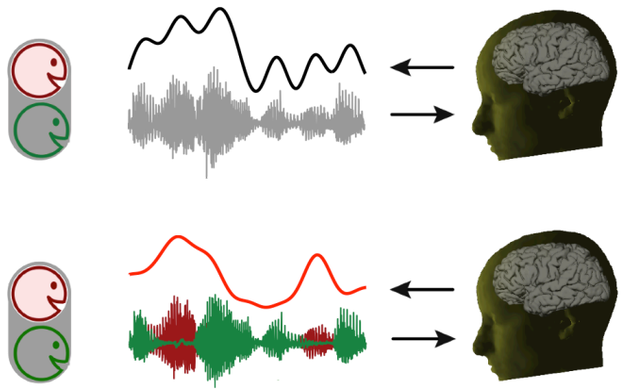
Magnetoencephalography



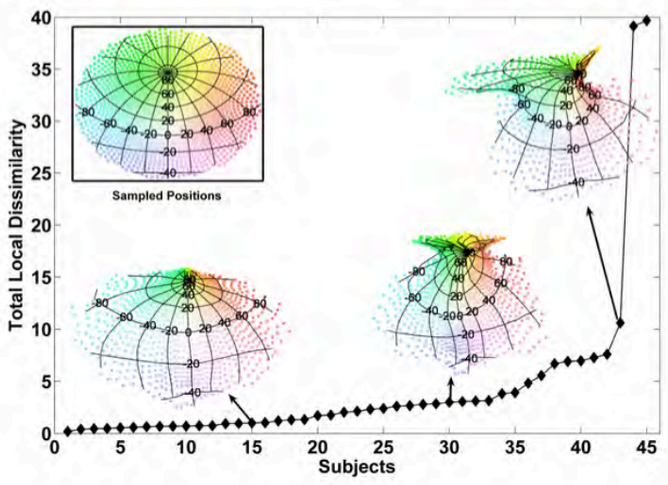
Neural Modeling



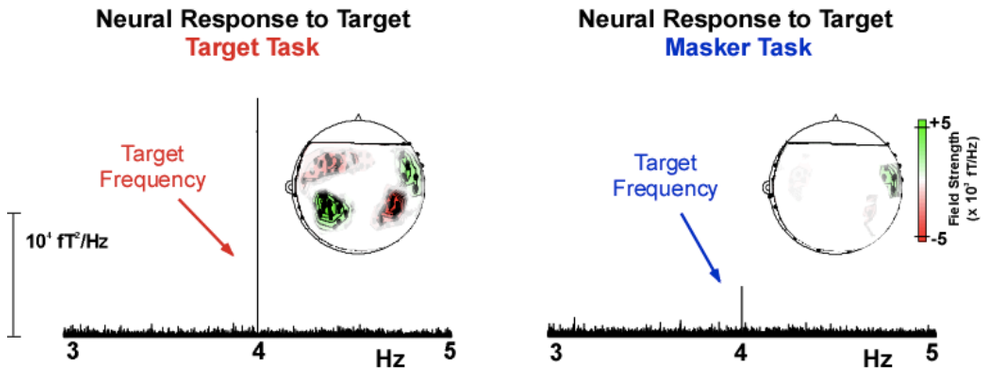
Neural Un-Mixing of Speech



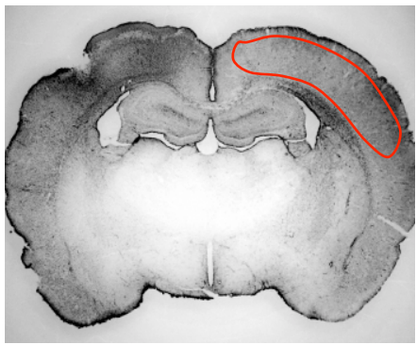
Neurally Inspired Algorithms



Neural Signal Processing



Advanced Neuroimaging



Acknowledgements

Grad Students

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Alex Presacco
Krishna Puvvada

Past Grad Students

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Funding

NIH R01 DC 008342
NIH R01 DC 007657
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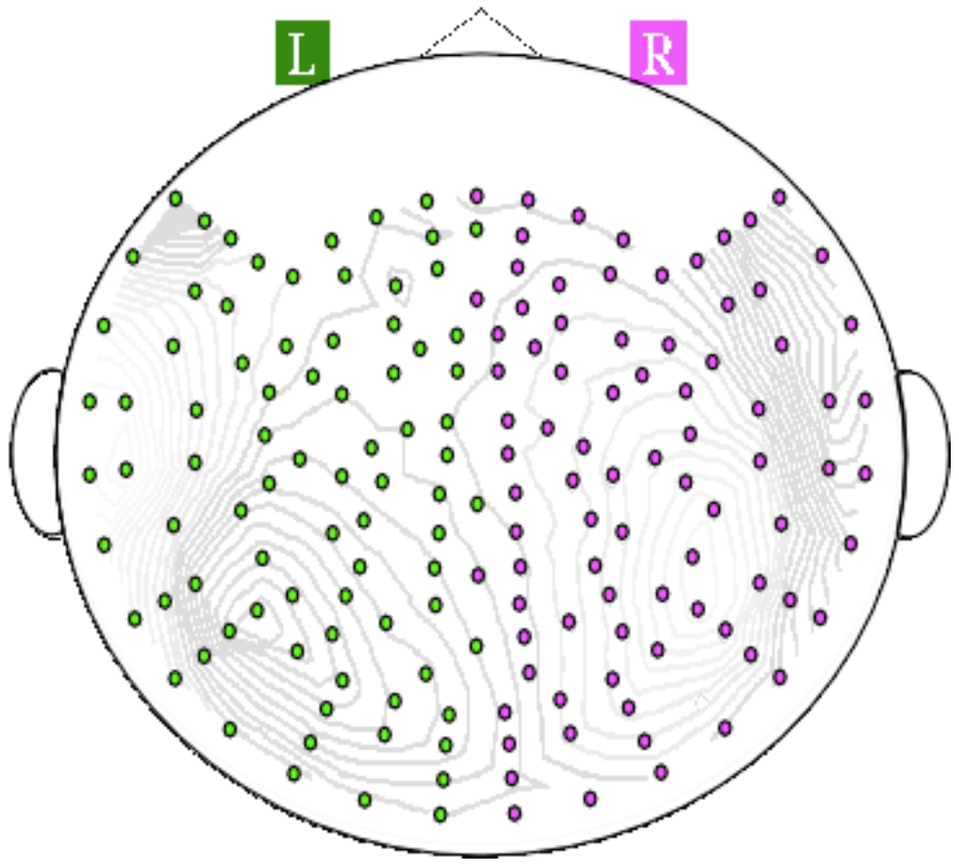
Introduction

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

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

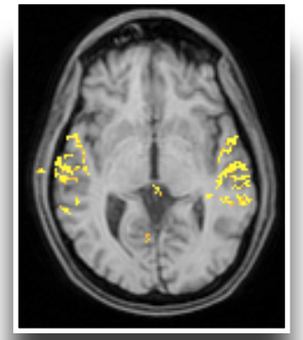


Functional Brain Imaging

Functional Brain Imaging
= Non-invasive recording from human brain

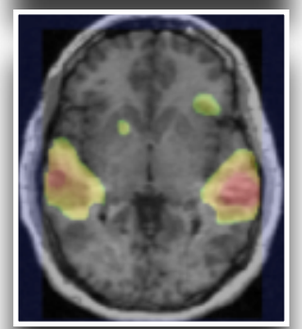
Hemodynamic techniques

fMRI
functional magnetic resonance imaging



Excellent Spatial Resolution **(~1 mm)**

PET
positron emission tomography

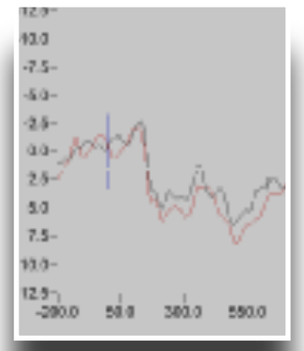


Poor Temporal Resolution **(~1 s)**

fMRI & MEG can capture effects in single subjects

Electromagnetic techniques

EEG
electroencephalography



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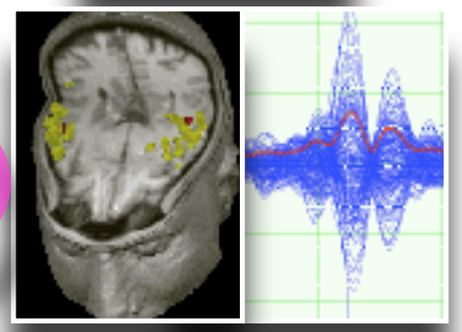

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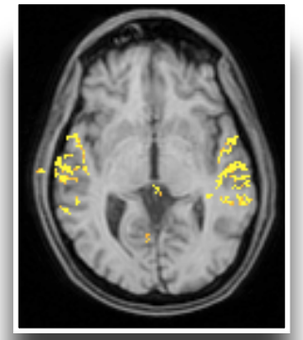

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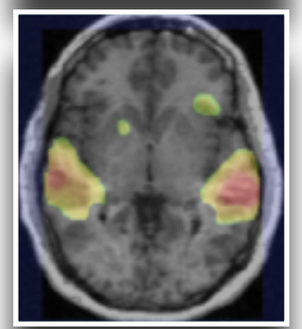

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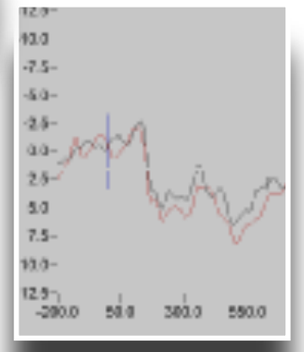

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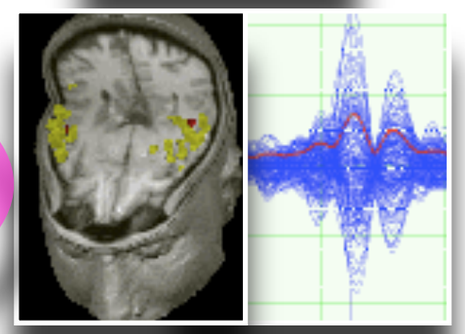

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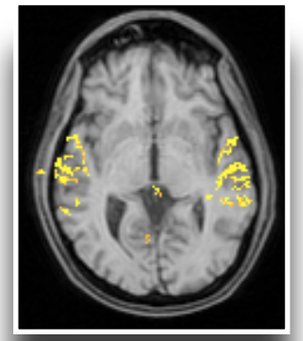

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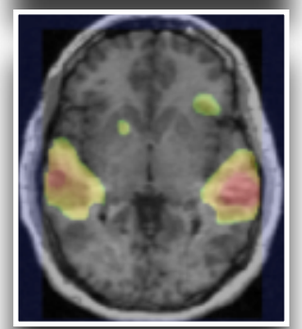

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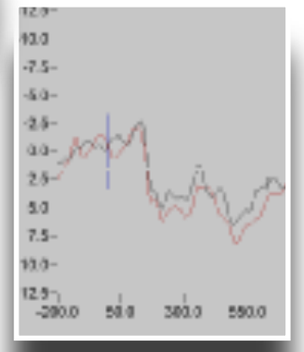

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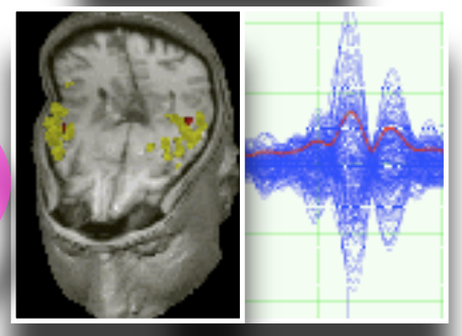


Excellent Temporal Resolution **(~1 ms)**

Neural Signals & MEG

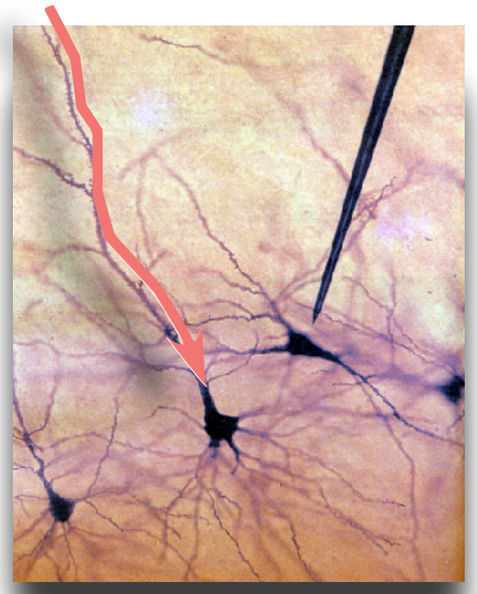
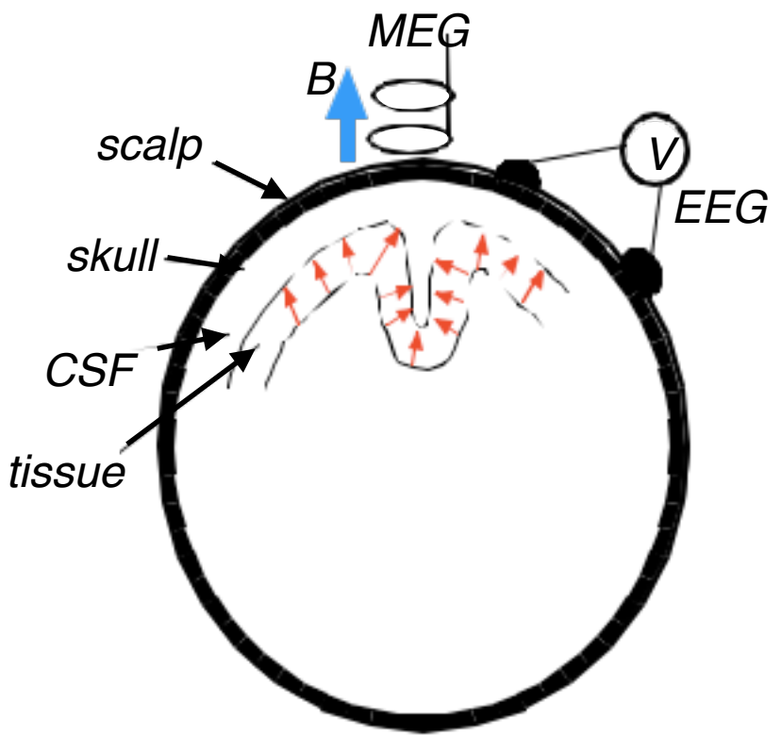
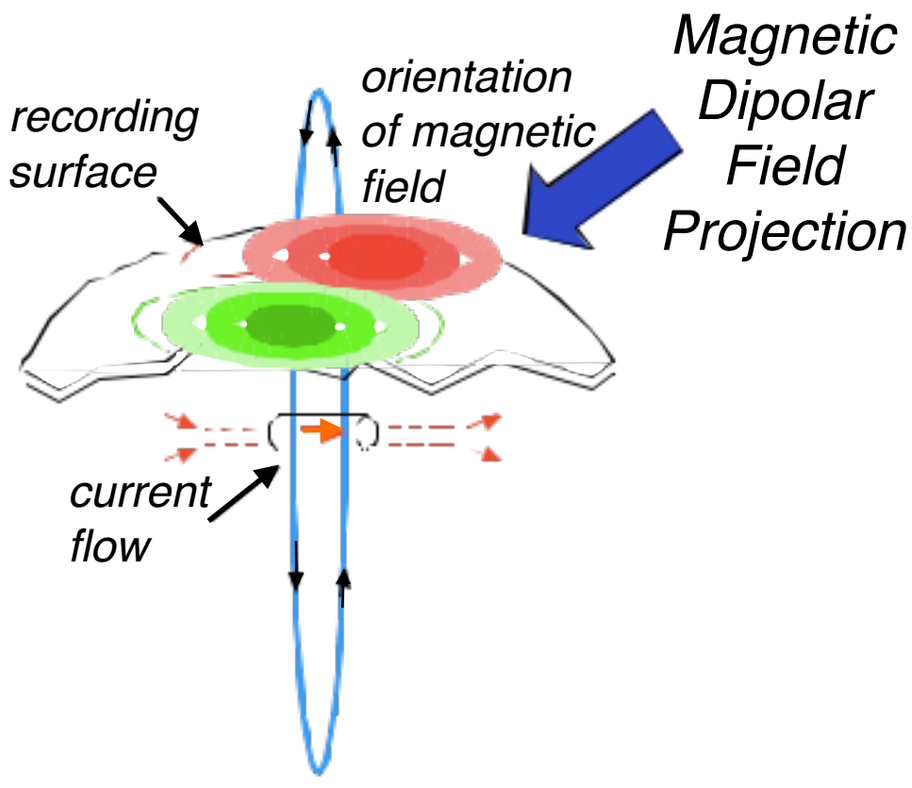


Photo by Fritz Goro





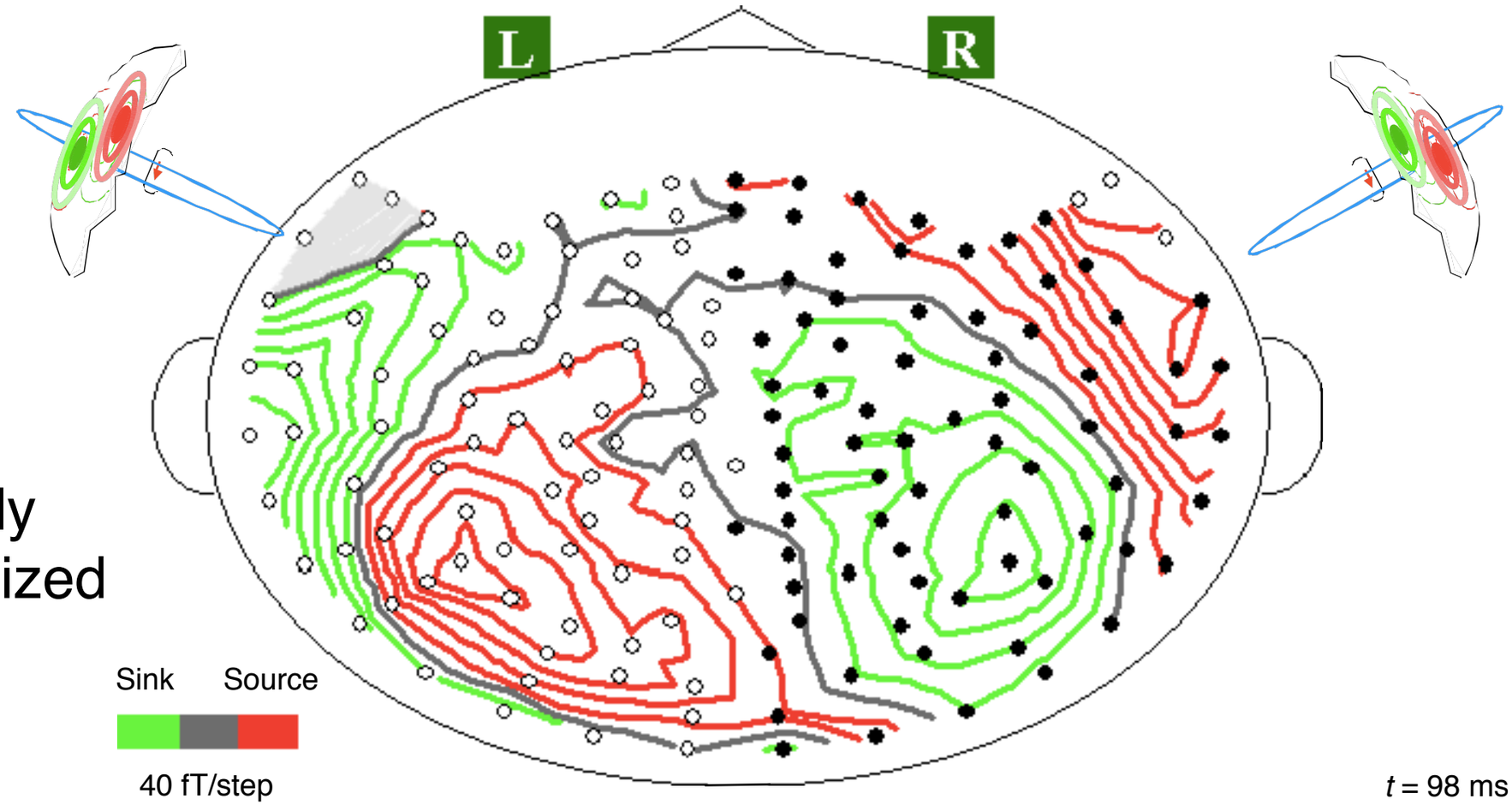
- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source

- 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

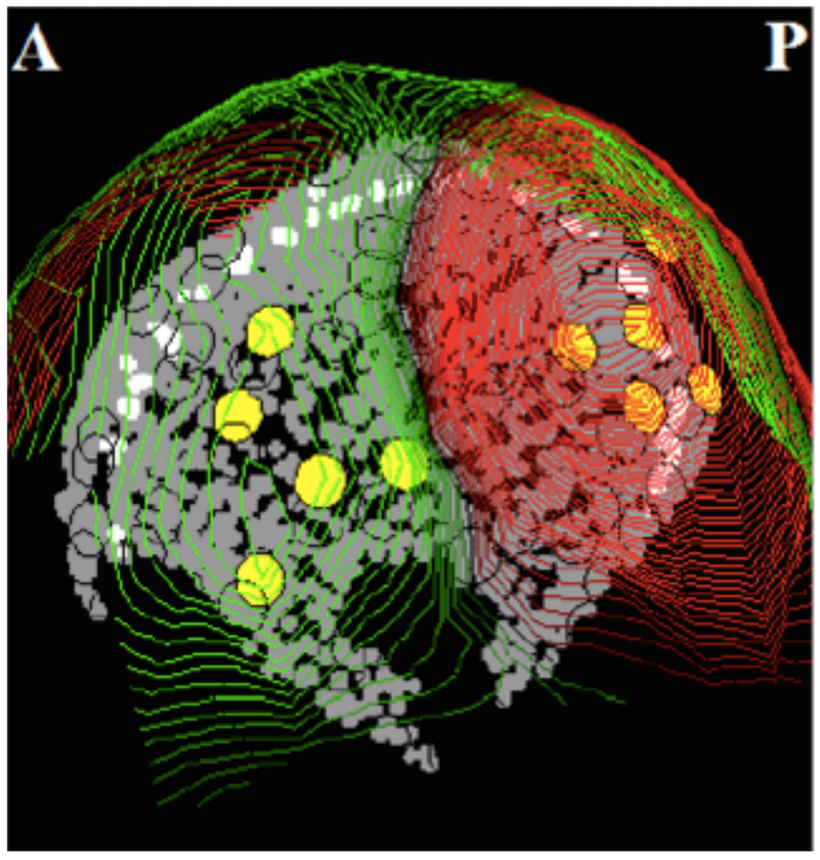


Strongly Lateralized

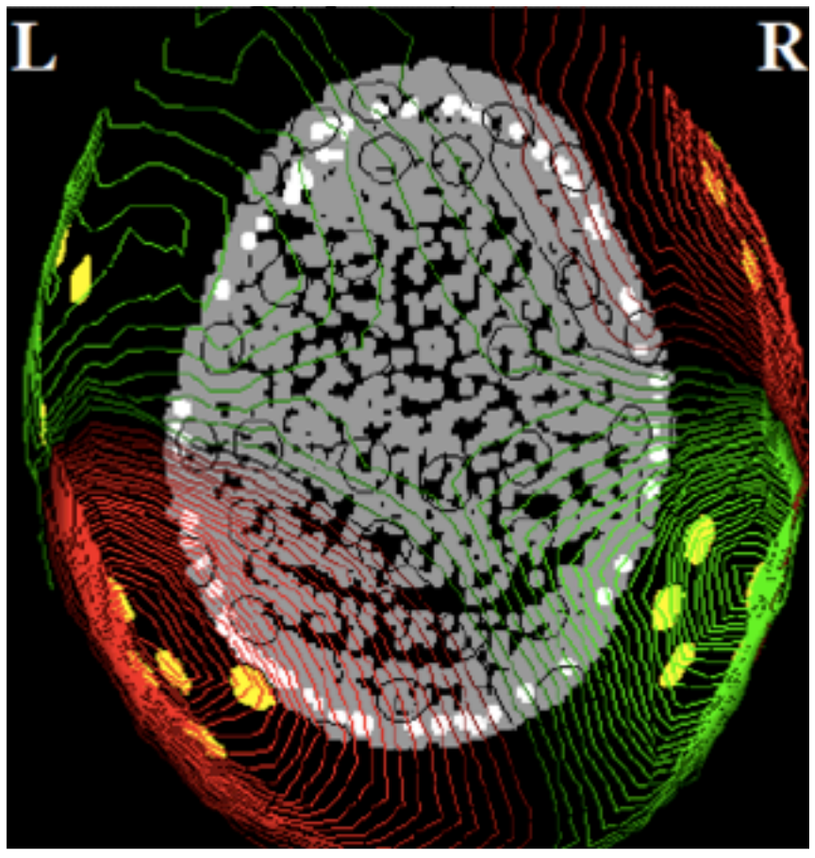
t = 98 ms

MEG Auditory Field

3-D Isofield Contour Map



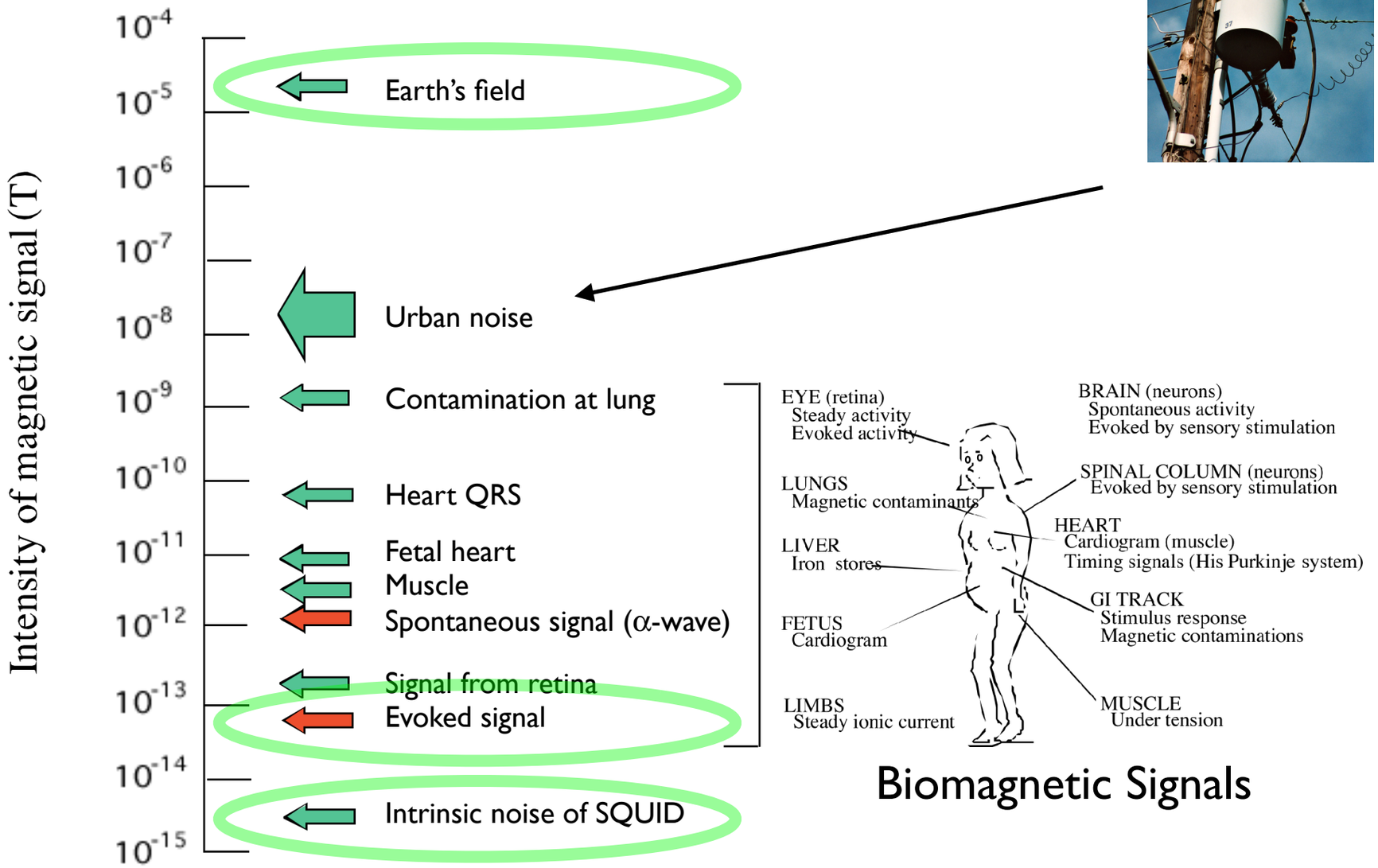
Sagittal View



Axial View

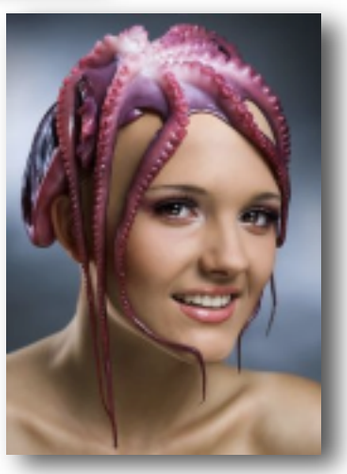
Chait, Poeppel and Simon, Cerebral Cortex (2006)

Magnetic Field Strengths



Biomagnetic Signals

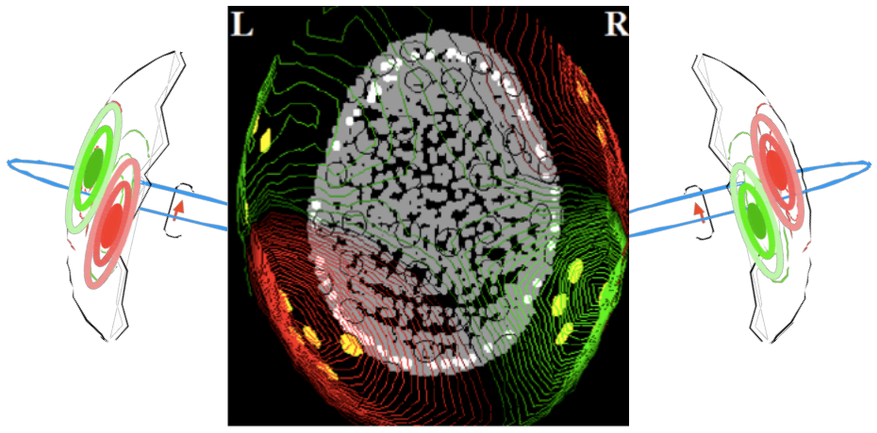
MEG = “Squid head”



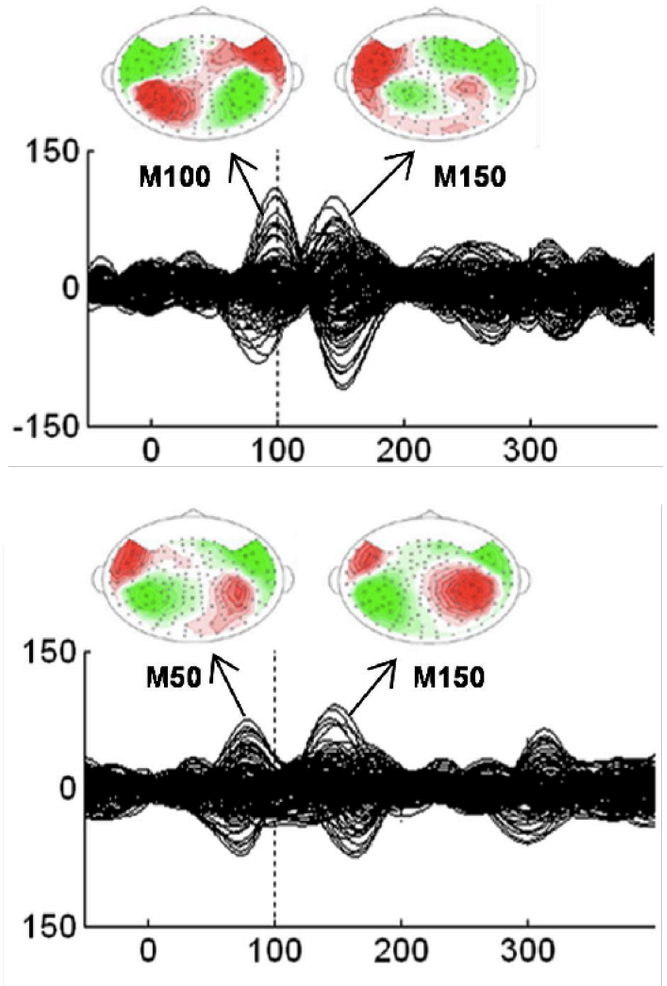
Time Course of MEG Responses

Auditory Evoked Responses

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

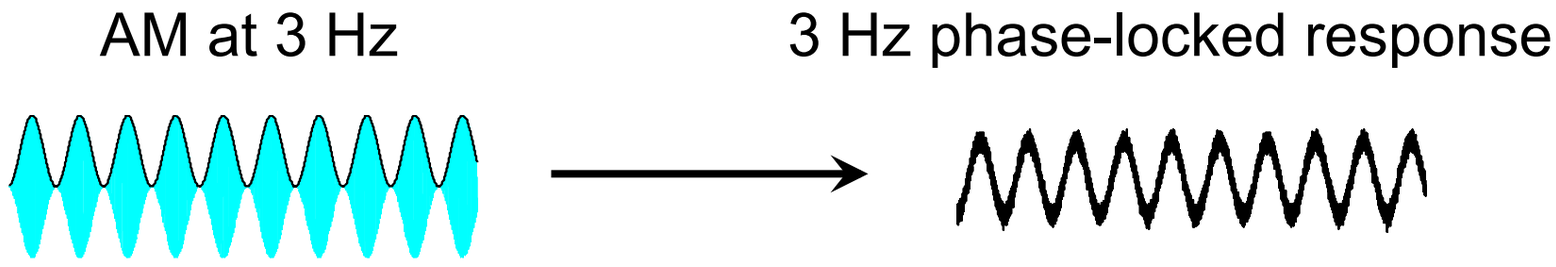


Pure Tone



Broadband Noise

Phase-Locking in MEG to Slow Acoustic Modulations



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

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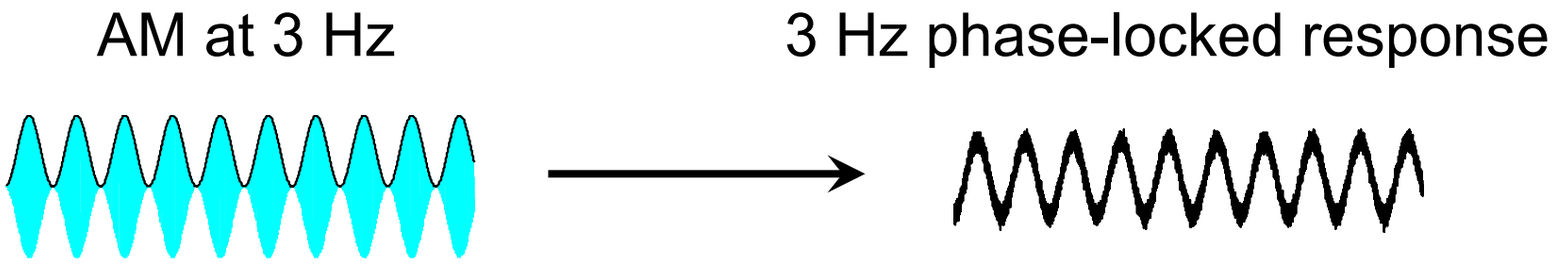
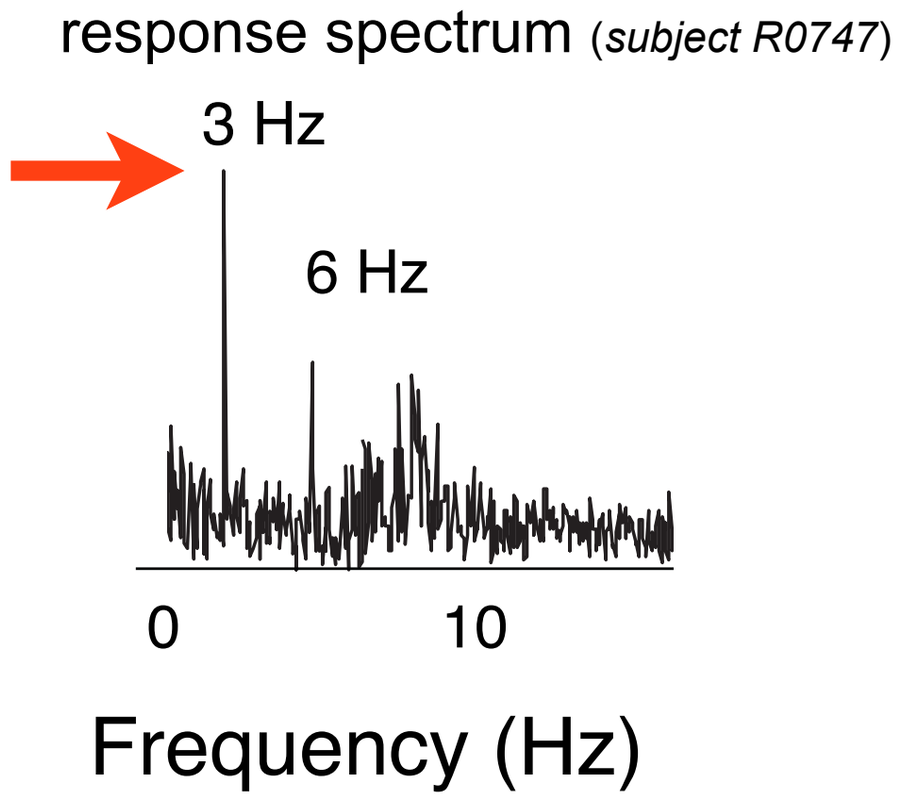


MEG activity is precisely phase-locked to temporal modulations of sound



Ding & Simon, J Neurophysiol (2009)
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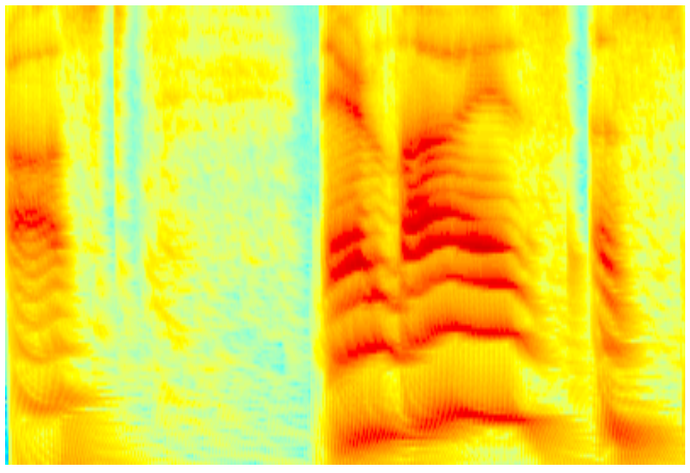
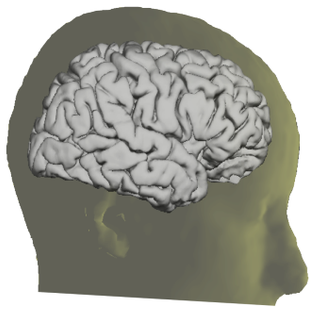
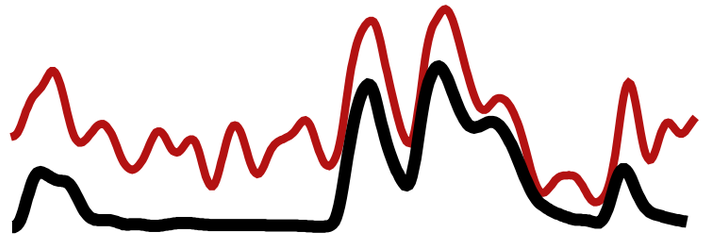
MEG Responses to Speech Modulations

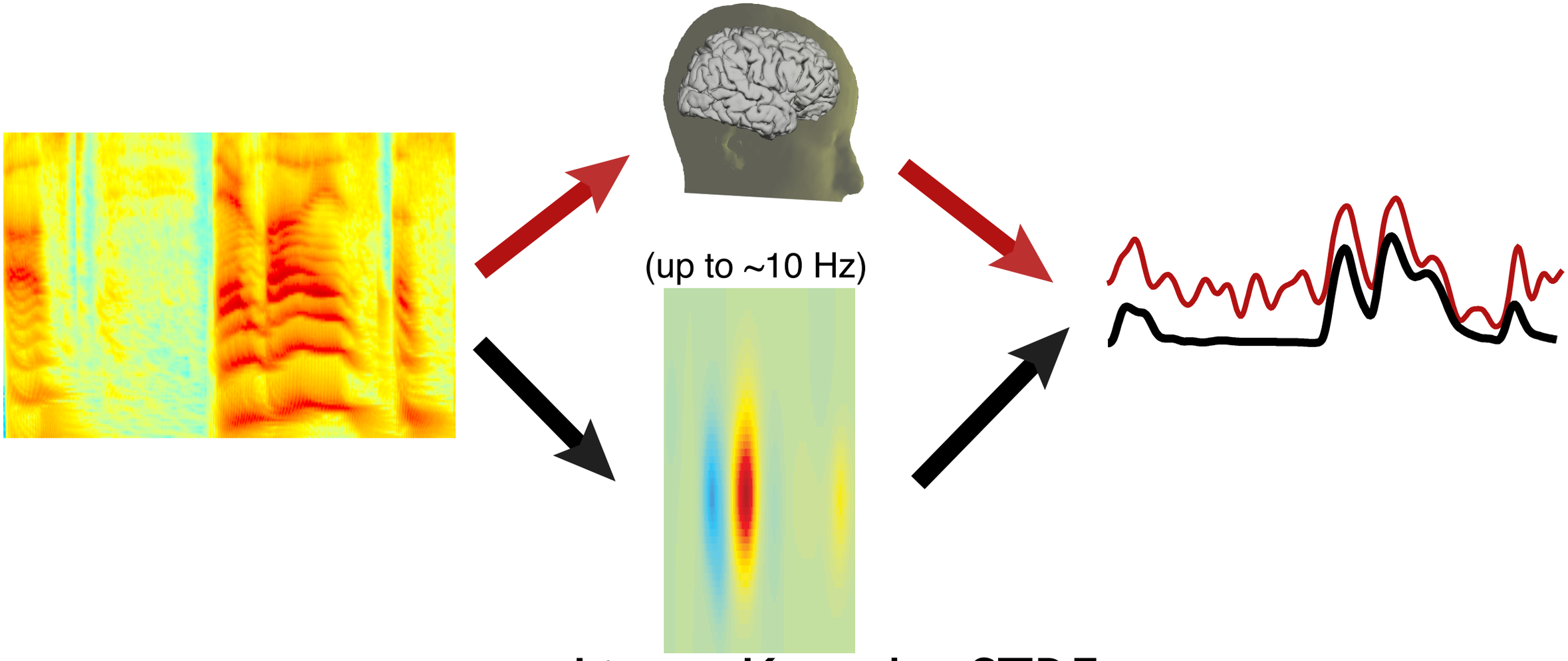




Auditory Model



MEG Responses Predicted by STRF Model

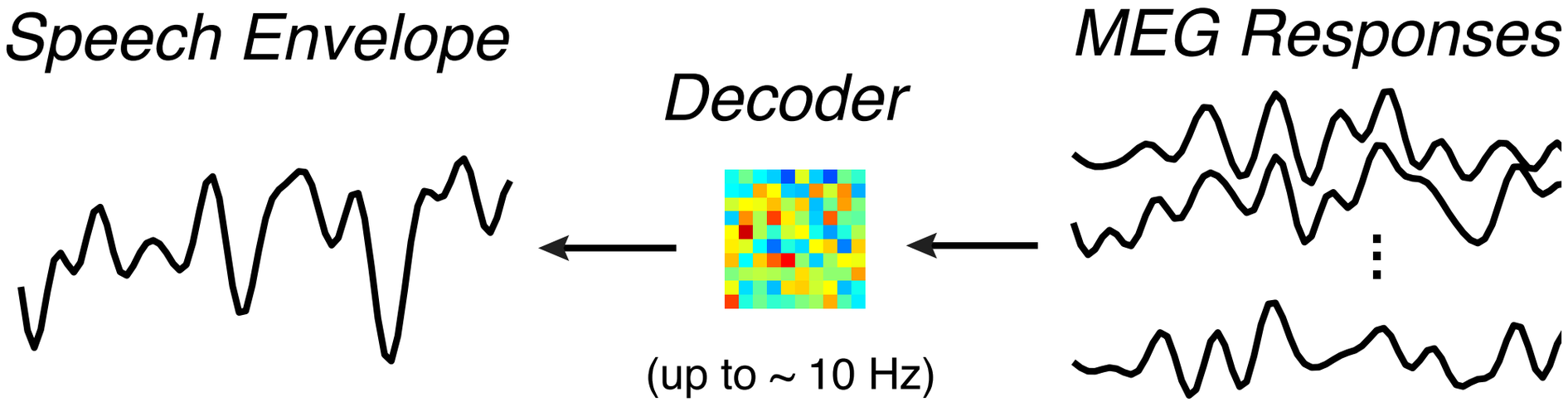


Linear Kernel = STRF

"Spectro-Temporal Response Function"

Ding & Simon, J Neurophysiol (2012)

Neural Reconstruction of Speech Envelope



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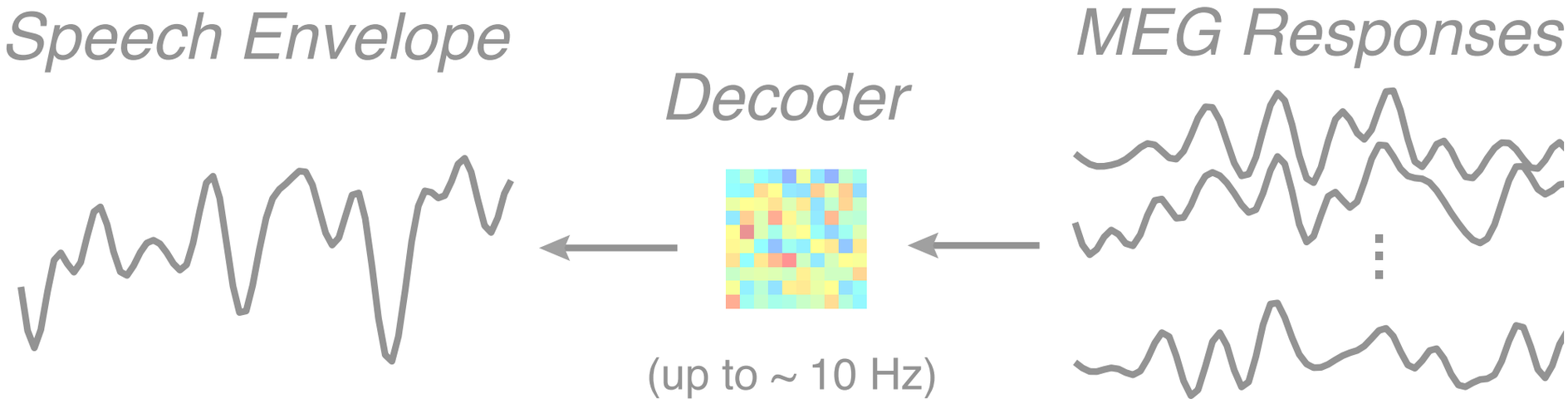
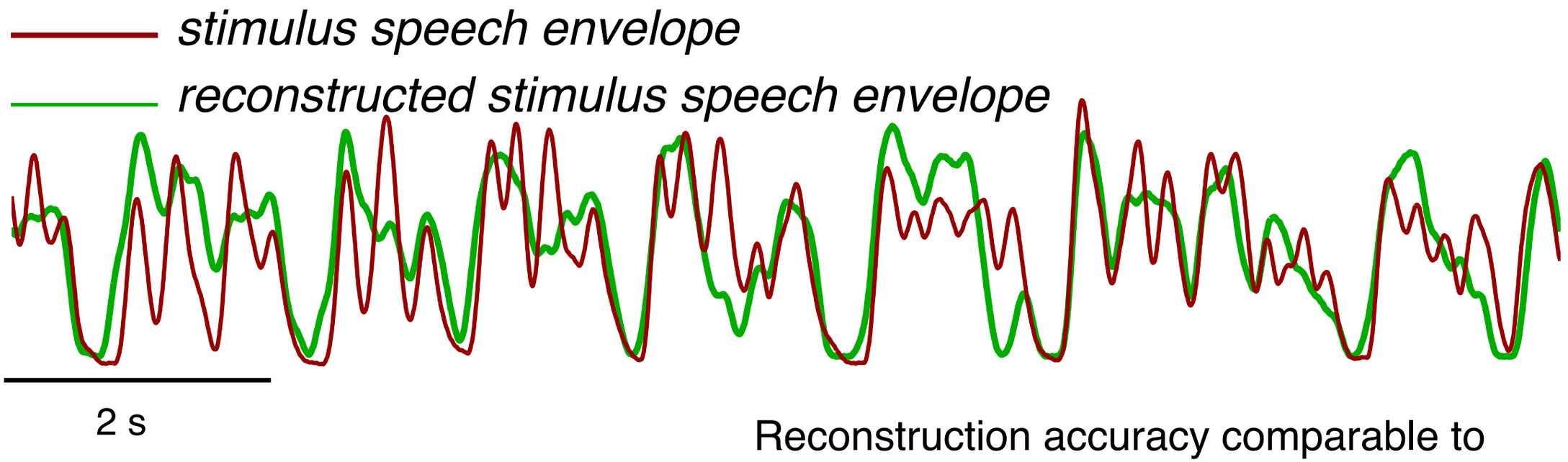
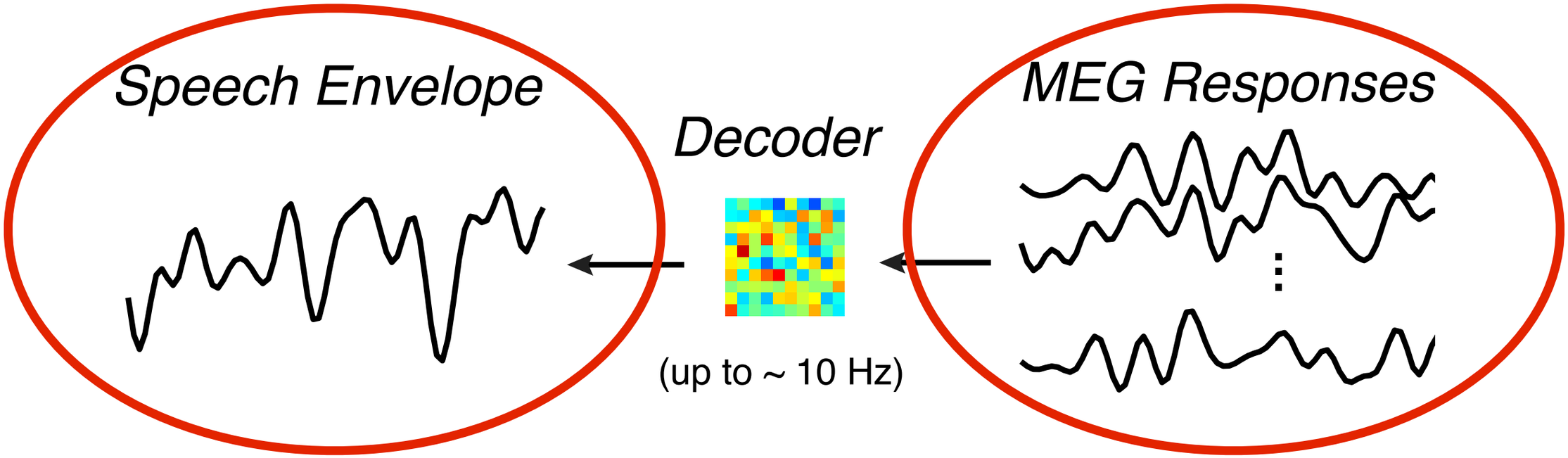




Reconstruction accuracy comparable to single unit & ECoG recordings

Ding & Simon, J Neurophysiol (2012)
Zion-Golumbic et al., Neuron (2013)


Speech Envelope
Decoder
MEG Responses
(up to ~ 10 Hz)

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

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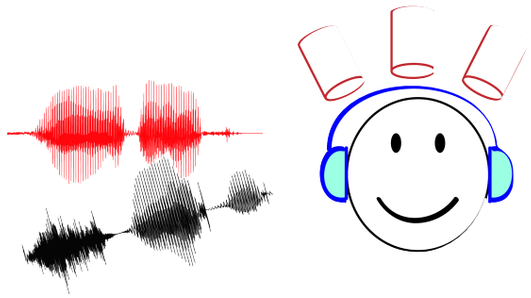
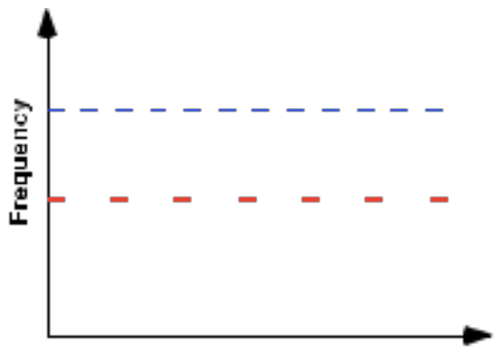
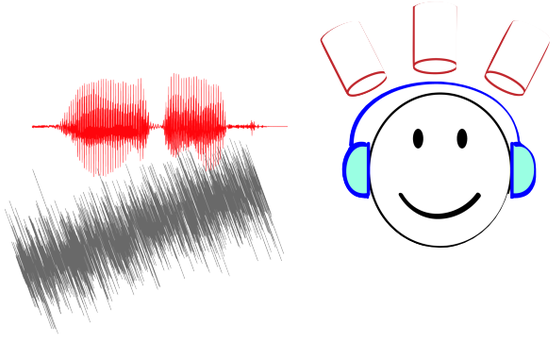
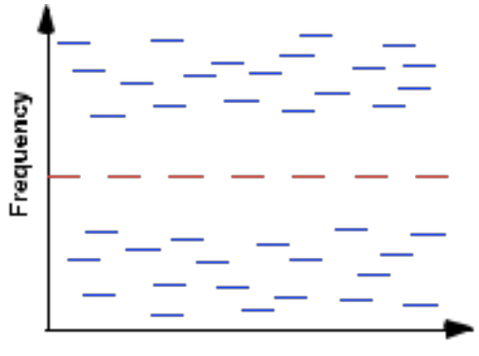
Experiments

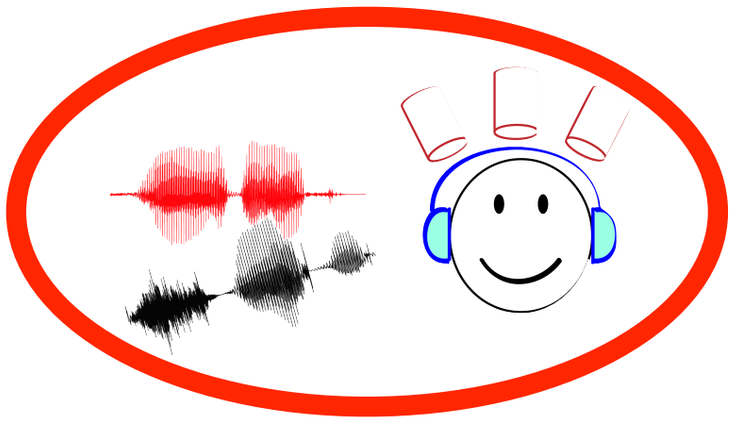


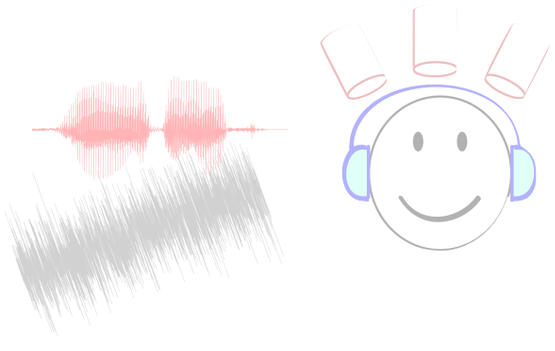


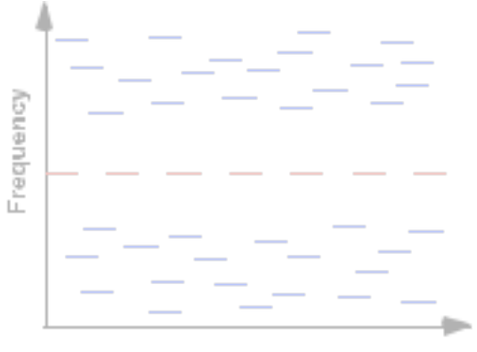




Experiments







Ding & Simon, PNAS (2012)

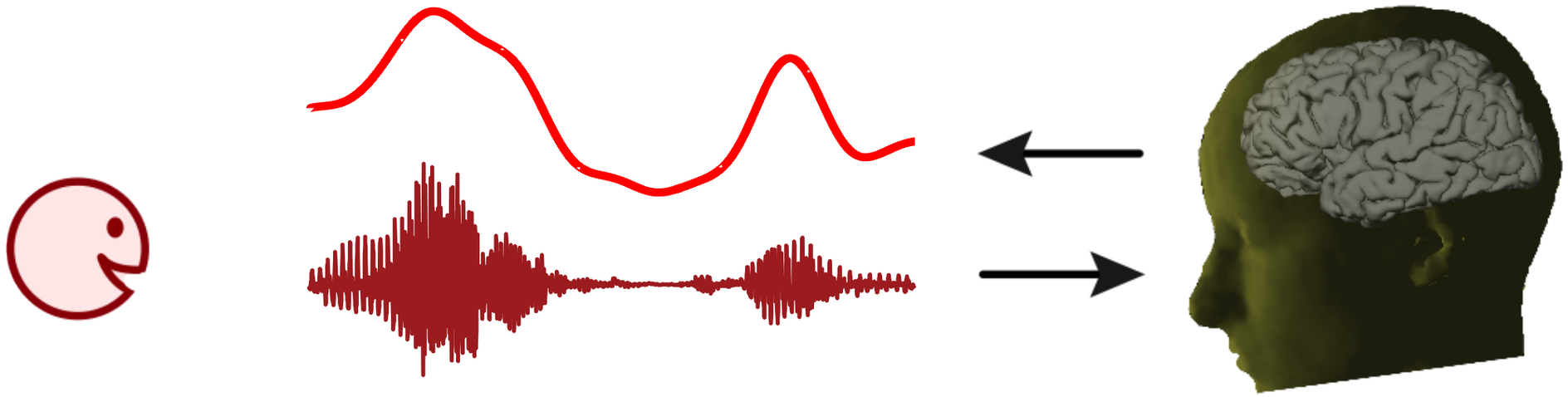
Speech Stream as an Auditory Object

- 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

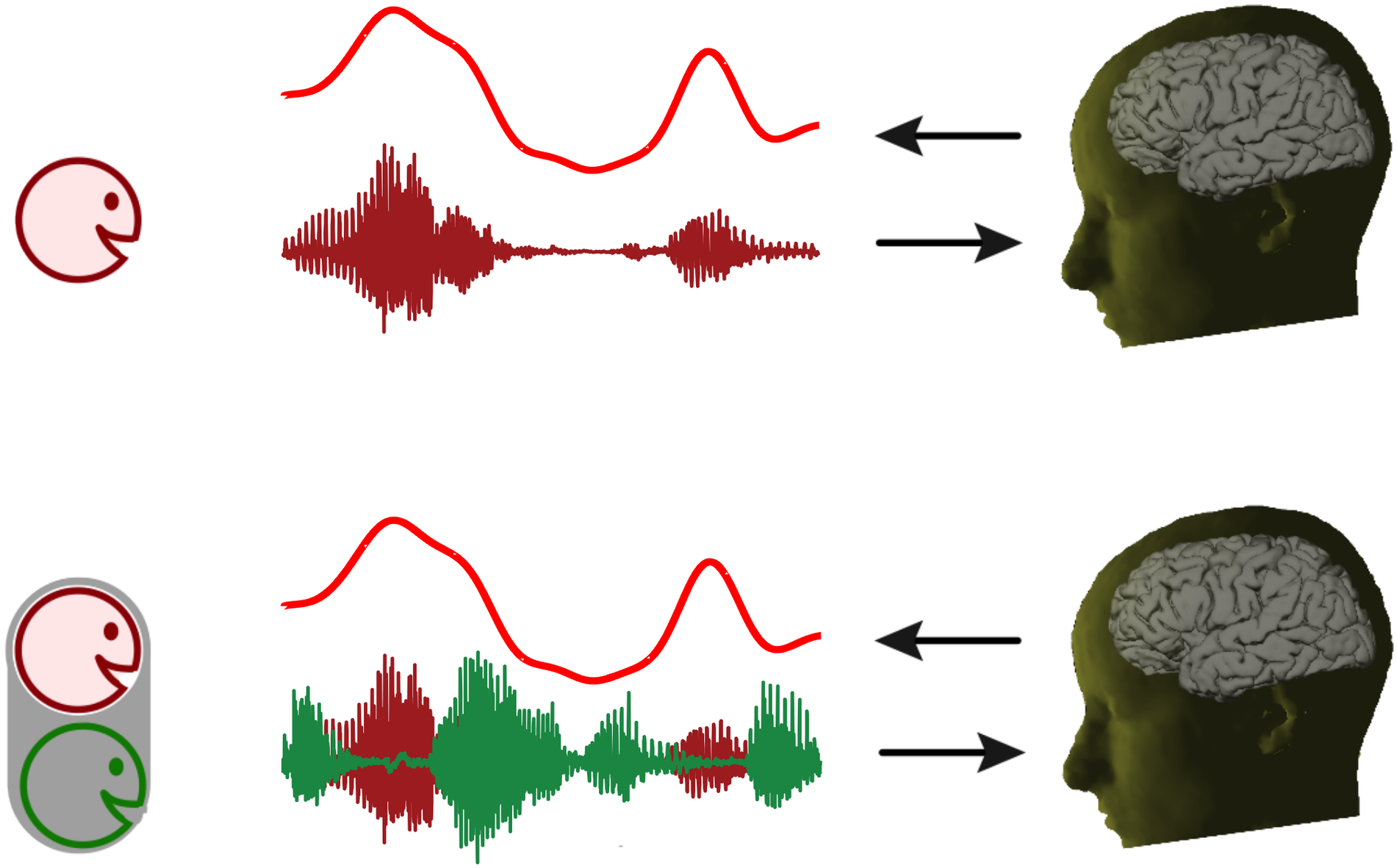
Neural Representation of an Auditory Object

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

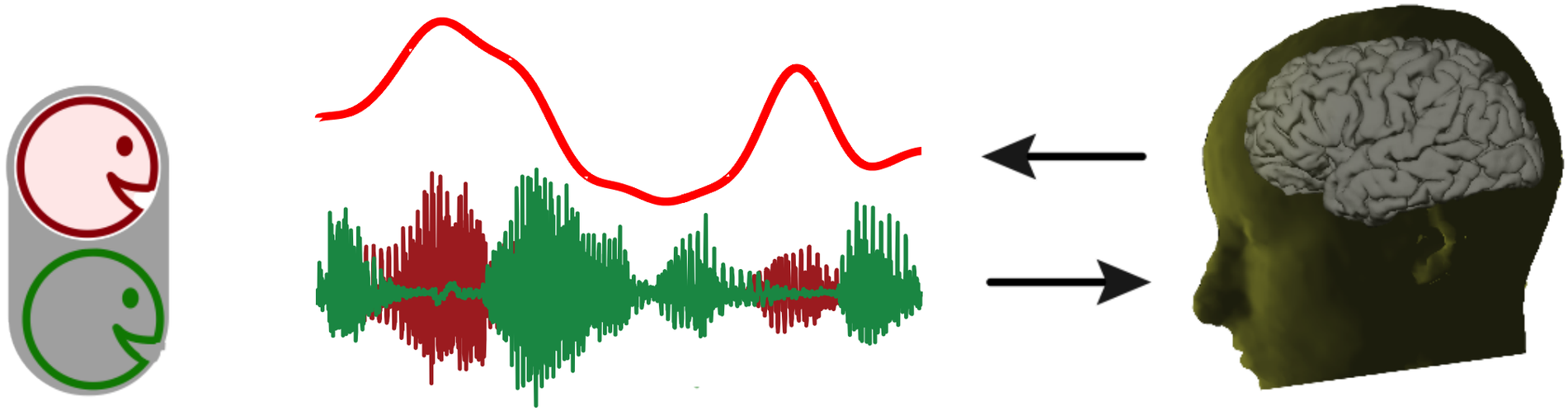
Selective Neural Encoding



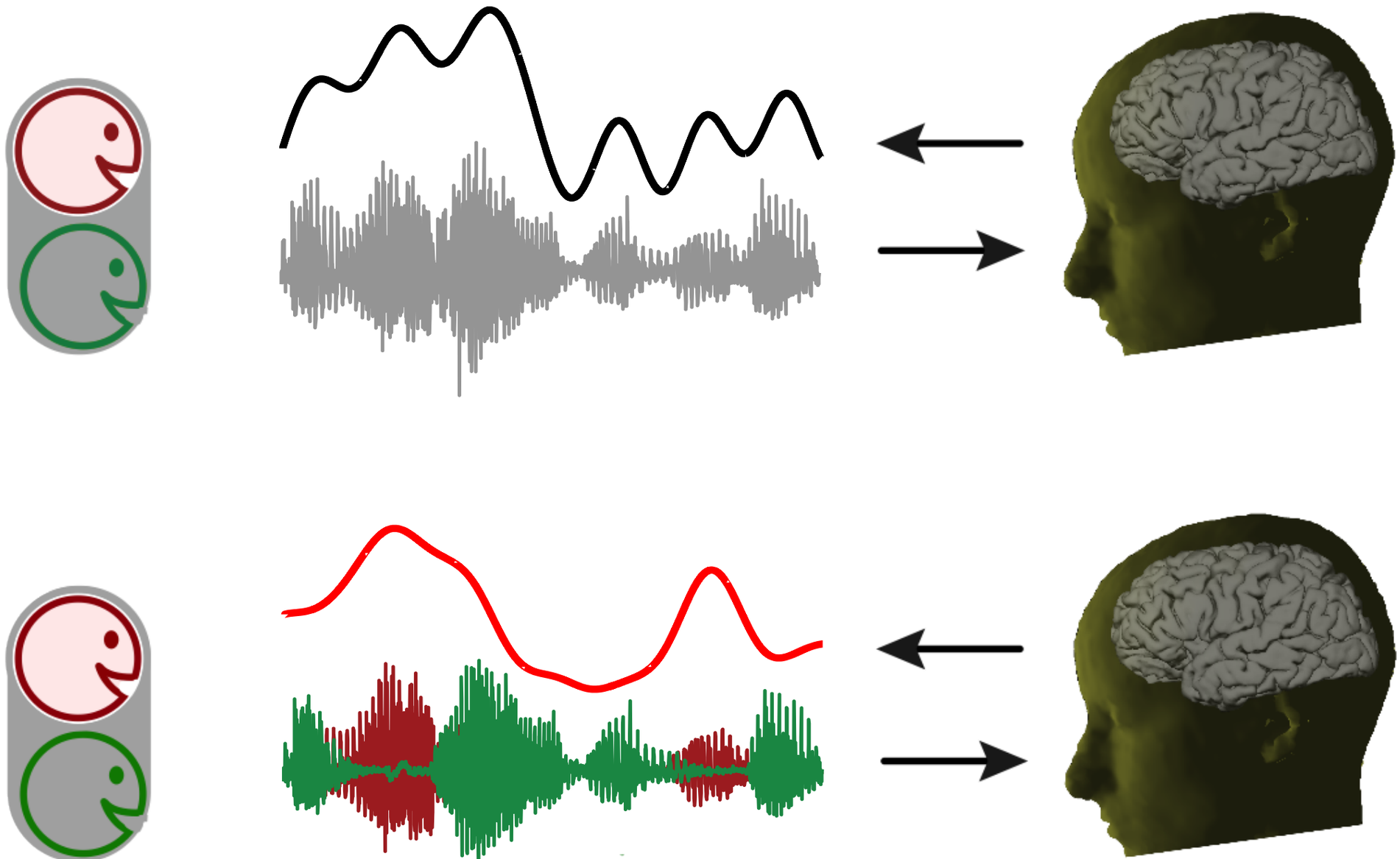
Selective Neural Encoding



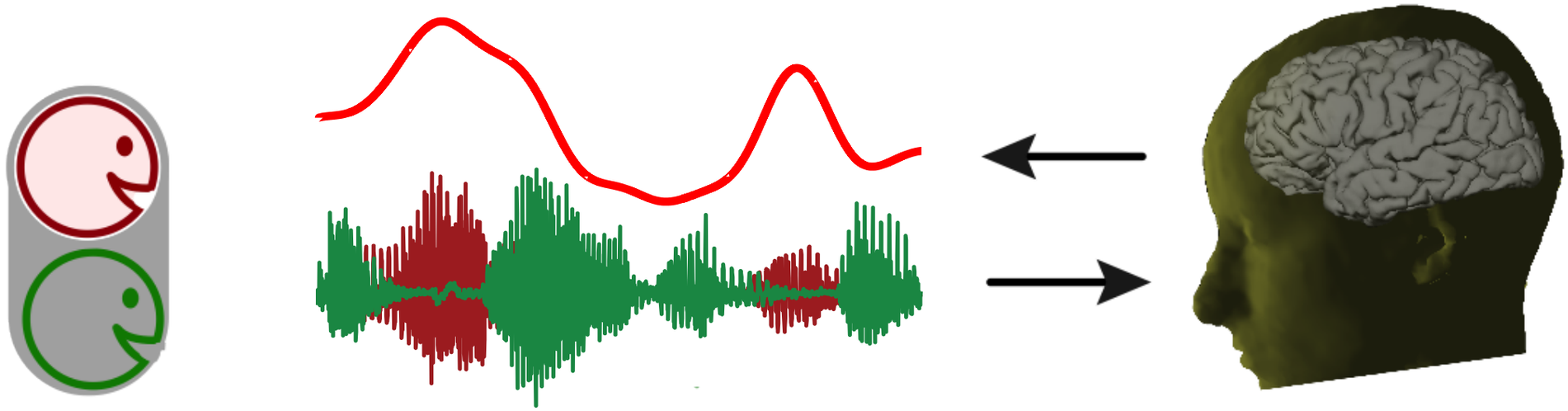
Selective Neural Encoding



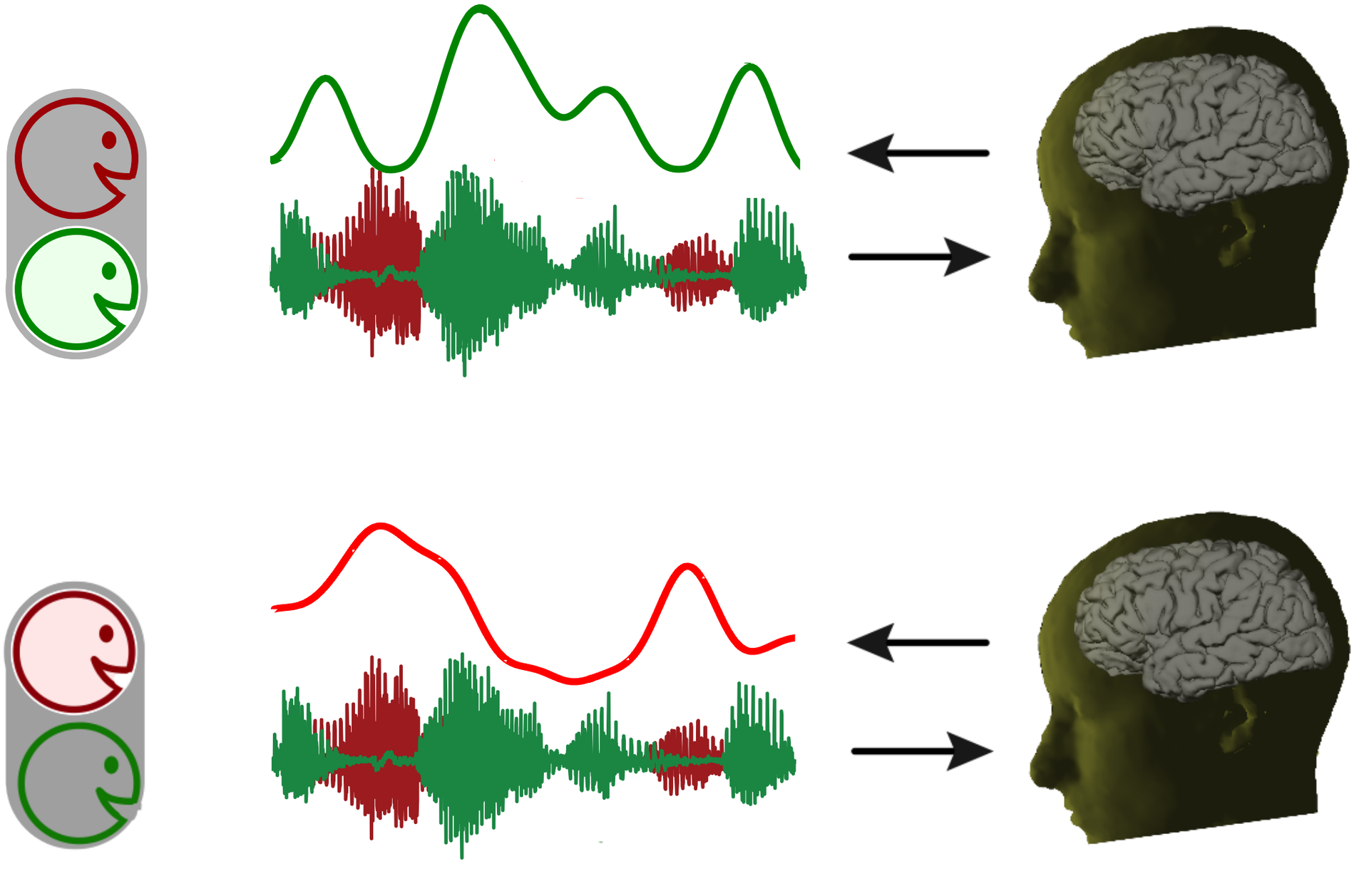
Unselective vs. Selective Neural Encoding



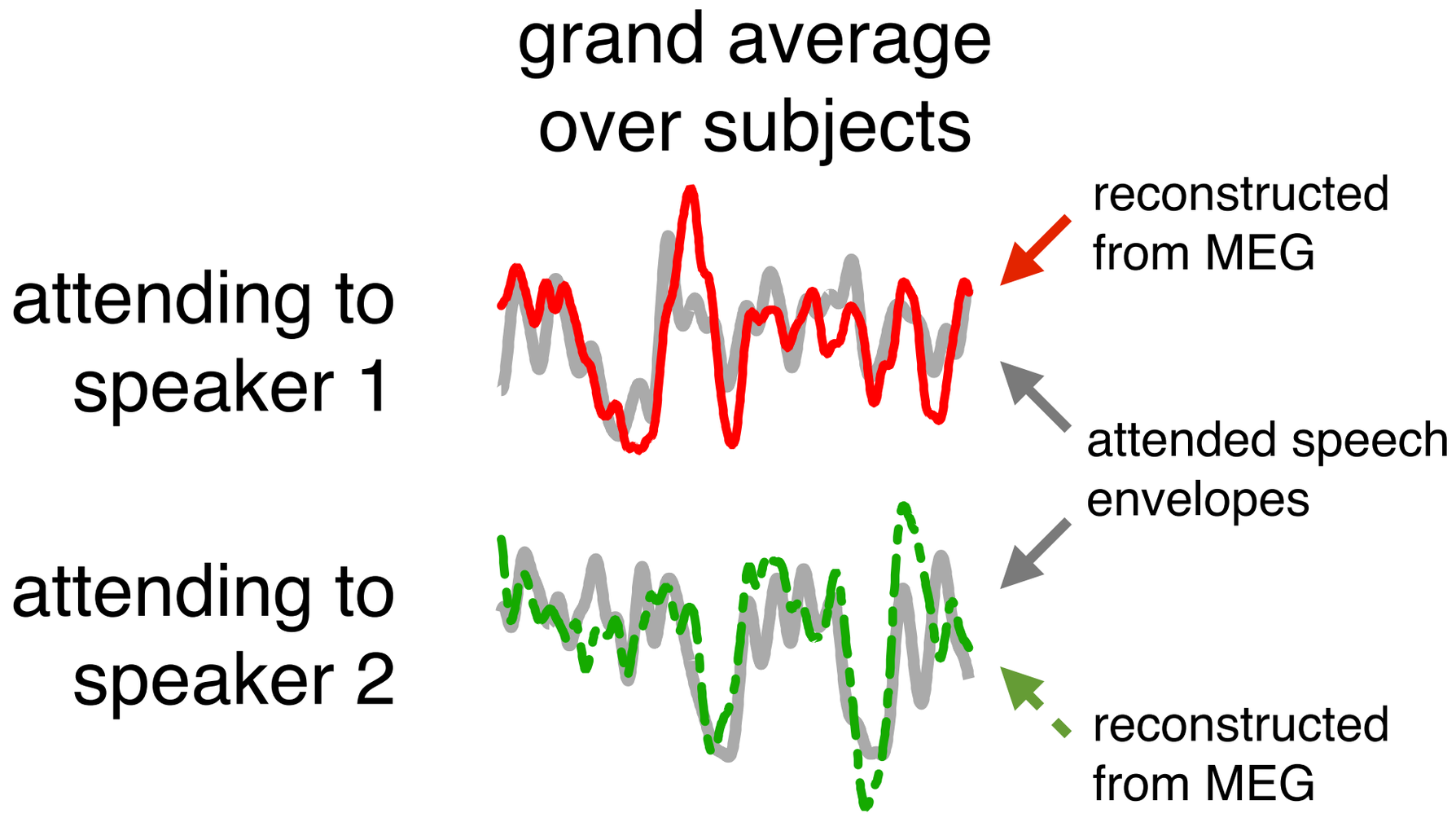
Unselective vs. Selective Neural Encoding



Selective Neural Encoding

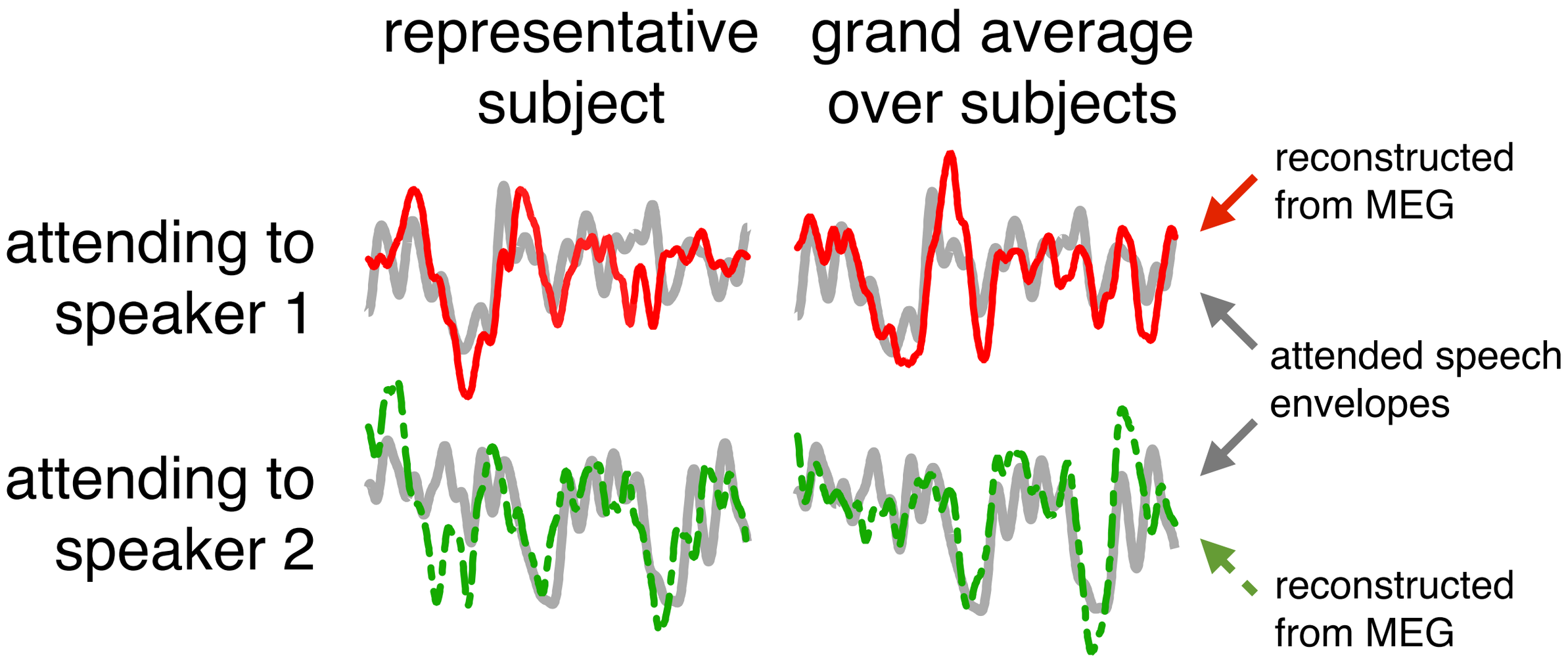


Stream-Specific Representation



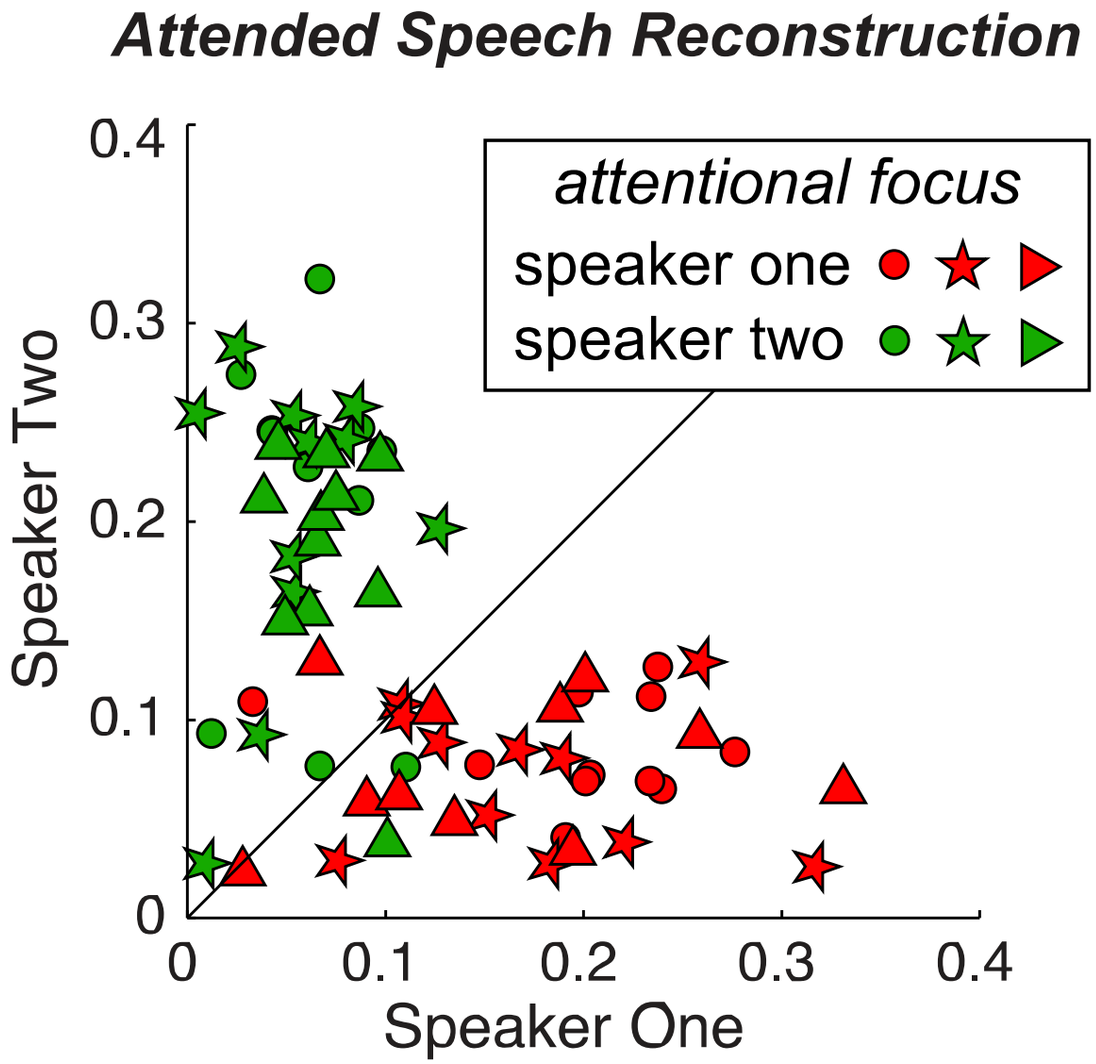
Identical Stimuli!

Stream-Specific Representation



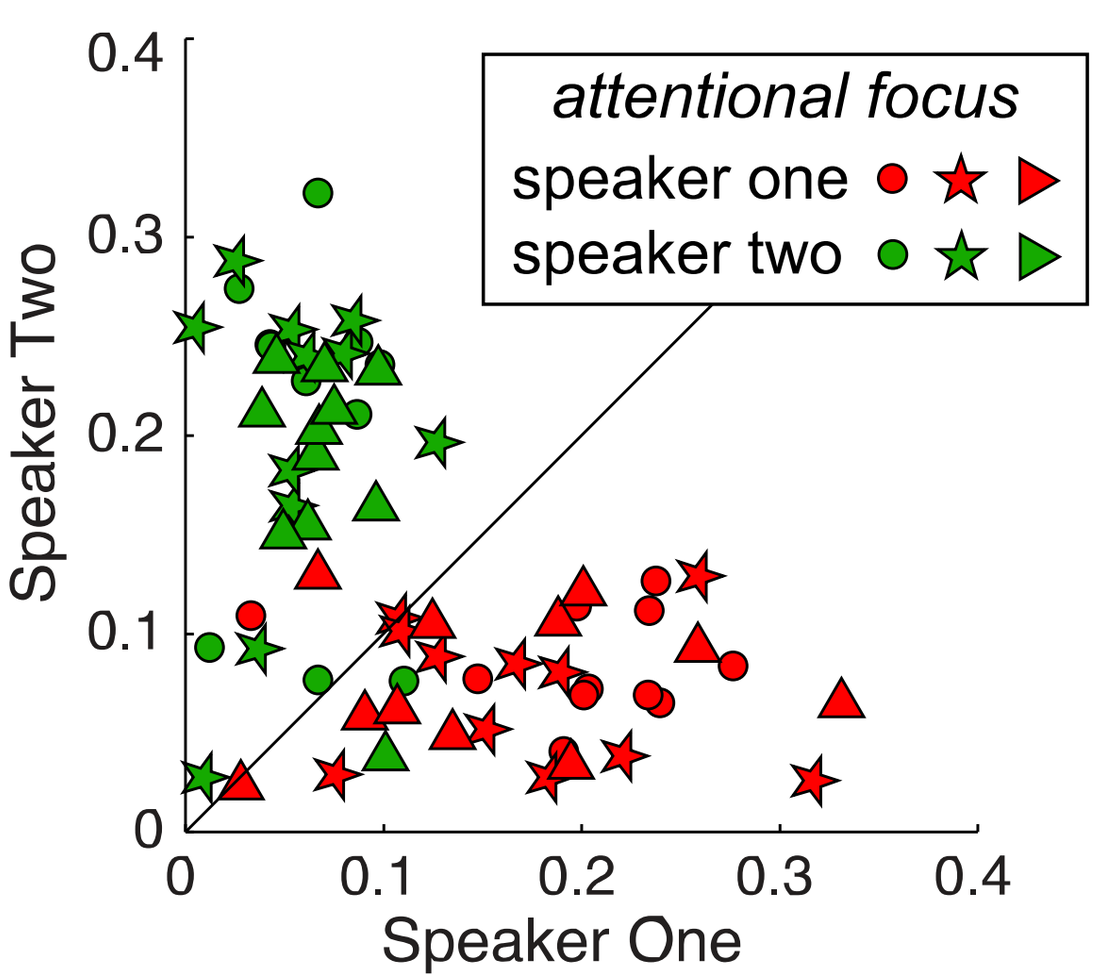
Identical Stimuli!

Single Trial Speech Reconstruction

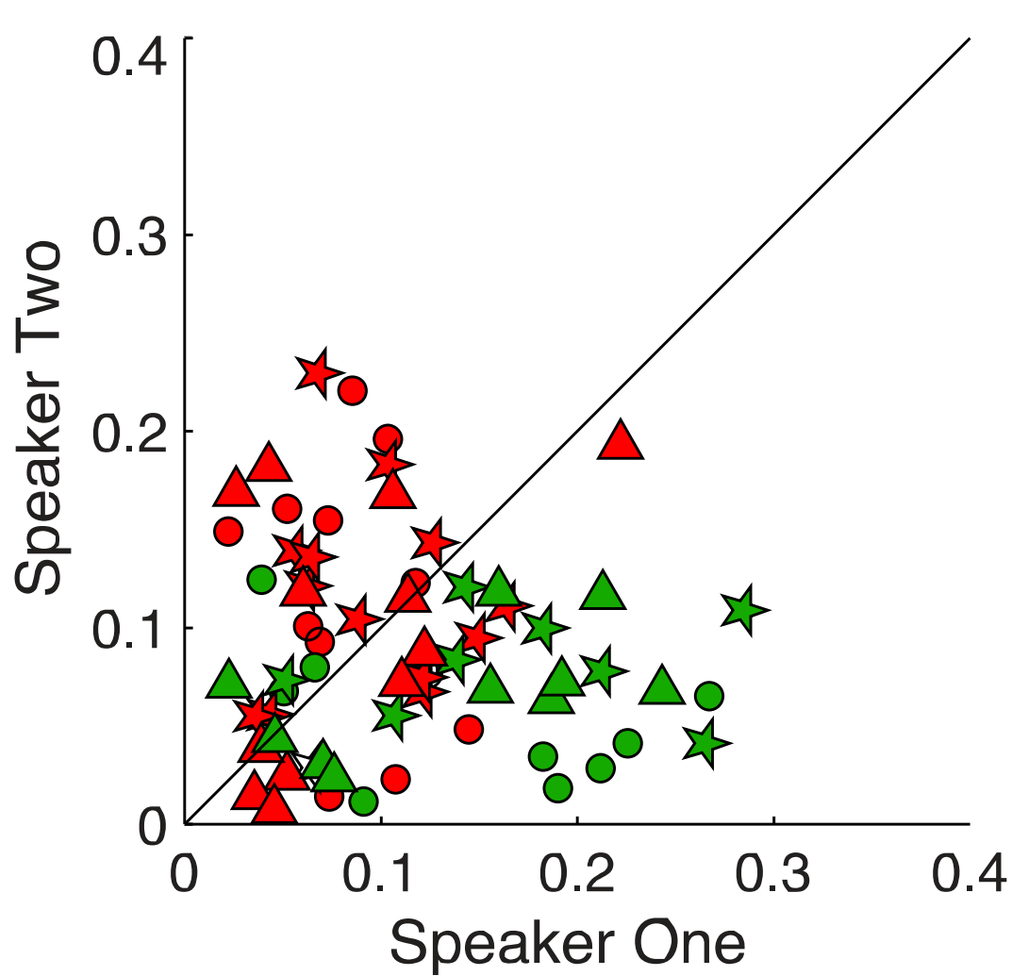


Single Trial Speech Reconstruction

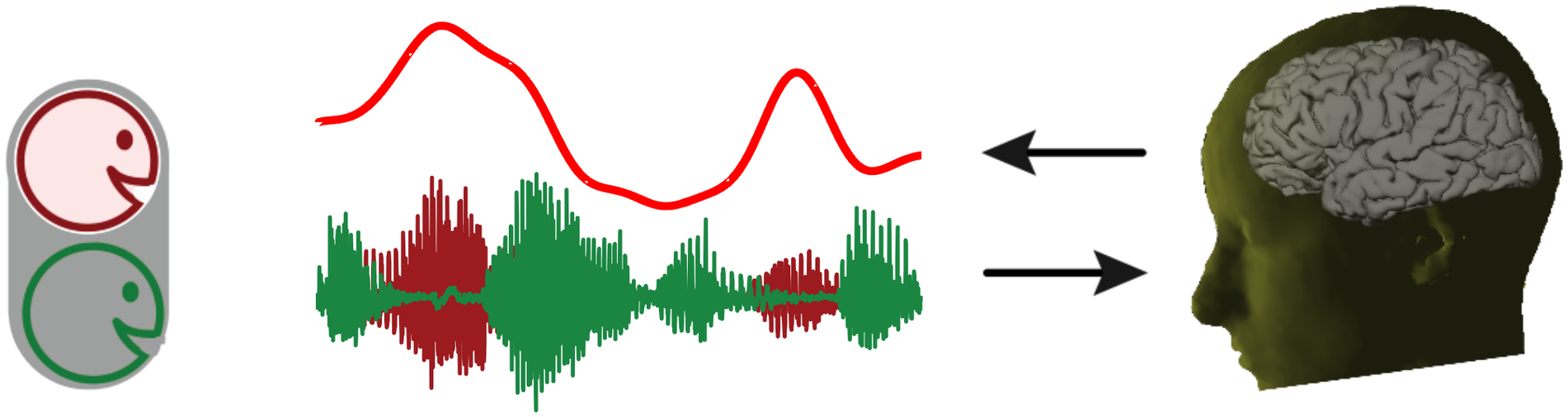
Attended Speech Reconstruction



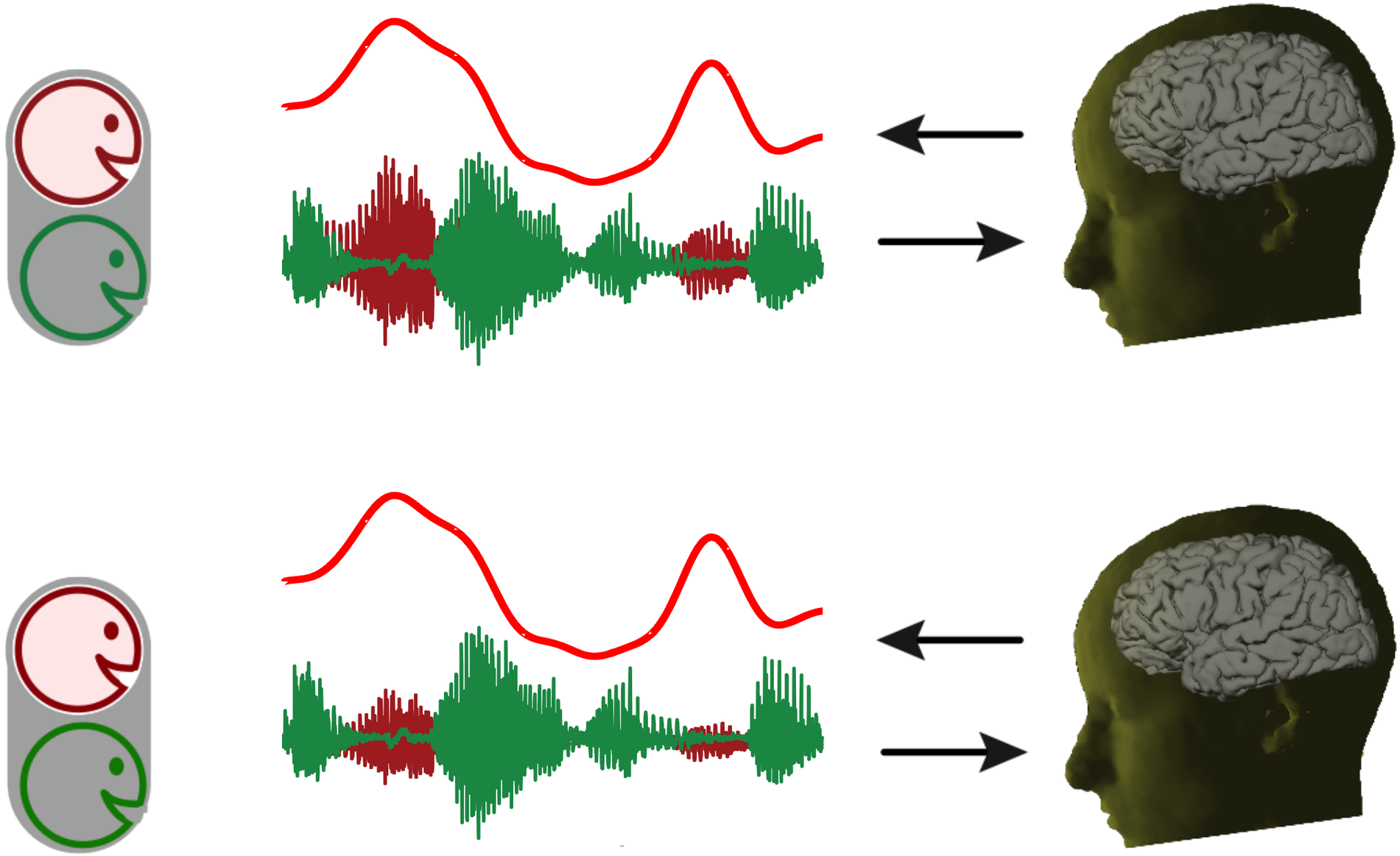
Background Speech Reconstruction



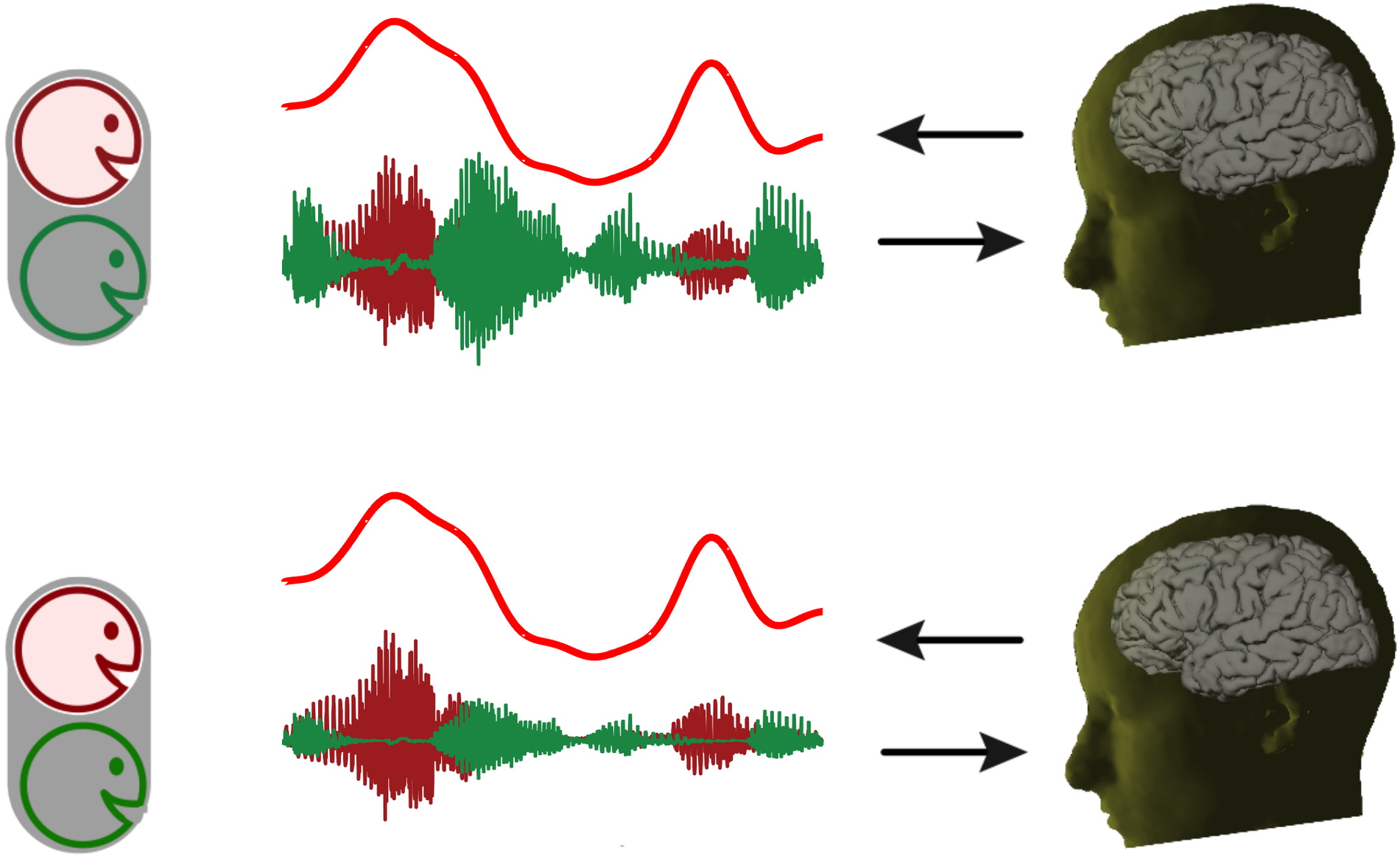
Invariance Under Acoustic Changes



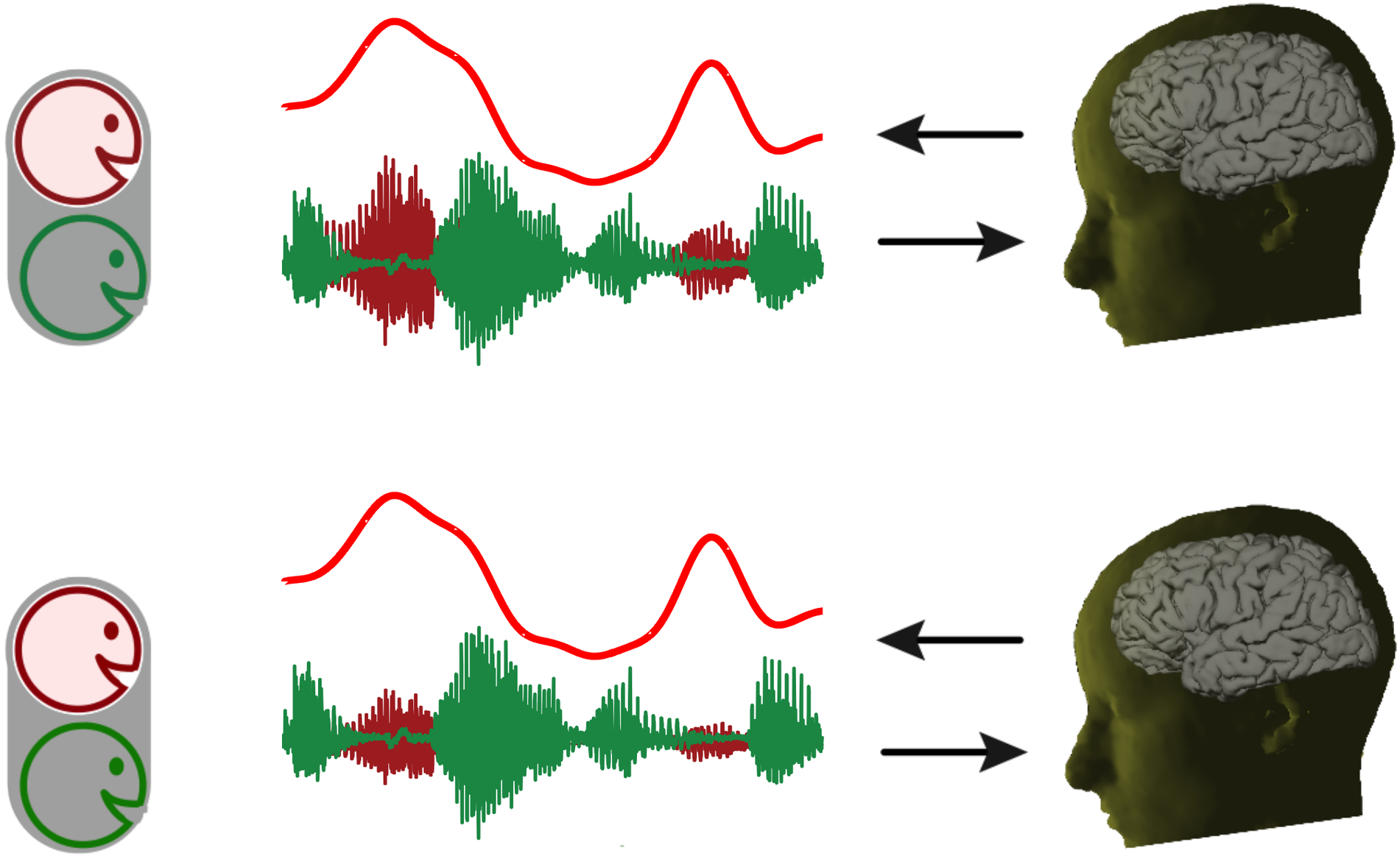
Invariance Under Acoustic Changes



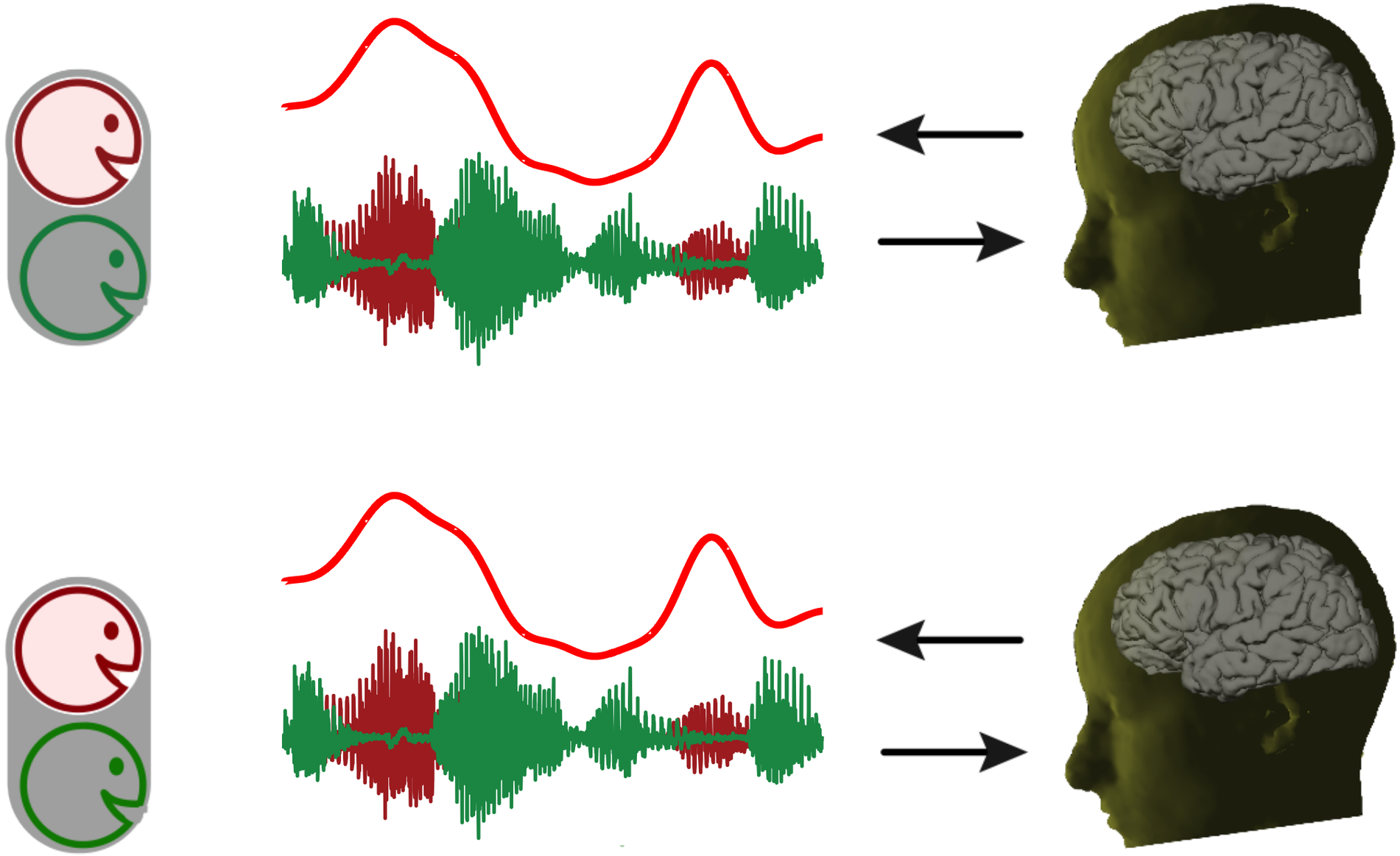
Invariance Under Acoustic Changes



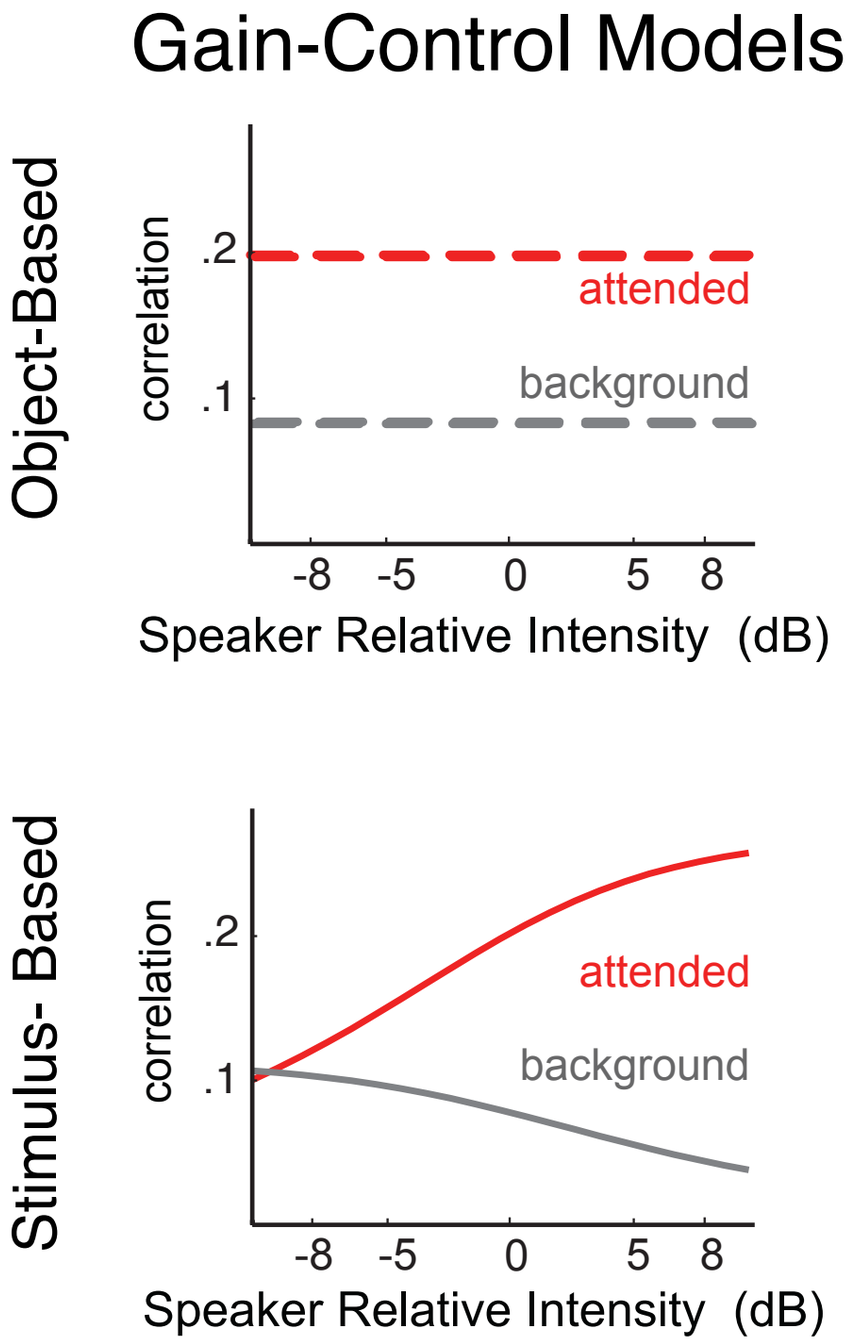
Invariance Under Acoustic Changes



Invariance Under Acoustic Changes



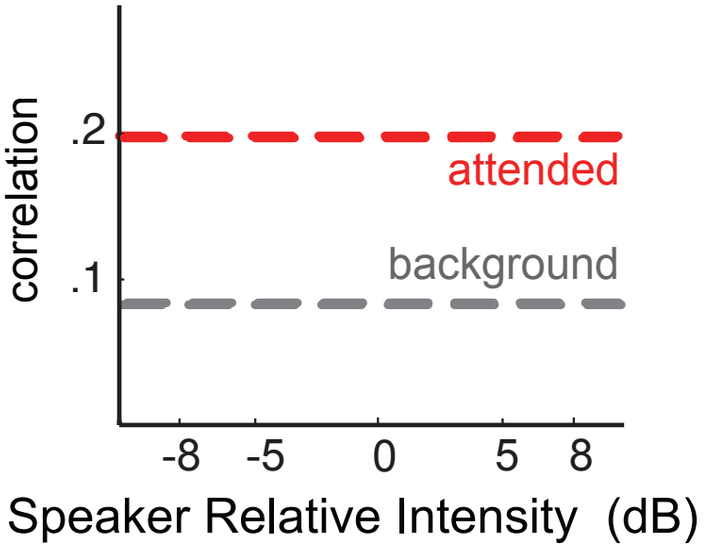
Stream-Based Gain Control?



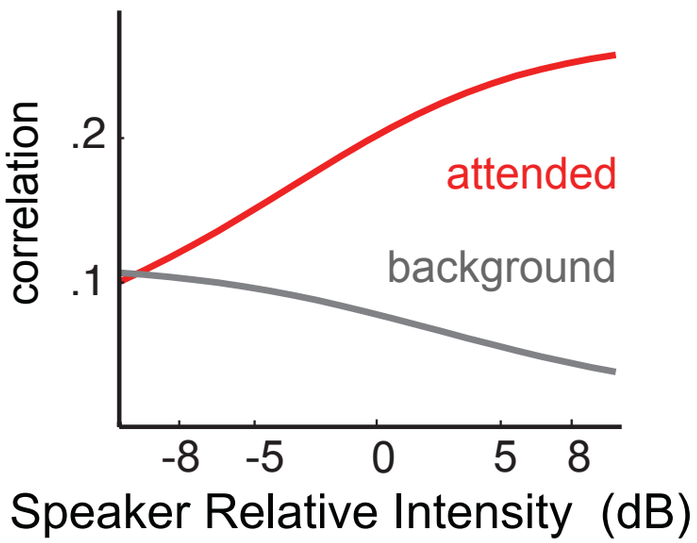
Stream-Based Gain Control?

Gain-Control Models

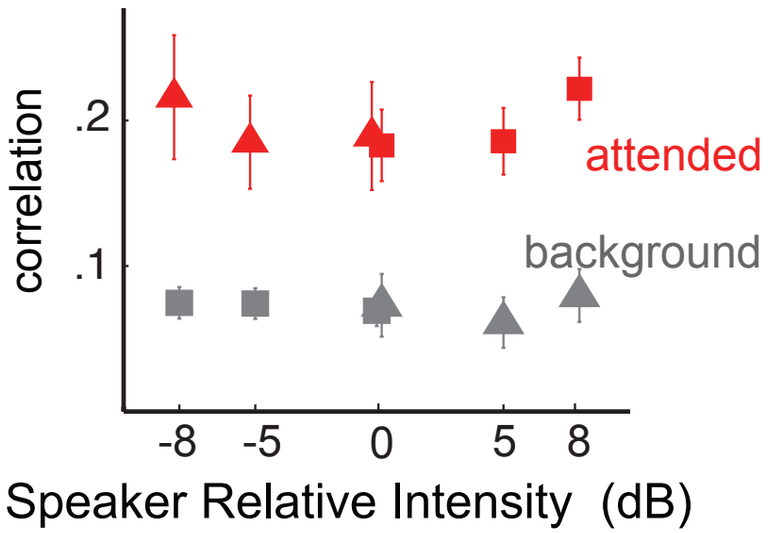
Object-Based



Stimulus- Based



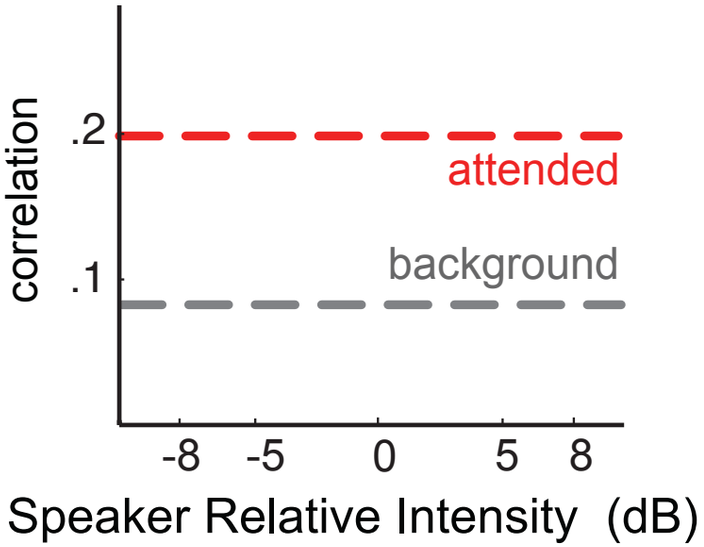
Neural Results



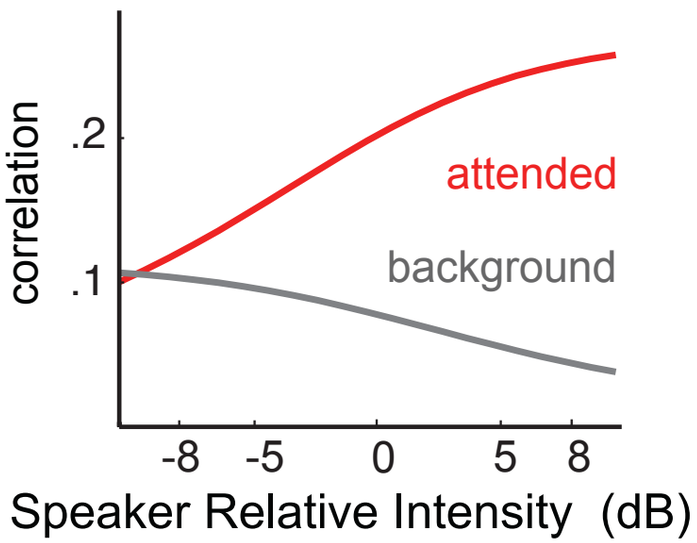
Stream-Based Gain Control?

Gain-Control Models

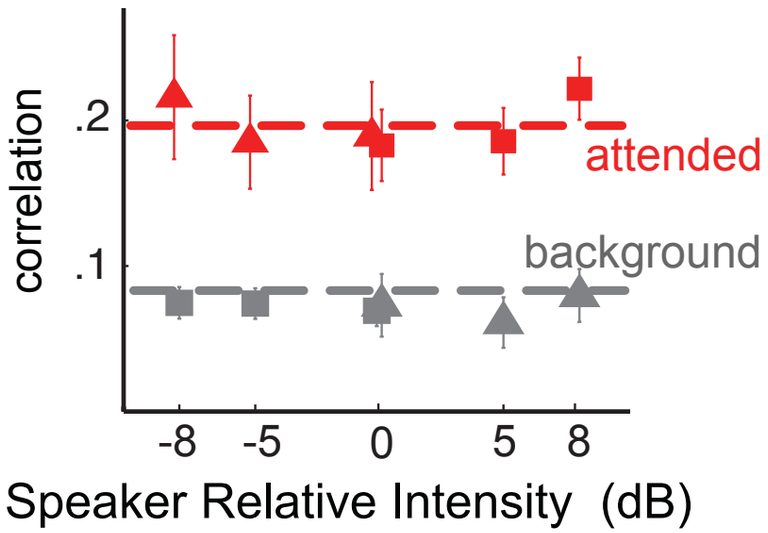
Object-Based



Stimulus- Based



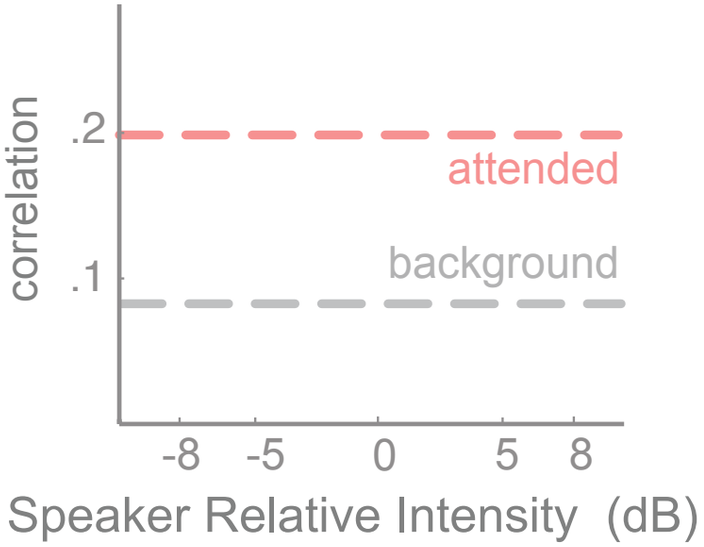
Neural Results



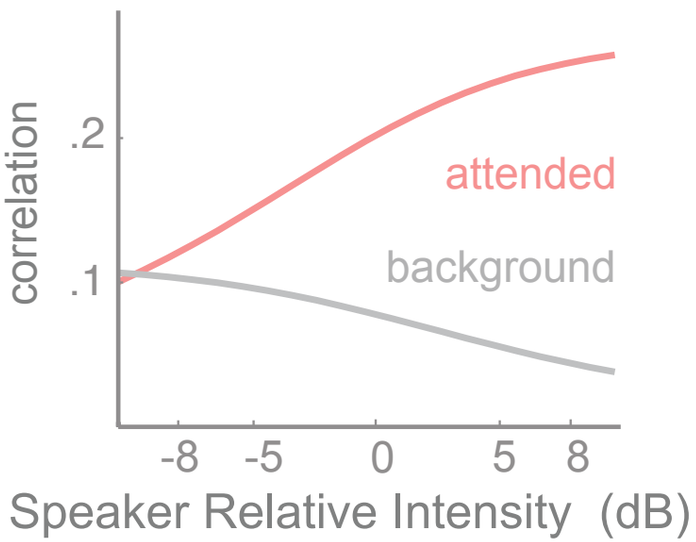
Stream-Based Gain Control?

Gain-Control Models

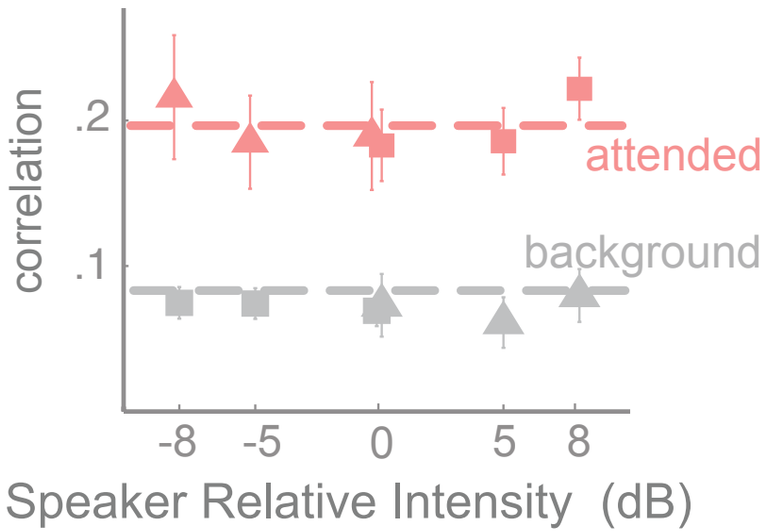
Object-Based



Stimulus- Based



Neural Results



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

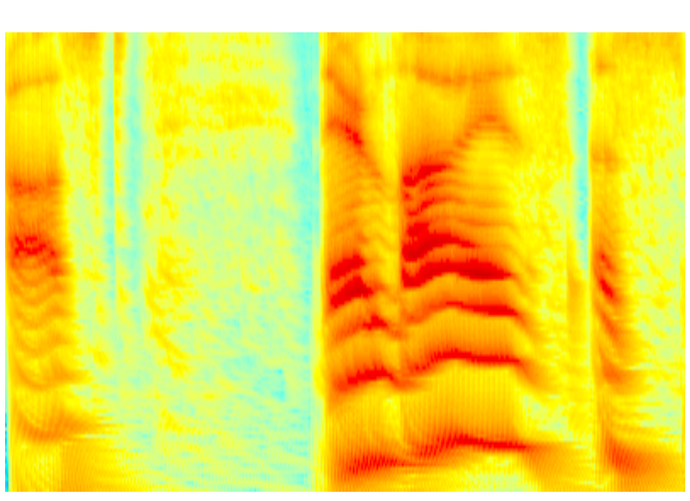
Neural Representation of an Auditory Object

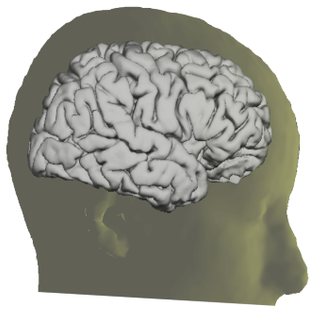
✓ neural representation is of something in sensory world

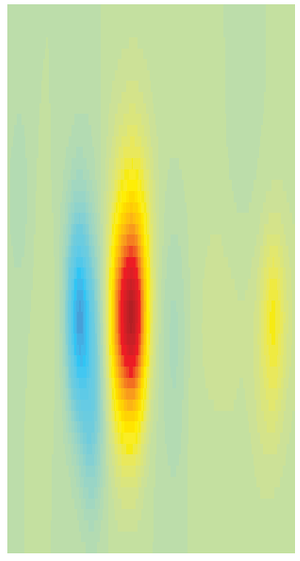
✓ when other sounds mixed in,
neural representation is of auditory object,
not entire acoustic scene

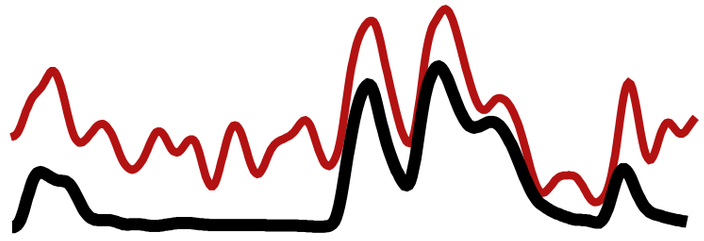
✓ neural representation invariant
under broad changes in specific acoustics

Forward STRF Model



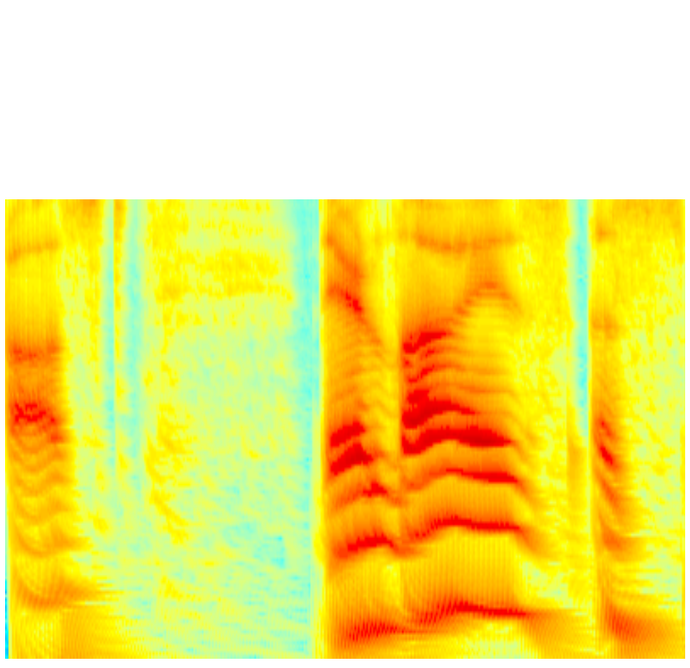


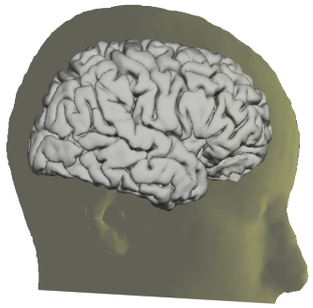


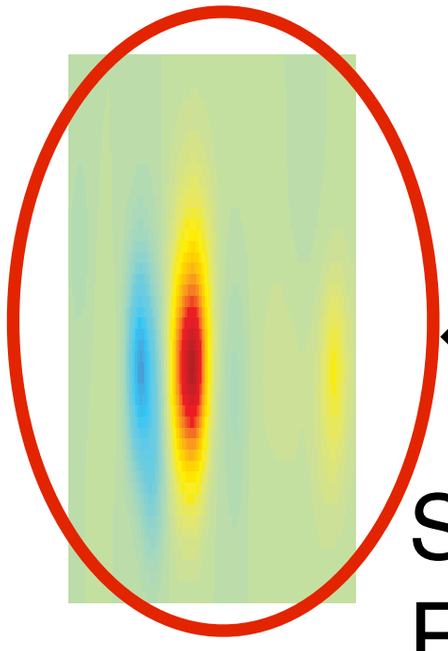


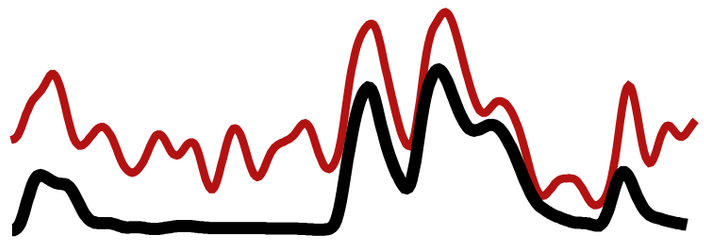
Spectro-Temporal Response Function (STRF)

Forward STRF Model



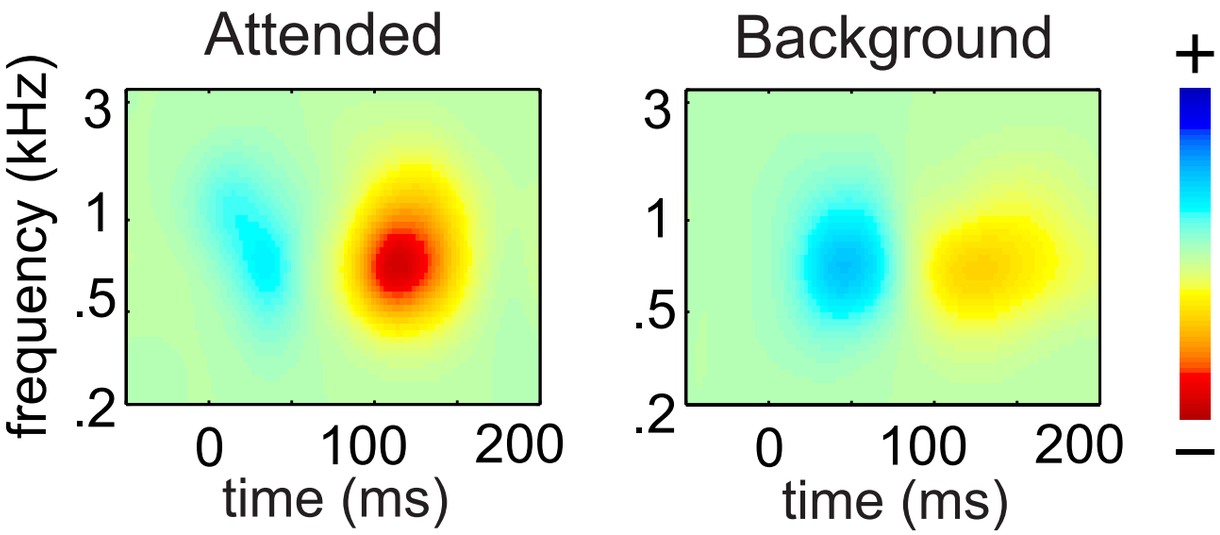






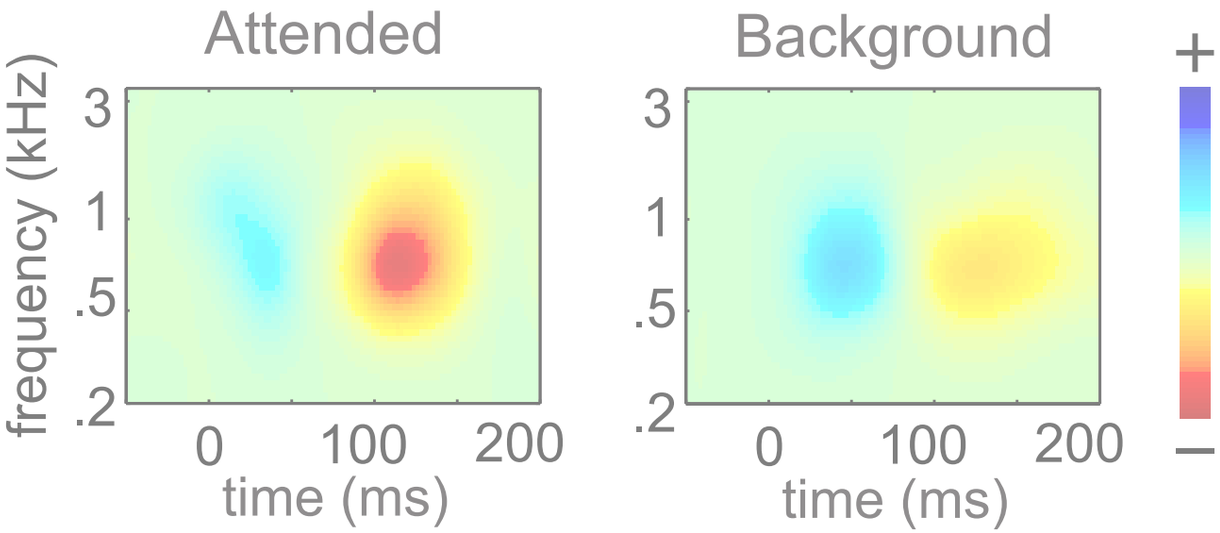
Spectro-Temporal
Response Function
(STRF)

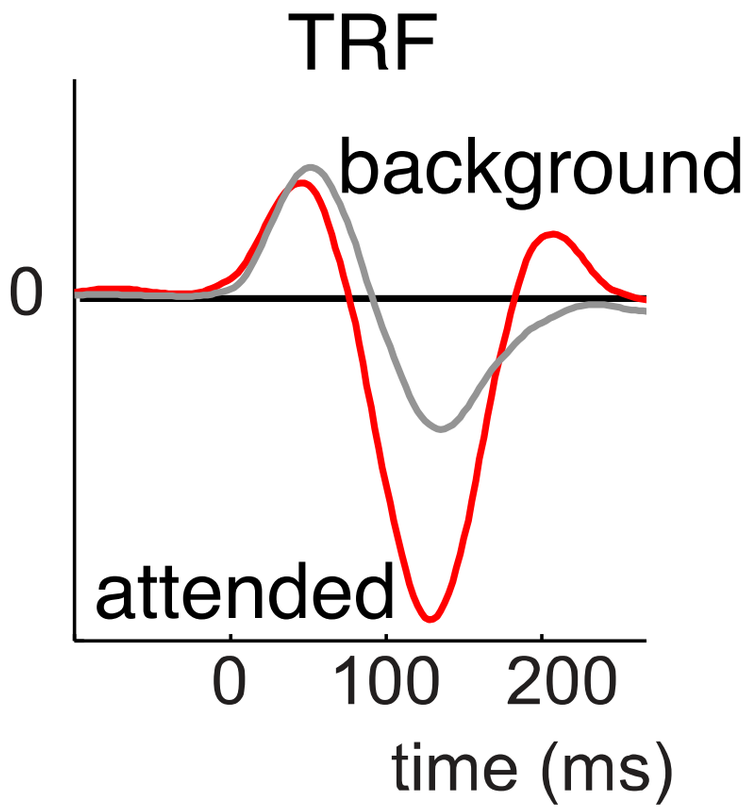
STRF Results



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

STRF Results





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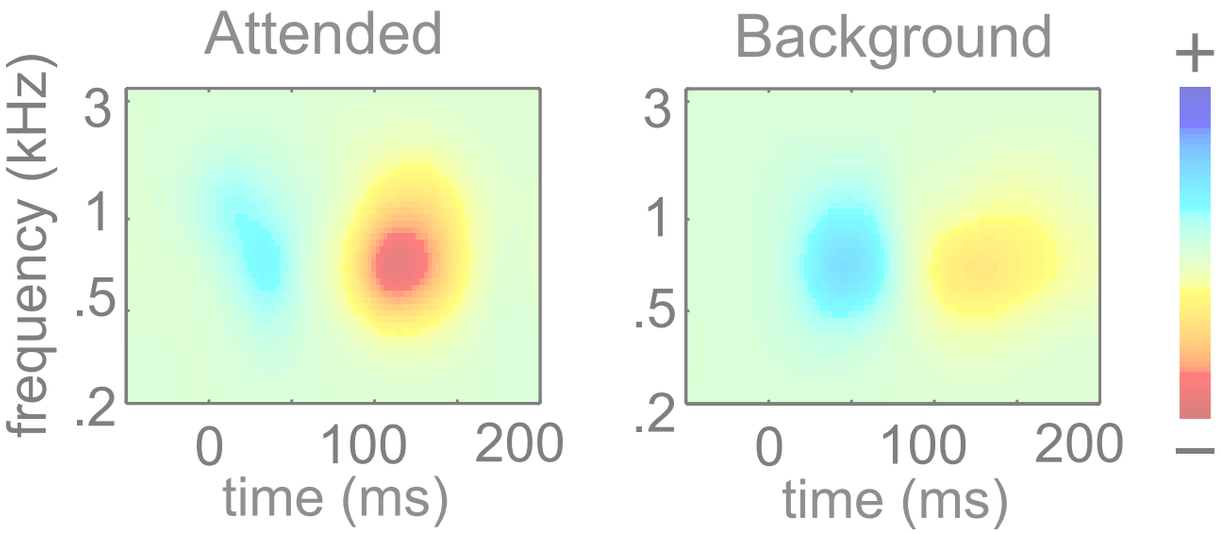
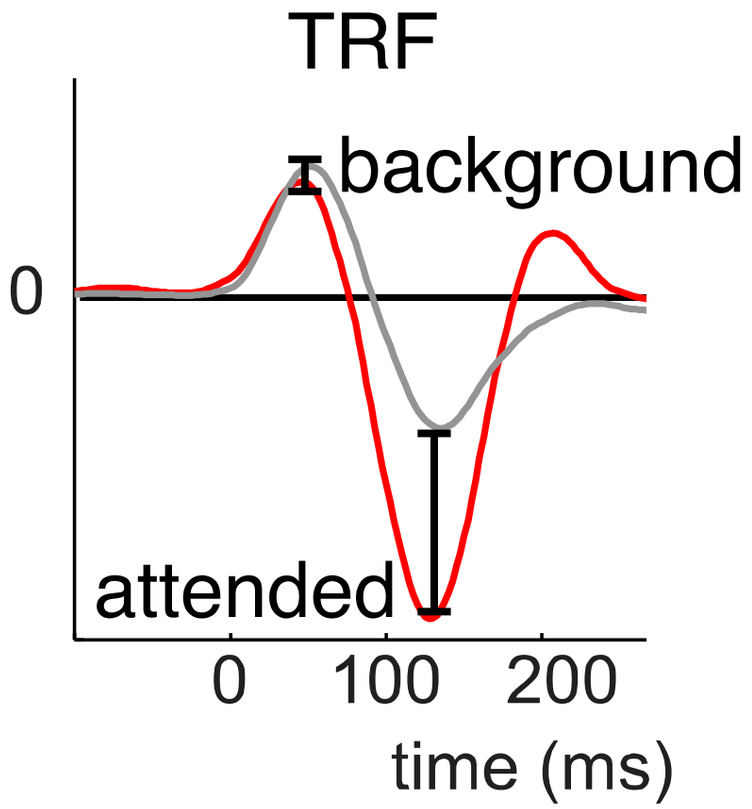
STRF Results



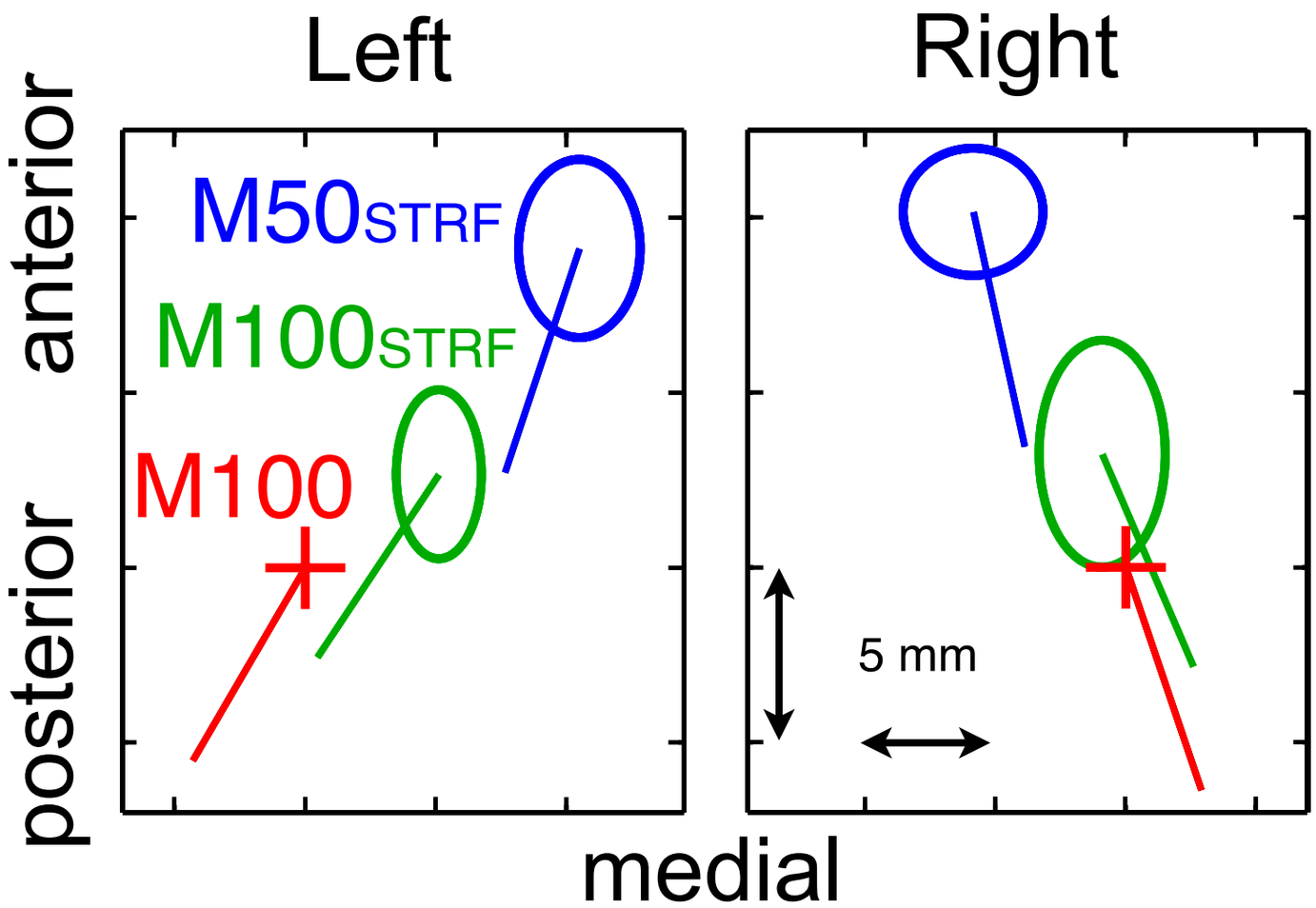


- STRF separable (time, frequency)
- 300 Hz - 2 kHz dominant carriers
- $M50_{STRF}$ positive peak
- $M100_{STRF}$ negative peak
- **$M100_{STRF}$ strongly modulated by attention, *but not $M50_{STRF}$***

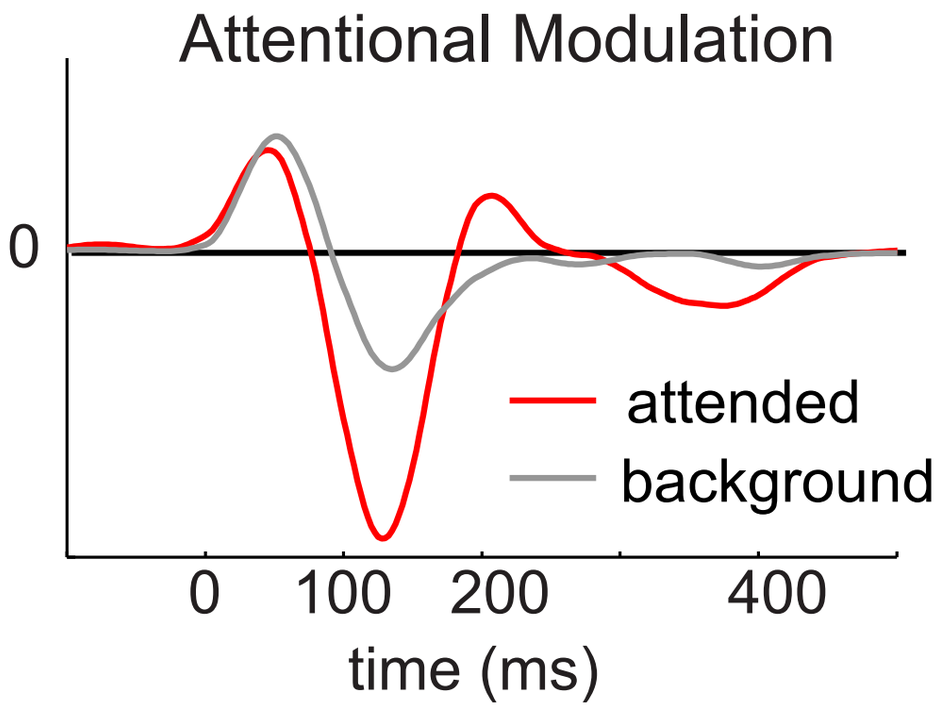
Neural Sources

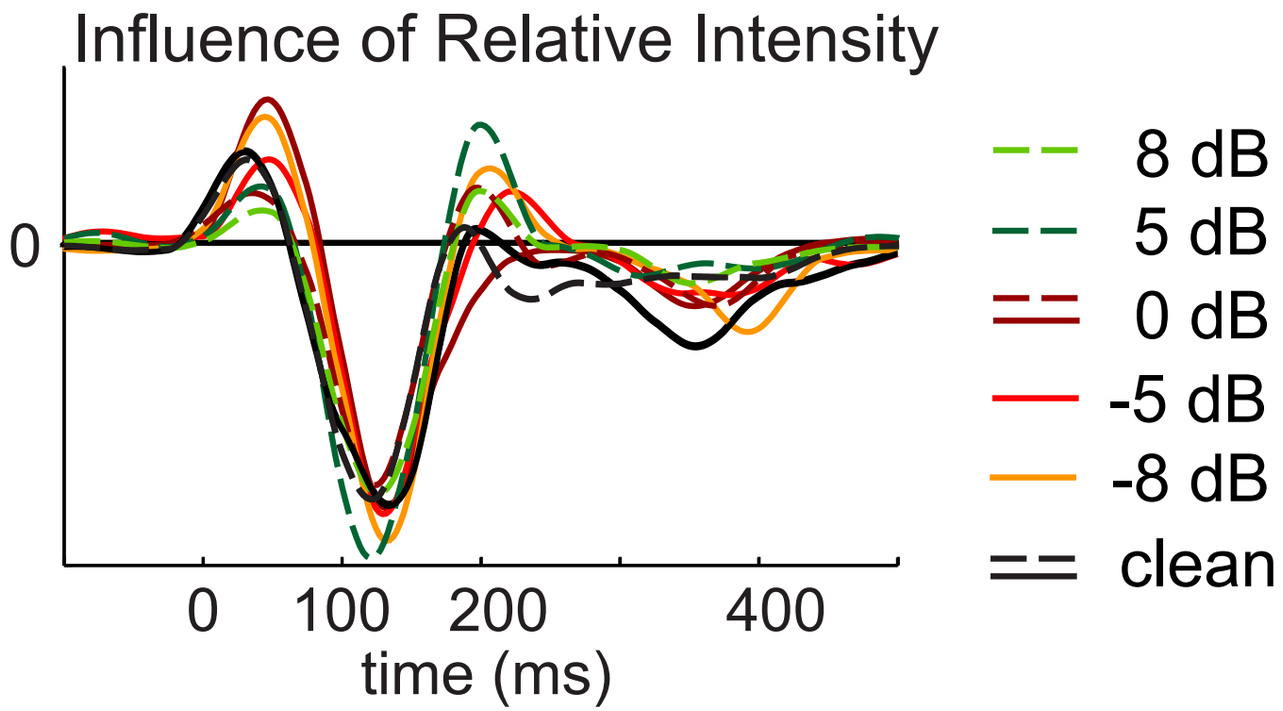
- M100$_{STRF}$ source near (same as?) M100 source:
  Planum Temporale

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



Cortical Object-Processing Hierarchy

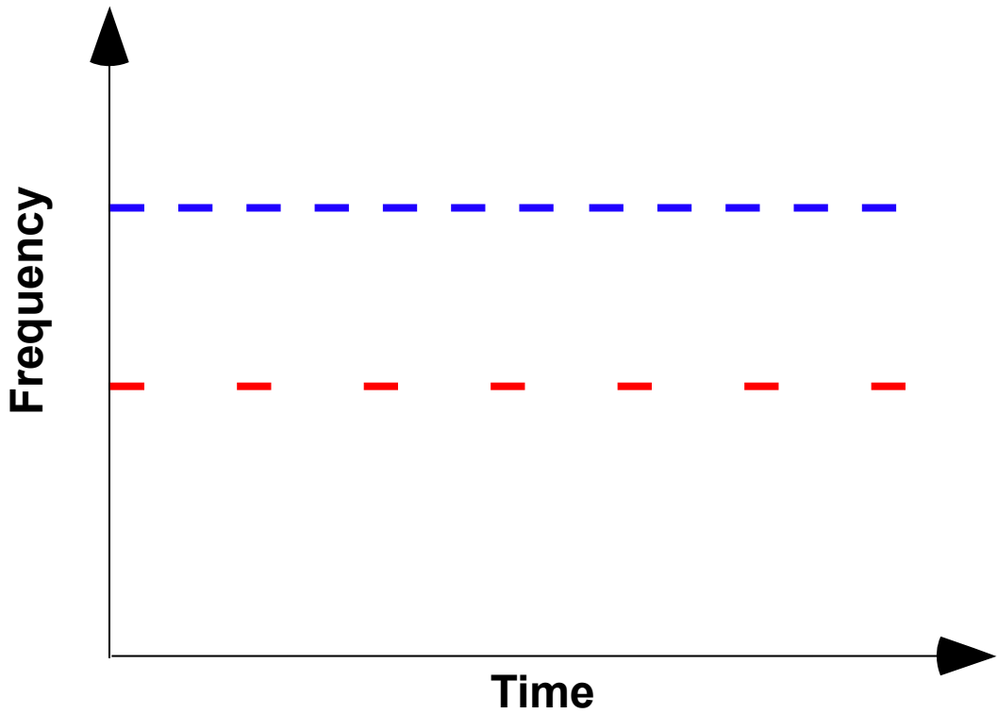




- $M100_{STRF}$ strongly modulated by attention, but not $M50_{STRF}$.
- $M100_{STRF}$ invariant against acoustic changes.
- Objects well-neurally represented at 100 ms, but not 50 ms.

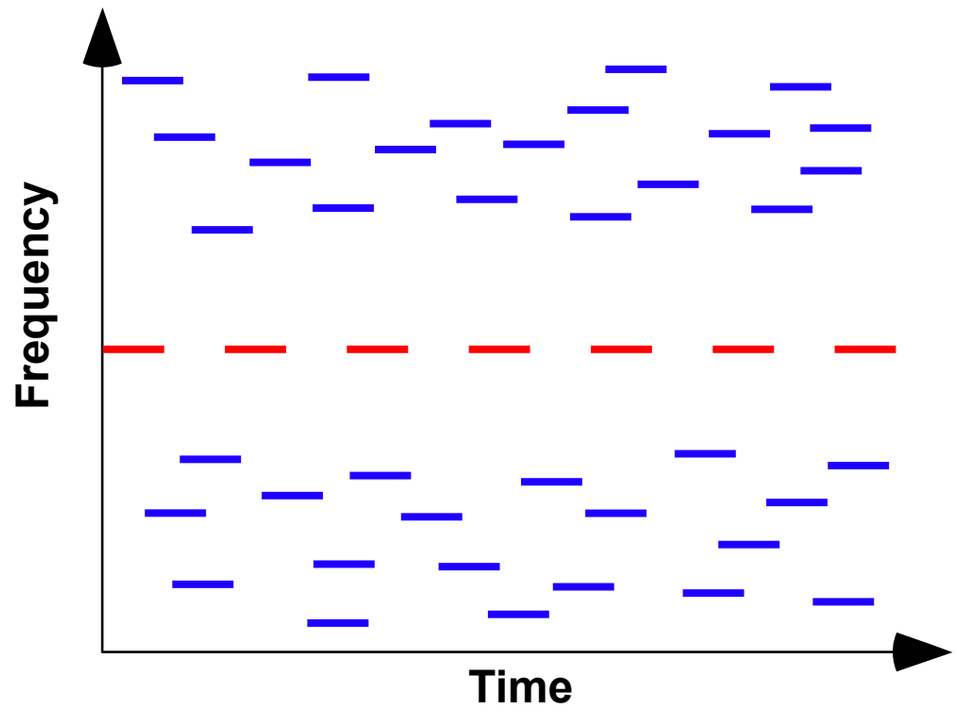
Not Just Speech

Competing Tone Streams



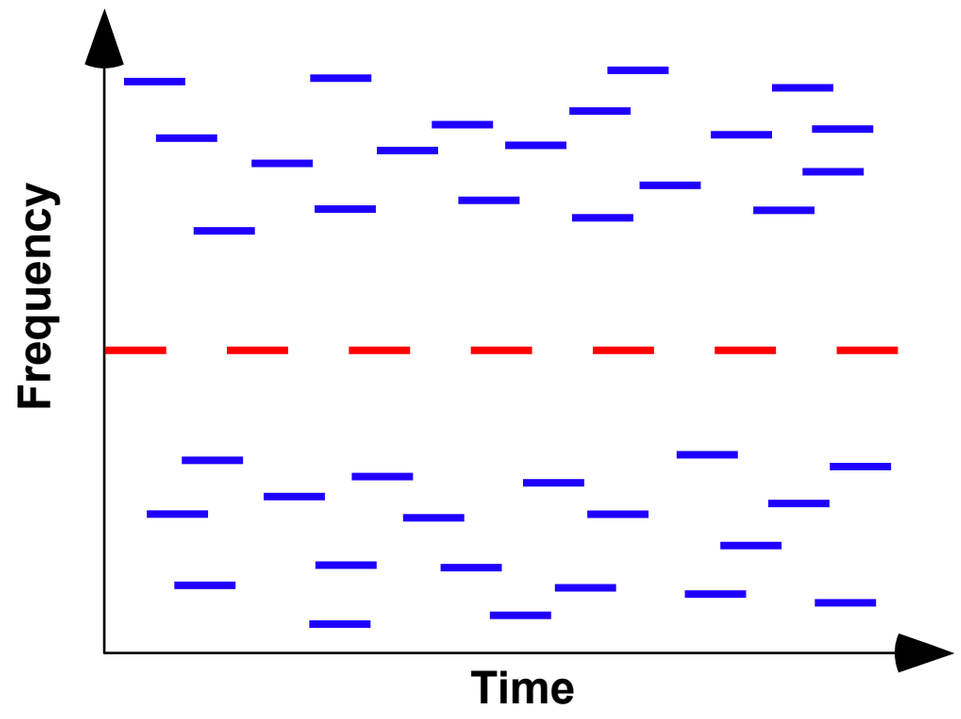
Xiang et al., J Neuroscience (2010)

Tone Stream in Masker Cloud

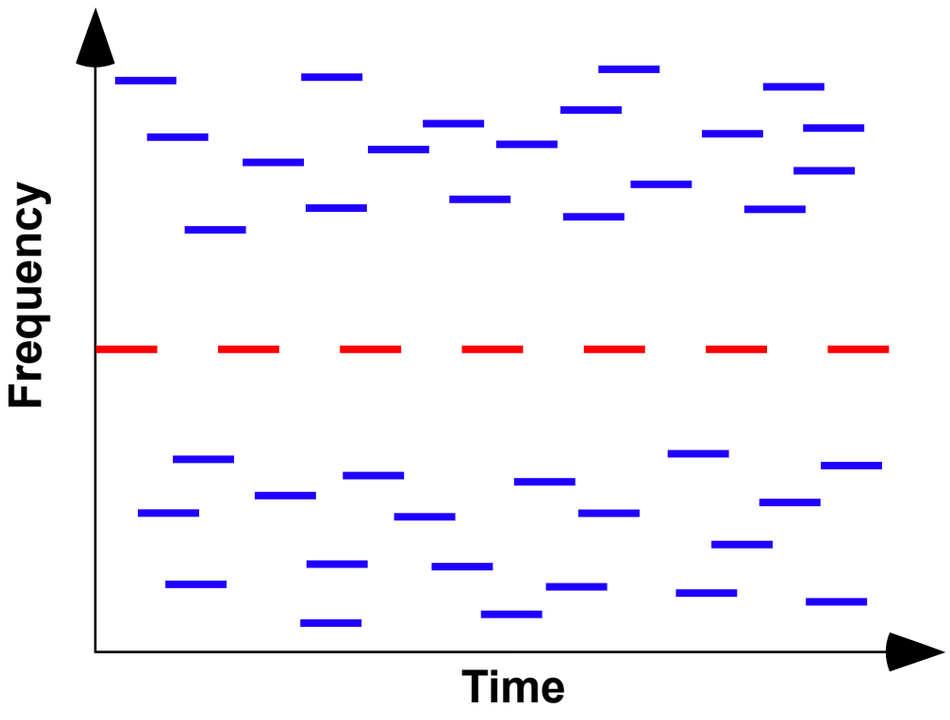


Elhilali et al., PLoS Biology (2009)

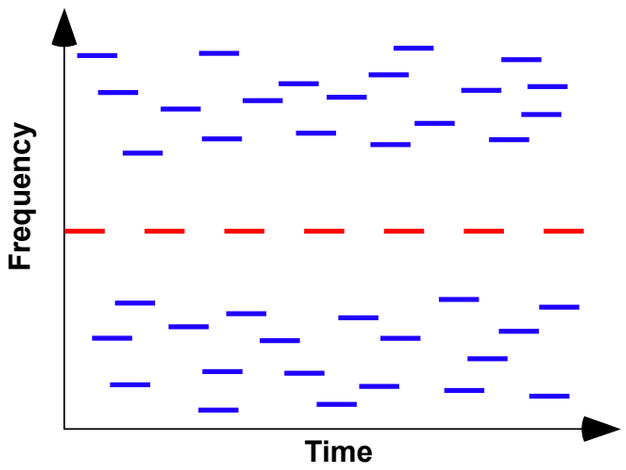
Tone Stream in Masker Cloud

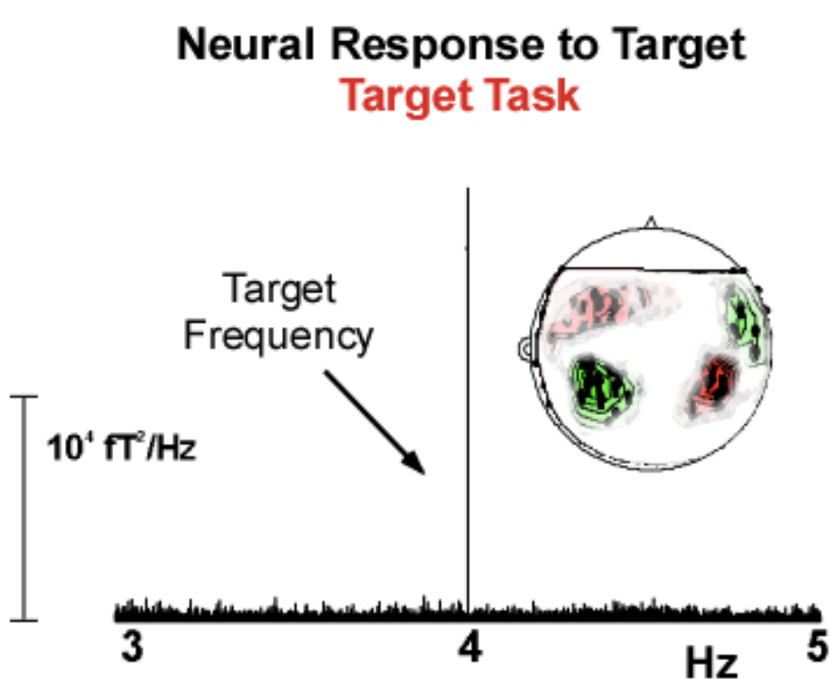


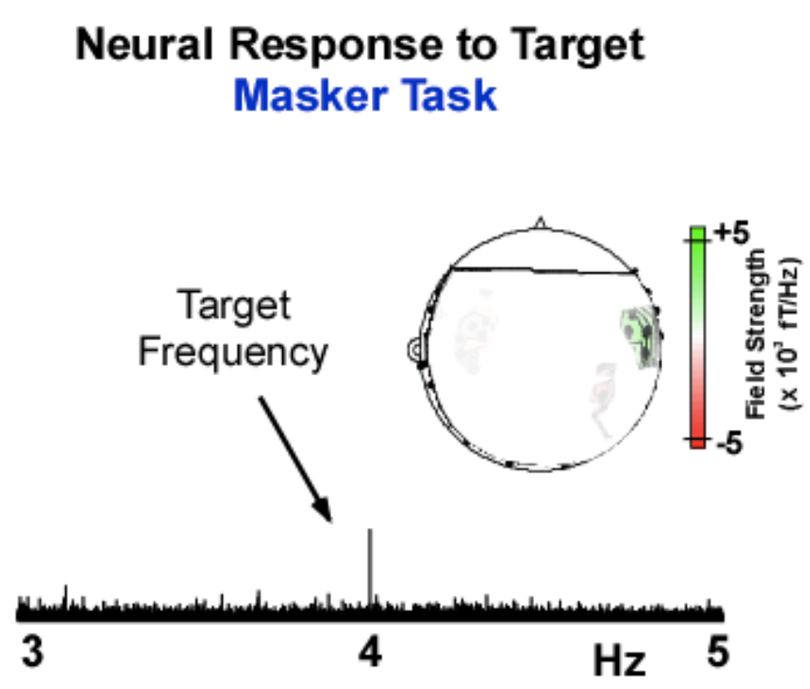
Tone Stream in Masker Cloud



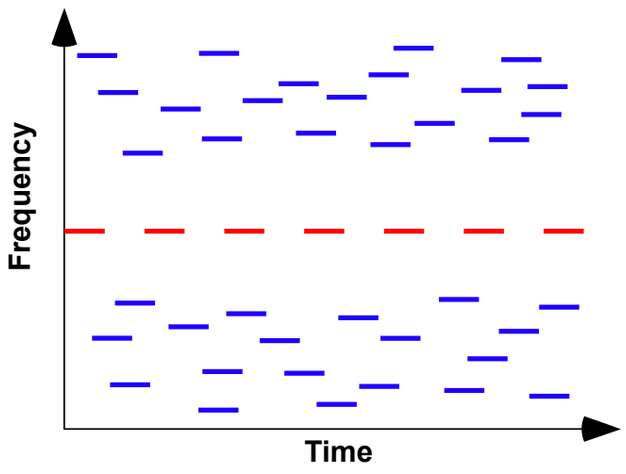
Tone Stream in Masker Cloud

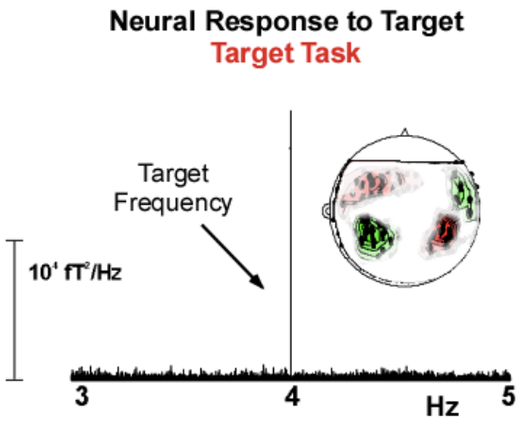


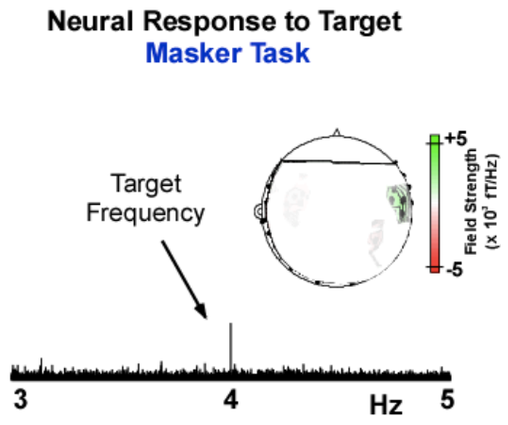


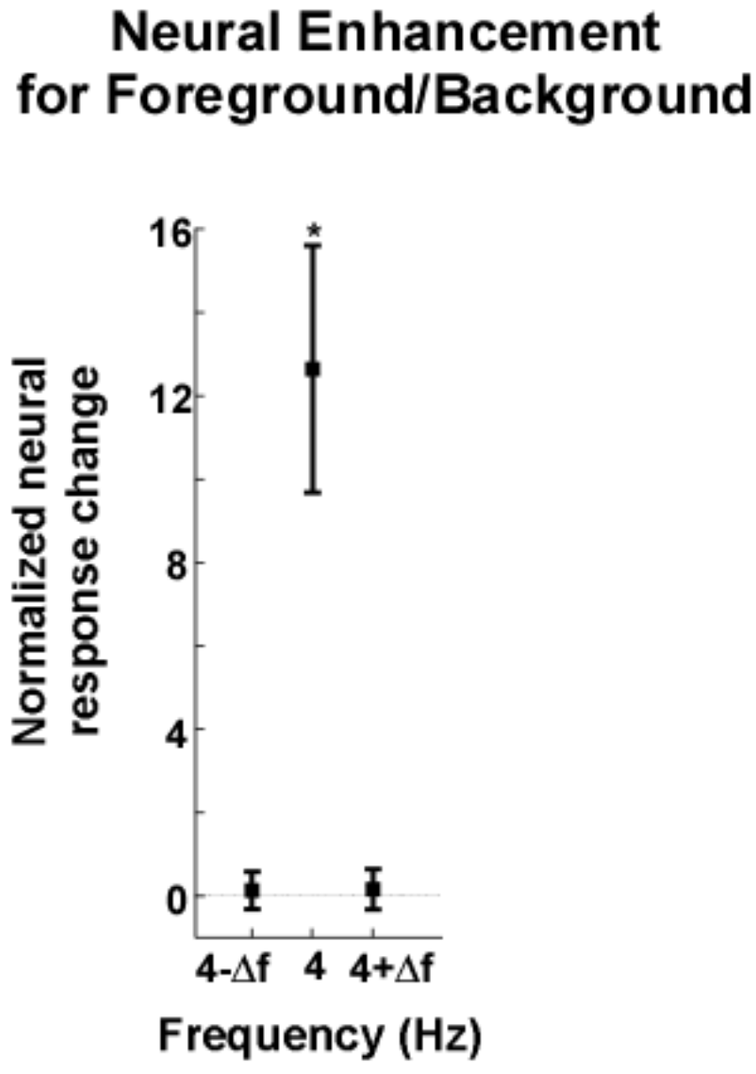


Tone Stream in Masker Cloud

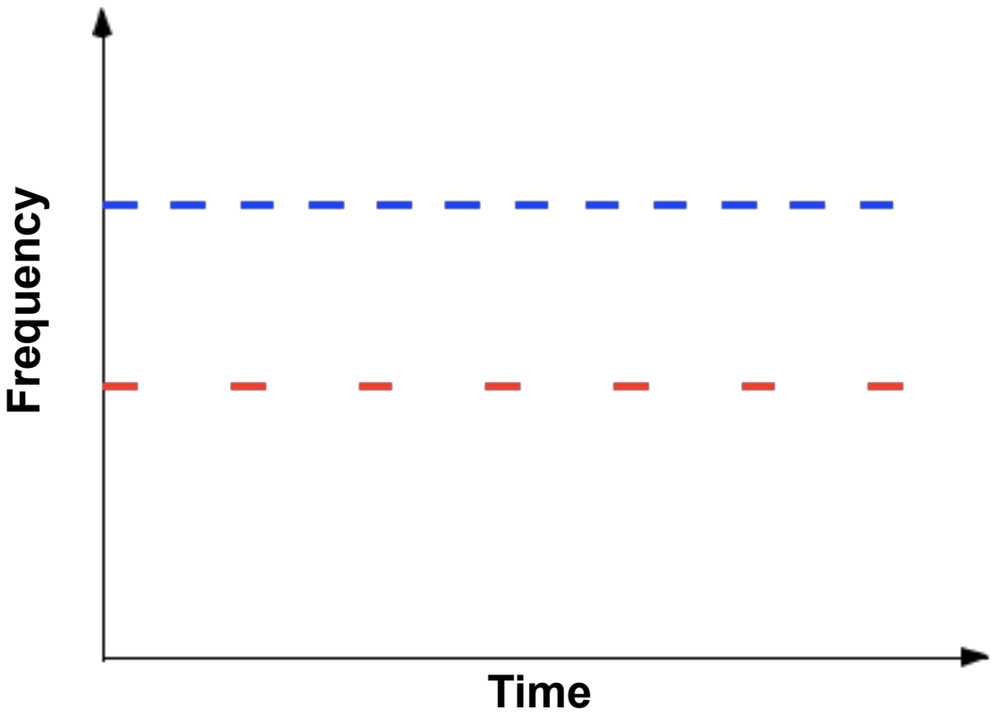








Competing Tone Streams



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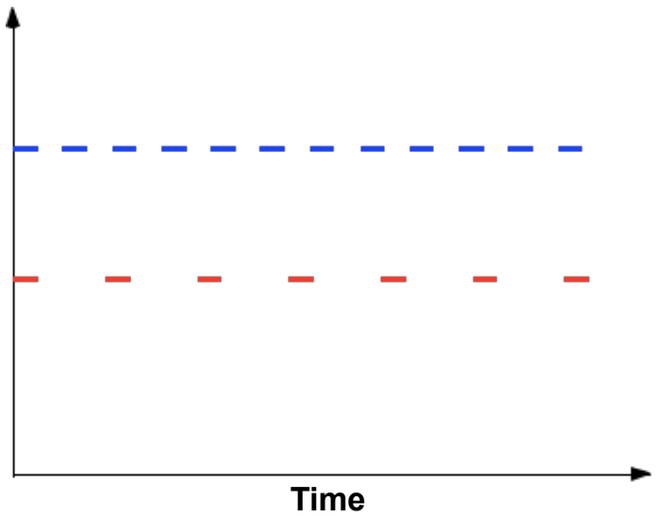

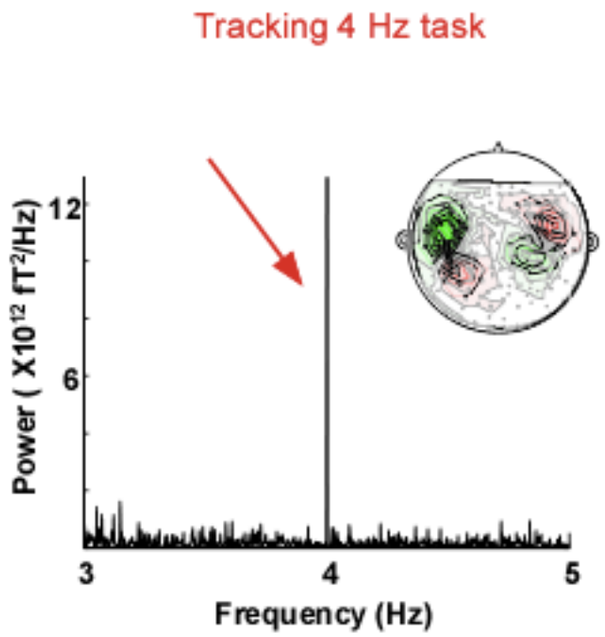

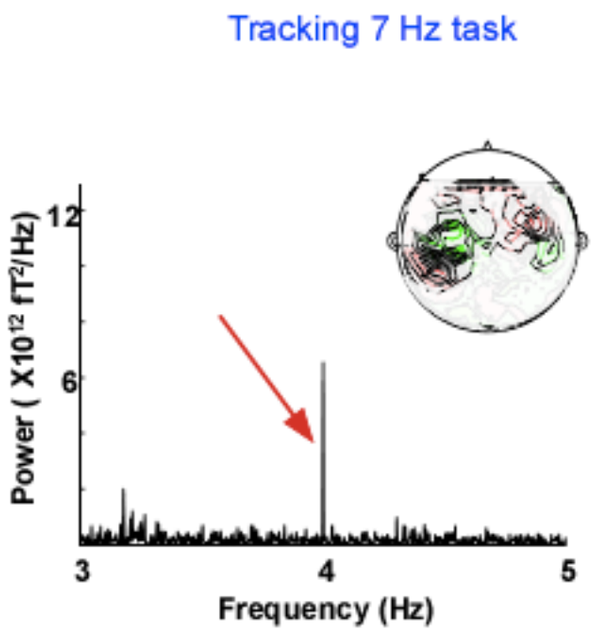

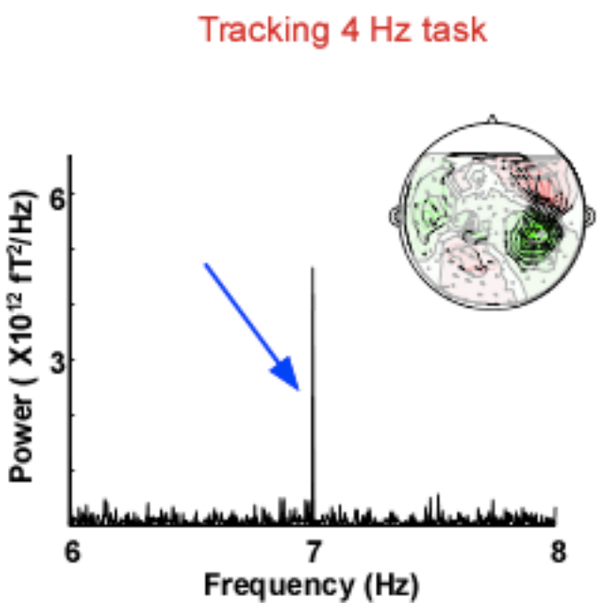

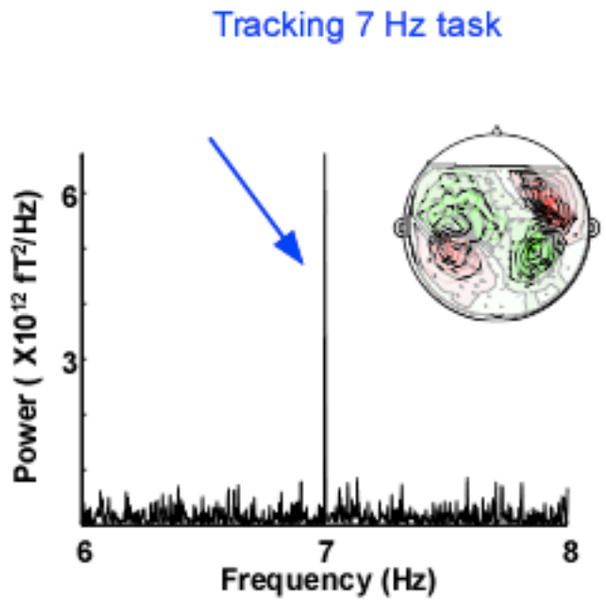

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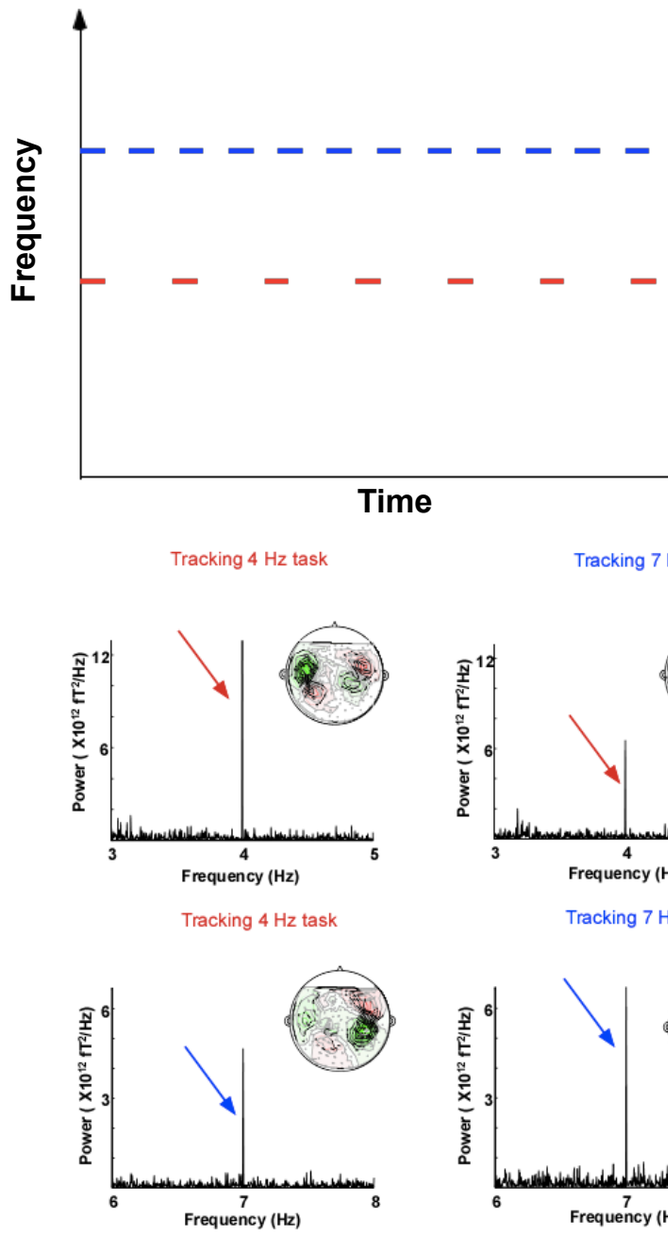

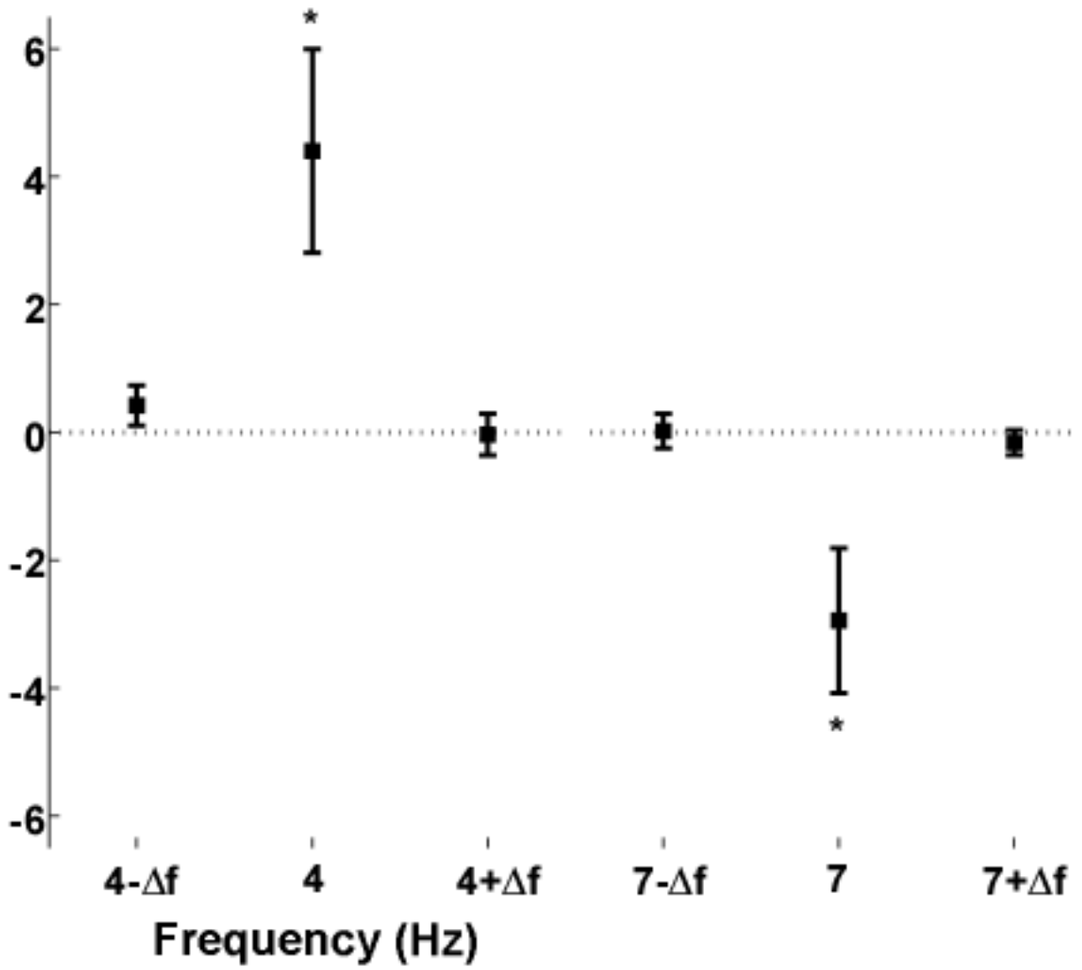

Summary

- Cortical representations of speech found here:
  - ✓ consistent with being *neural* representations of auditory *(perceptual)* objects
    - ✓ meet 3 formal criteria for auditory objects
- Object representation fully formed by 100 ms latency (PT), but not by 50 ms (HG)
- Not special to speech

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Integrated Life Sciences & HLSC 374

HONORS COLLEGE
INTEGRATED LIFE SCIENCES

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Courses

ILS courses are based on the national initiatives for reforming undergraduate biology education: *BIO 2010*, *Scientific Foundations for Future Physicians*, and *Vision and Change*. These initiatives provide explicit guidelines for designing multidisciplinary life sciences curricula necessary for preparing life science and pre-medical students for successful careers in the 21st century. The ILS academic program is composed of a core of four accelerated courses in integrated organismal biology, genetics and genomics, mathematical modeling in Biology, and scholarship-in-practice, plus the first-semester introduction course. These courses represent either honors versions of BSCI courses or unique new courses designed to satisfy the objectives of the national initiatives linked above. Furthermore, all ILS courses emphasize innovative pedagogy strategies intended to encourage student active engagement and small-group problem solving.

Course Descriptions

HLSC 100: Developing Life Scientists for the Global Good (1 credit) - TThis small group, service-learning course provides students with the information needed to develop into professionals in the Life Sciences. Class dialogue focuses on the resources available to students at UMD as well as three important facets of the life sciences: the social determinants of health, sustainability, and STEM education. Students also participate in an ongoing service experience where they work with an organization that focuses on addressing the needs of the local community. (Those students entering ILS as rising second-year students may substitute other UNIV 100 courses to satisfy this requirement.) This course satisfies the freshmen seminar requirement for most majors.Sample Syllabus

HLSC 207 Principles of Biology III: Organismal Biology (3 credits) - This course is recognized as a national model for teaching rigorous introductory organismal biology, since it utilizes mathematical, physical, chemical, genomic, and evolutionary principles to develop an integrated perspective toward the functioning and evolution of all organisms, including humans. This course is equivalent to BSCI 207 Sample Syllabus

HLSC 322 Genetics and Genomics (4 credits) -This course starts with an overview of basic Mendelian and molecular genetics, then focuses on the understanding and application of genomics to contemporary research, medicine, biotechnology, and societal issues. This course is equivalent to BSCI 222 Sample Syllabus

HLSC 374 Mathematical Modeling in Biology(4 credits) - This course is designed specifically to teach students how to apply advanced mathematics and modeling techniques in order to: 1) address important problems in human physiology, epidemiology, and complex biological systems, and 2) do research in emerging disciplines, such as molecular biophysics and bioinformatics. NOTE: The prerequisite for this course is two semesters of Calculus or the equivalent AP credits. This course is equivalent to BSCI474 Sample Syllabus

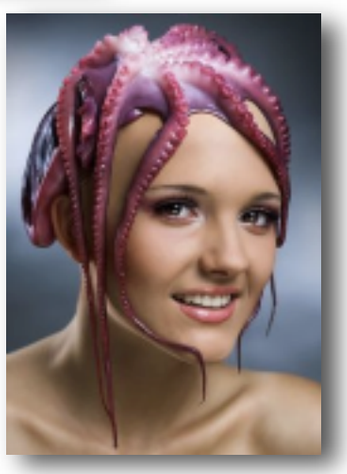
HLSC 374: Mathematical Modeling in Biology

"Models are chosen from a variety of biological disciplines, including biological population dynamics, infectious disease models, molecular evolution models, and phylogenetic tree construction."

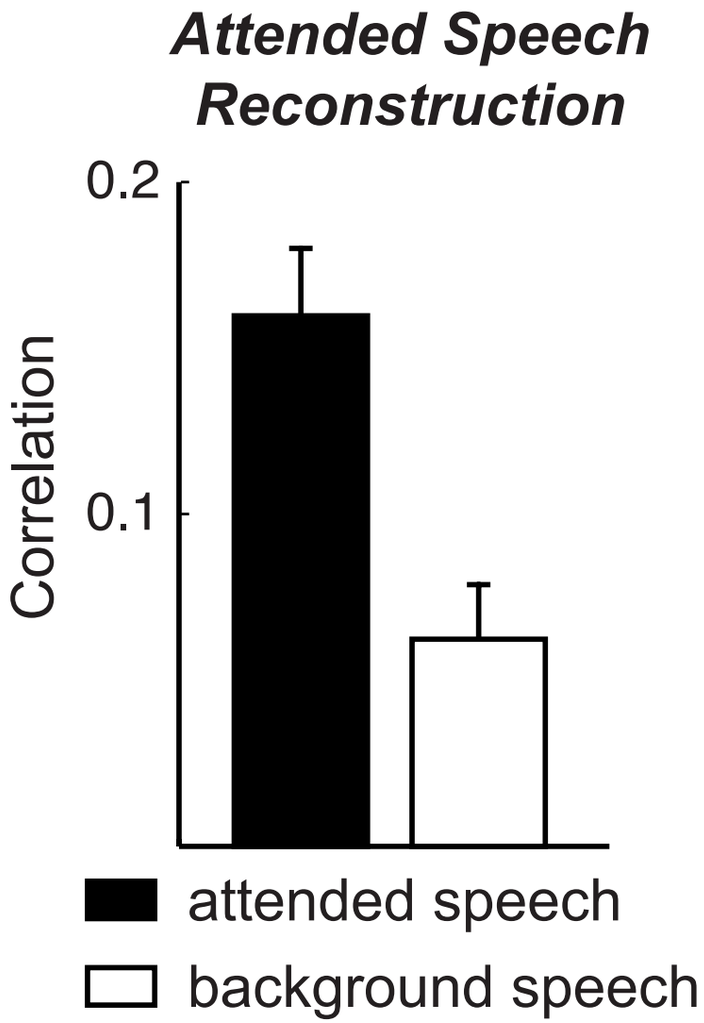
Looking for Guest Lecturer!

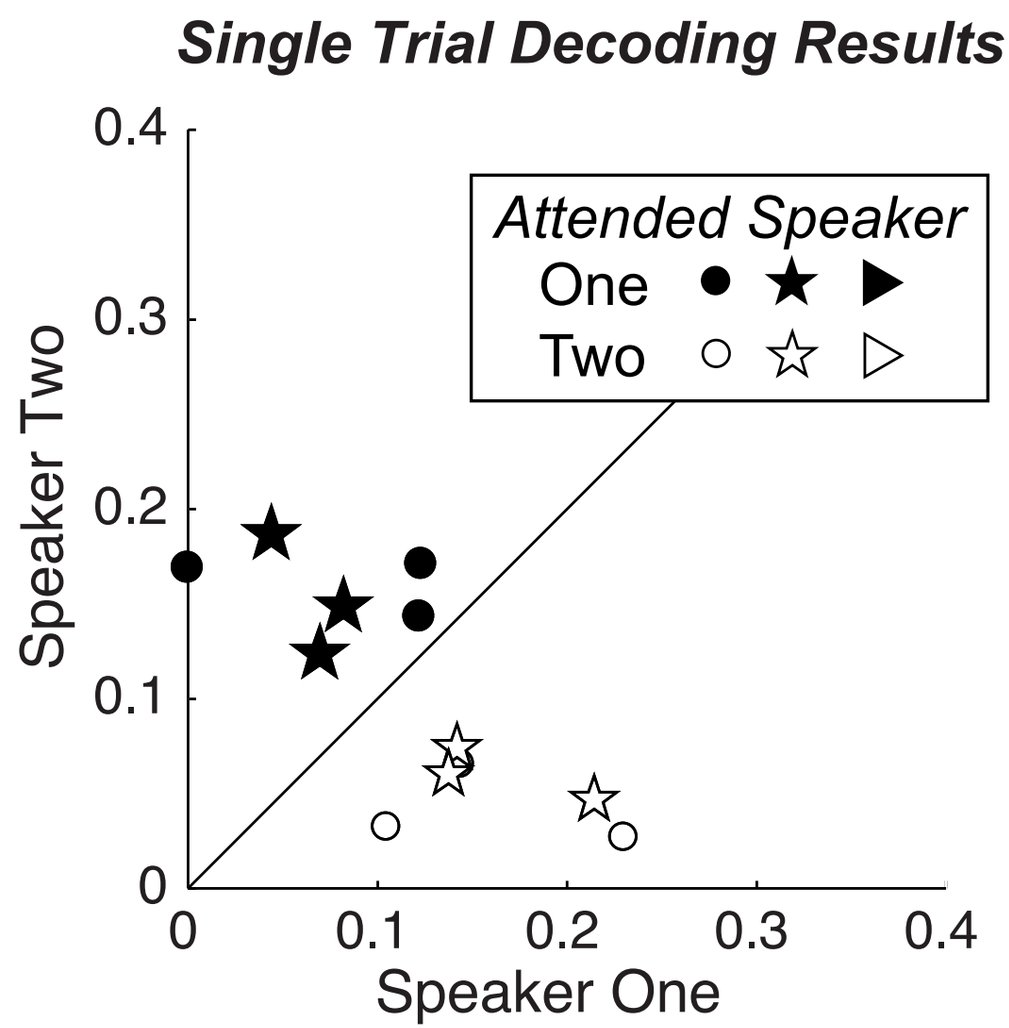
Thank You


HELLO NEW MEMBERS
NO HATS
At the monthly meeting of
Squidheads Anonymous

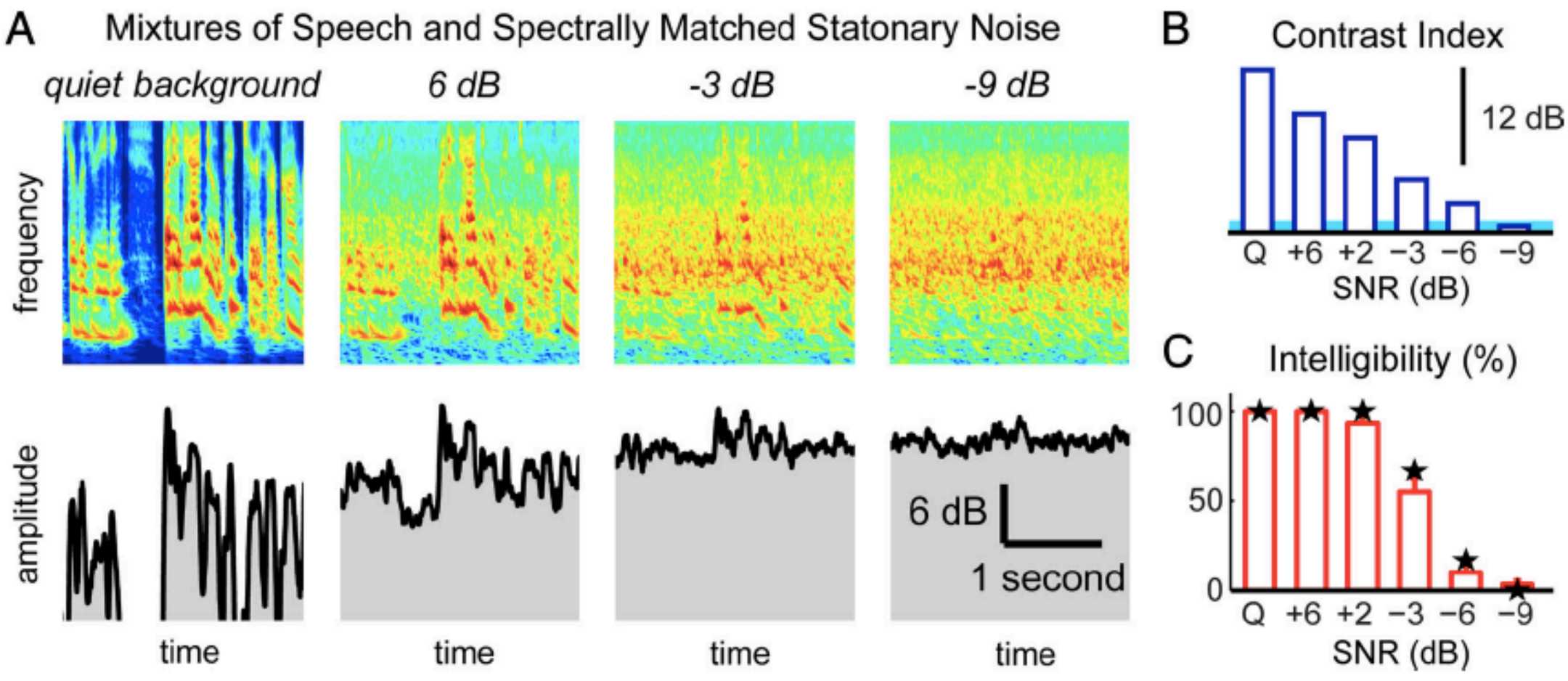


Reconstruction of Same-Sex Speech

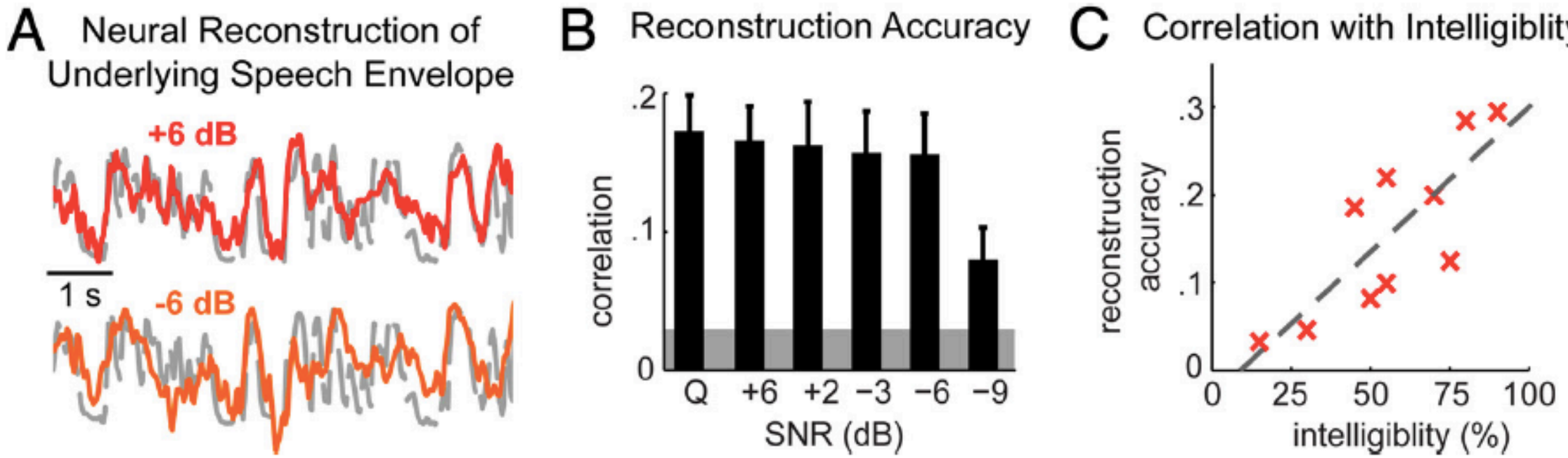




Speech in Noise: Stimuli



Speech in Noise: Results



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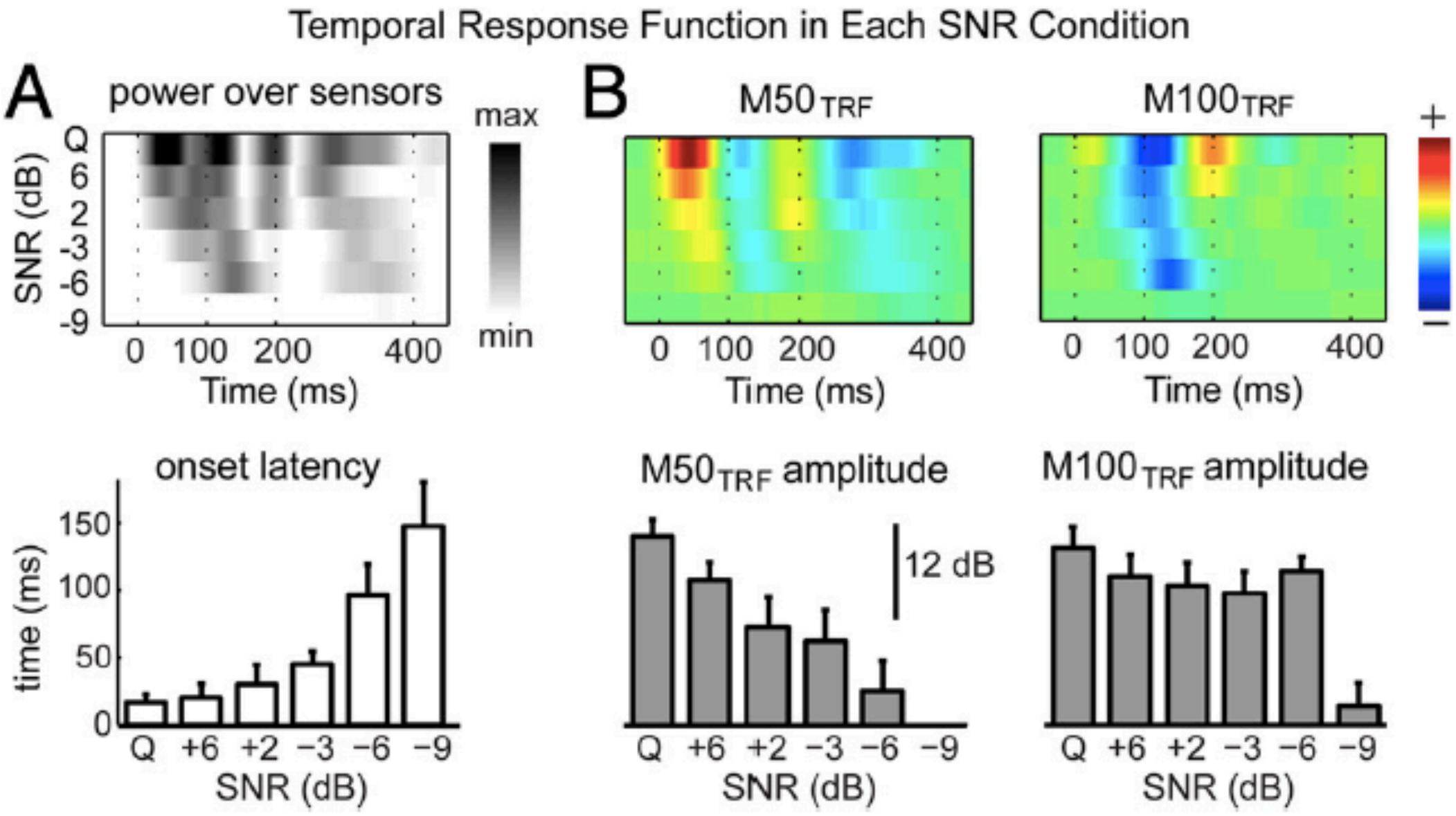

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