Neural Representations of Continuous Speech in Auditory Cortex

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Acknowledgements

Grad Students

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Nayef Ahmar
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Marisel Villafane Delgado
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Murat Aytekin
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Past Postdocs

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Shihab Shamma

Funding

NIH R01 DC 008342
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Introduction

- Magnetoencephalography (MEG)
- Cortical Representations of Speech
  - Encoding vs. Decoding
  - Attended vs. Unattended Speech
  - Foreground vs. Background

Neural Signals & MEG

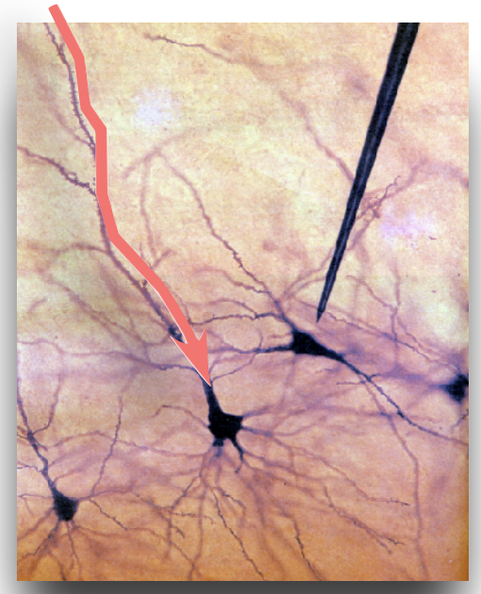
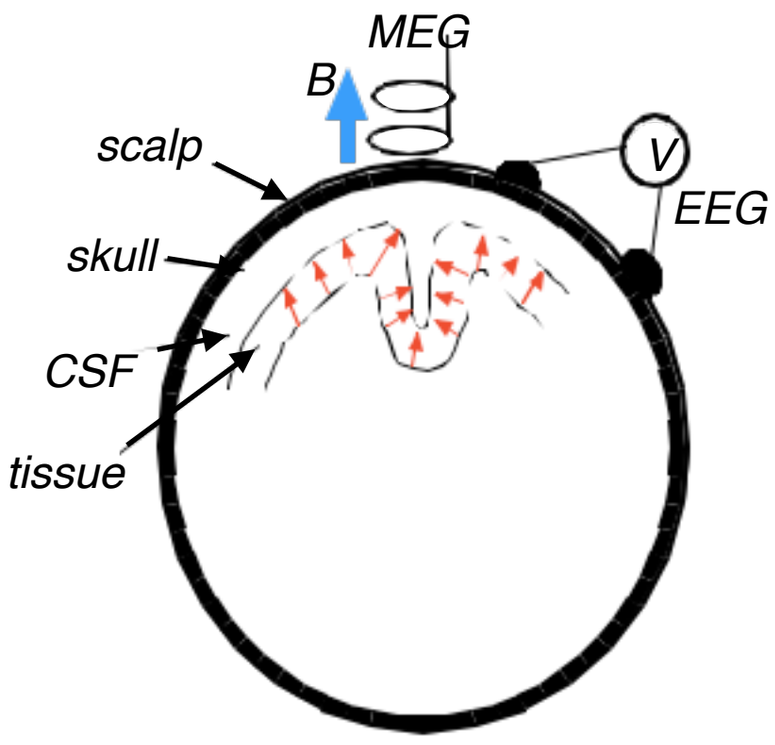
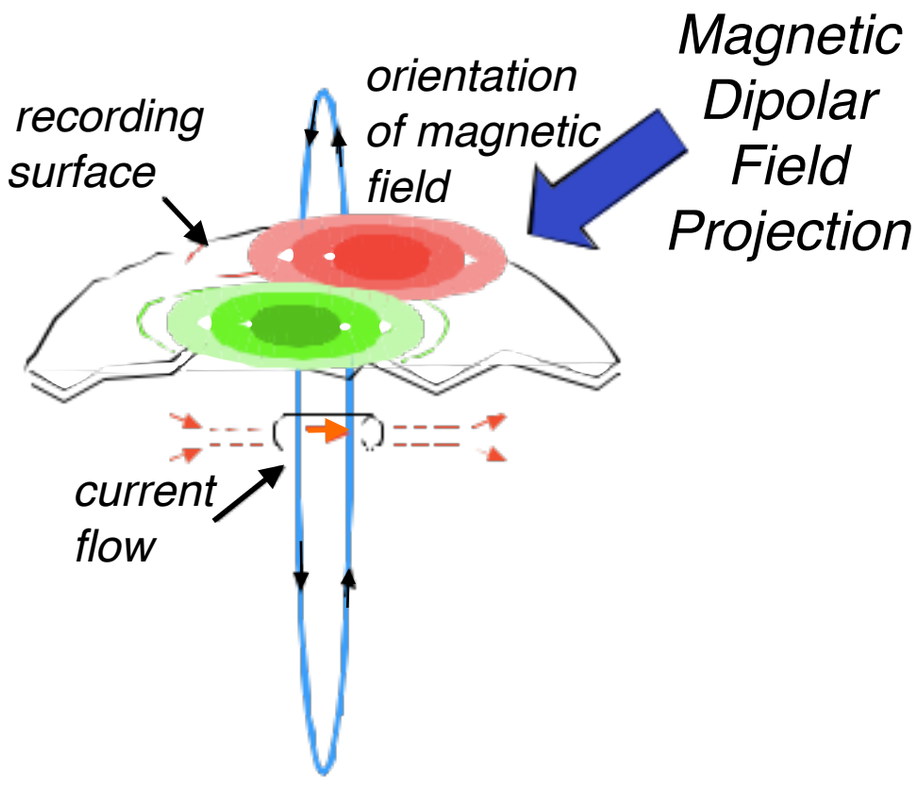


Photo by Fritz Goro

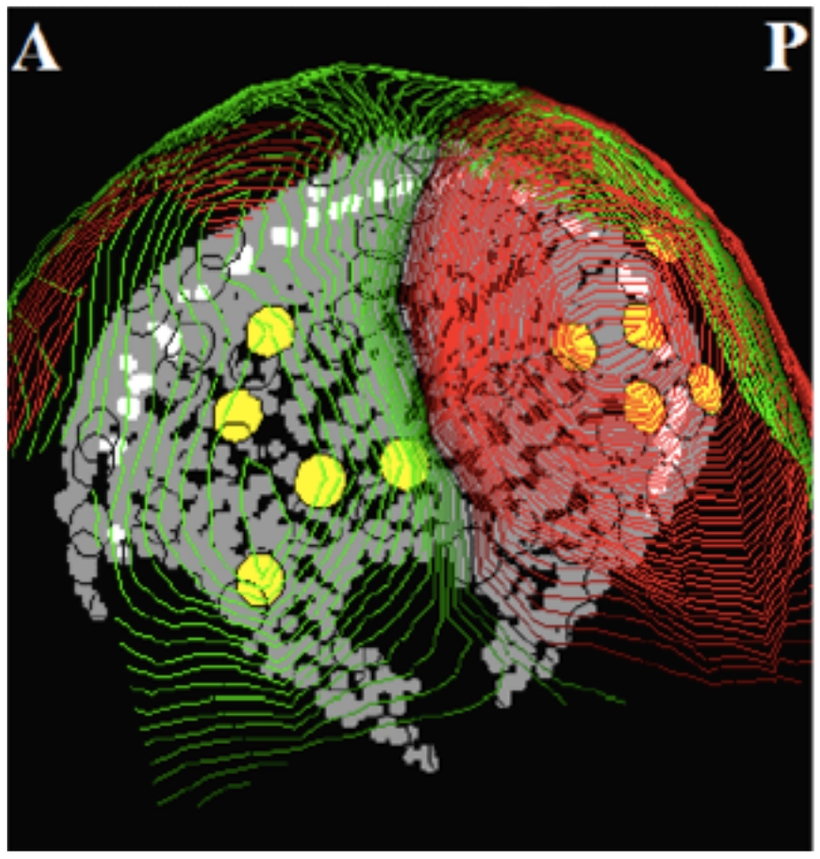




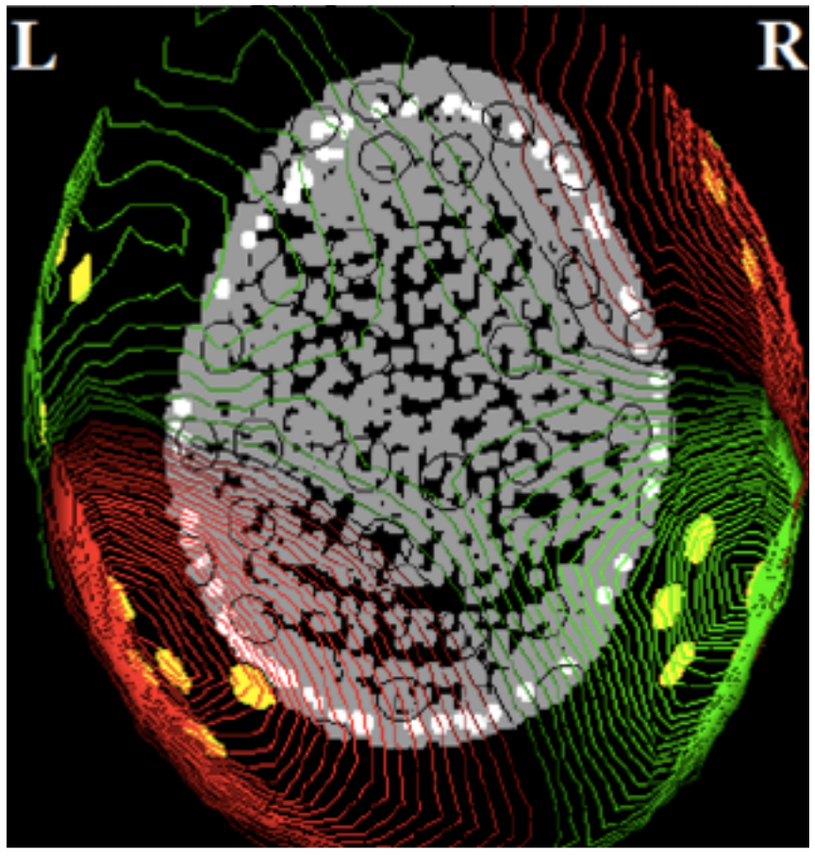
- Direct electrophysiological measurement
  - not hemodynamic
  - real-time
- No unique solution for distributed source

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

MEG Auditory Field



Sagittal View

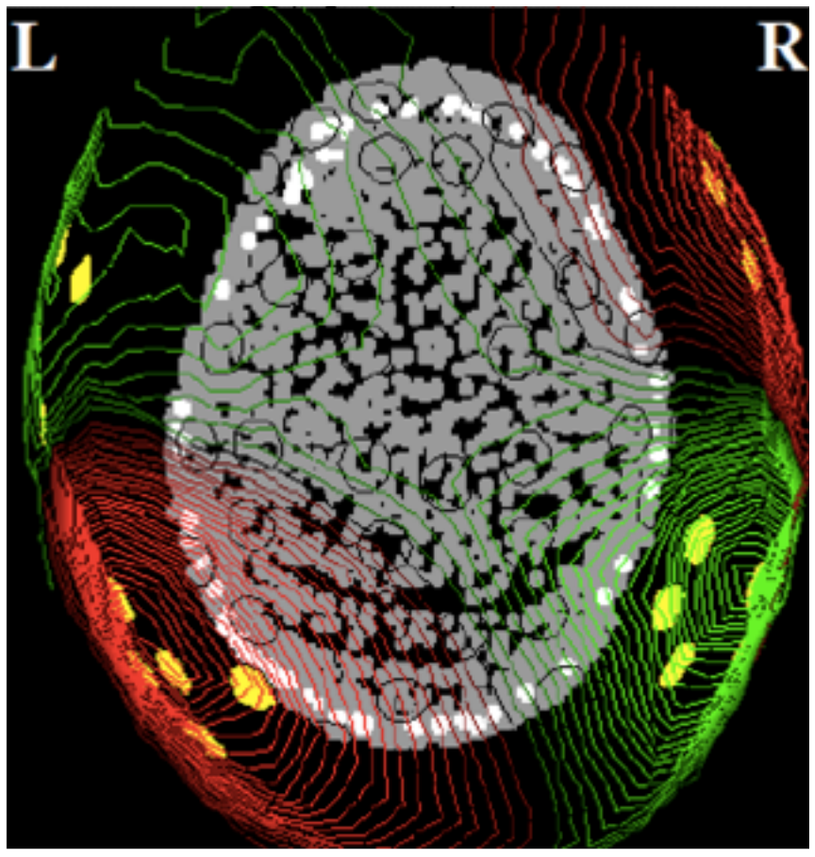


Axial View

Strongly
Lateralized

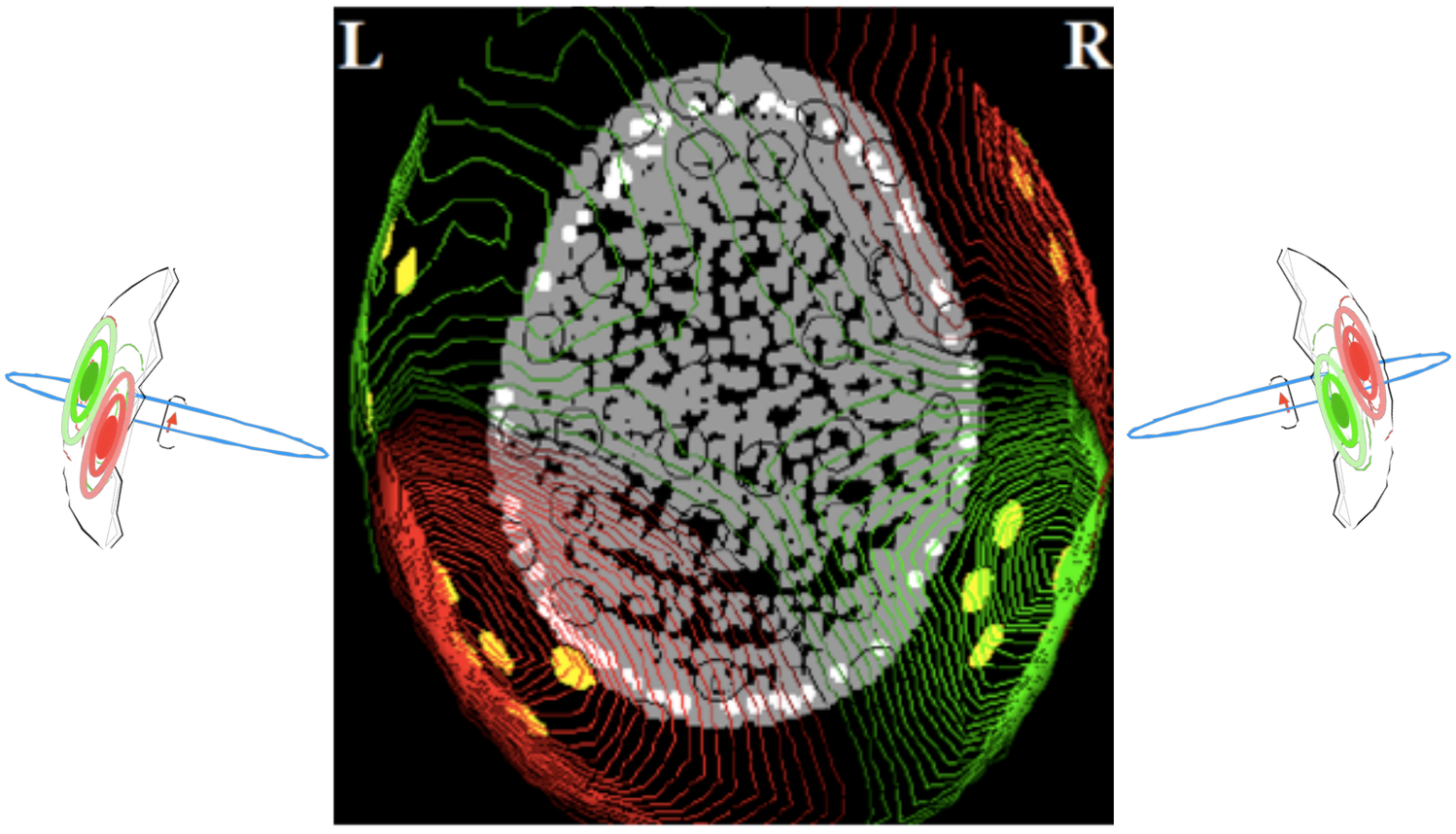
Chait, Poeppel and Simon, Cerebral Cortex (2006)

MEG Auditory Field



Chait et al., Cerebral Cortex (2006)

MEG Auditory Field

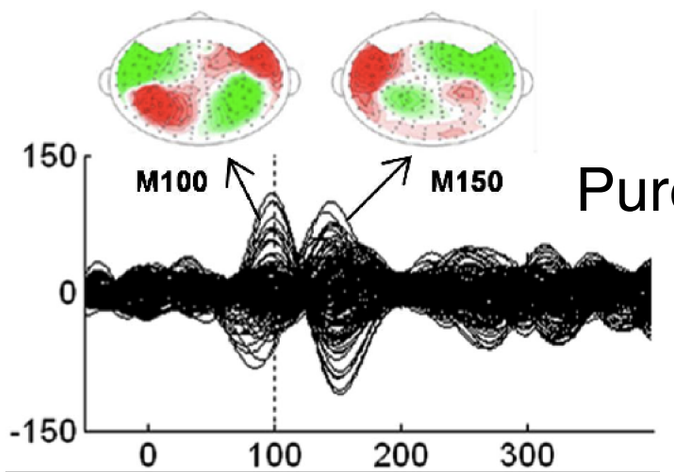


Chait et al., Cerebral Cortex (2006)

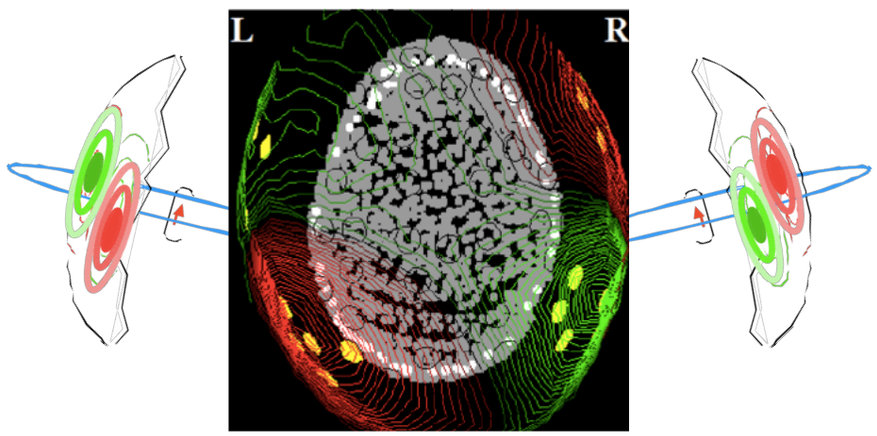
Time Course of MEG Responses

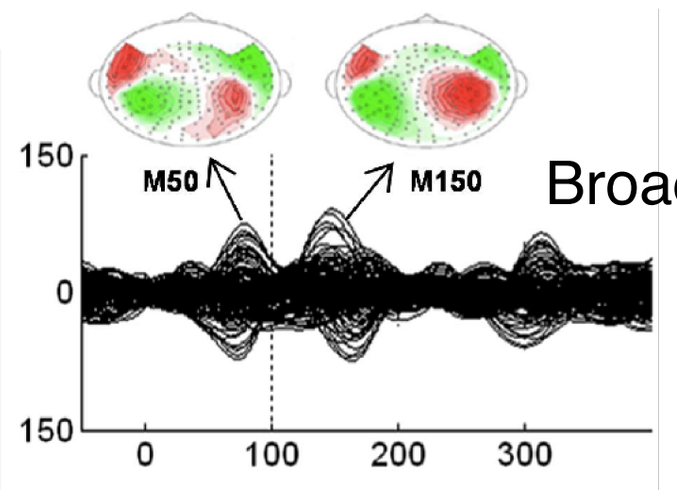
Auditory Evoked Responses

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



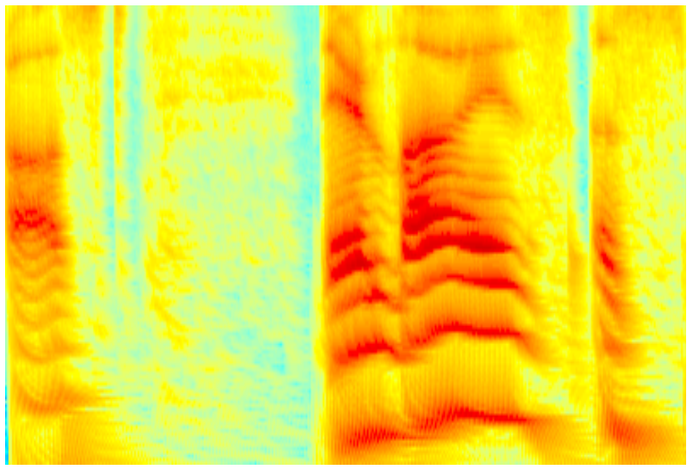
Pure Tone

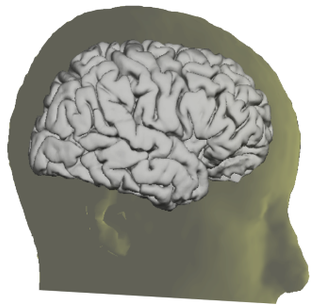




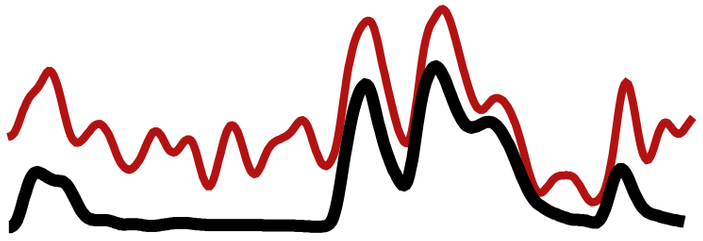
Broadband Noise

MEG Responses to Speech Modulations

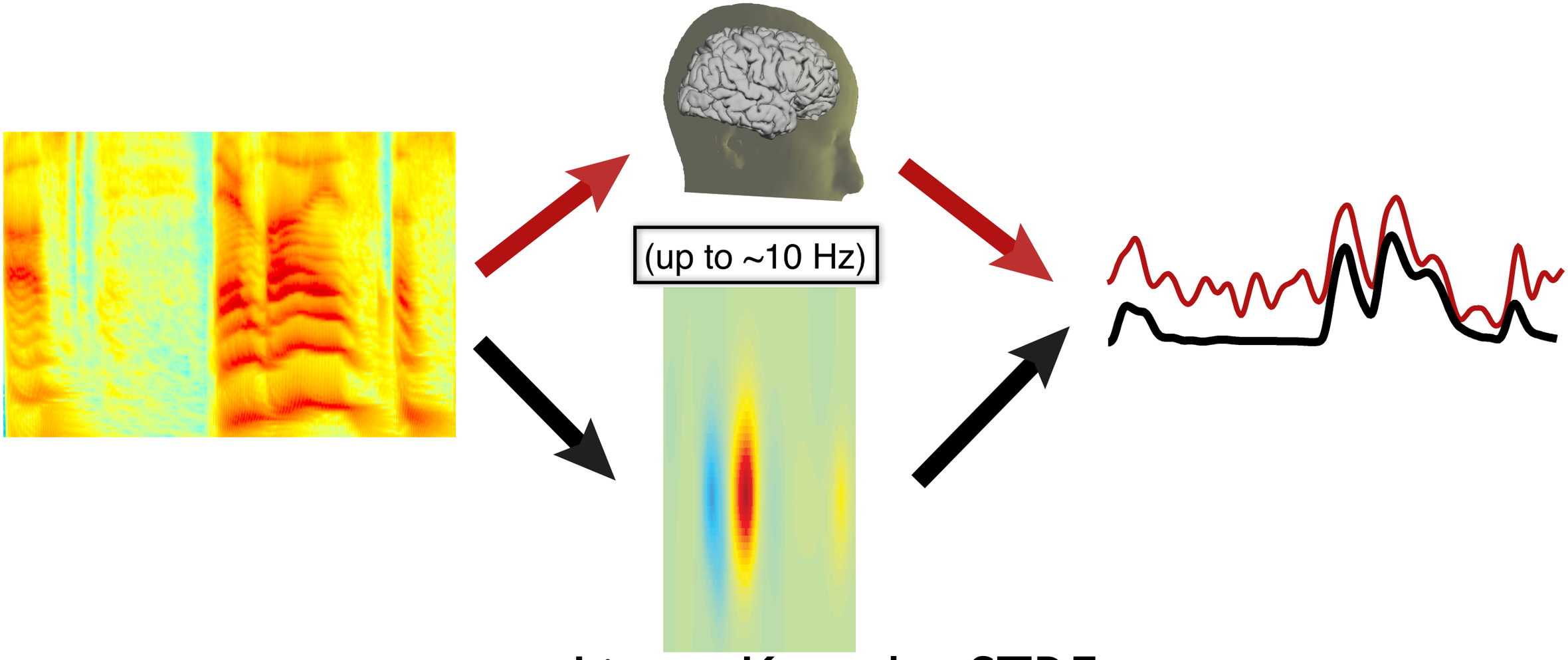




Auditory Model



MEG Responses Predicted by STRF Model

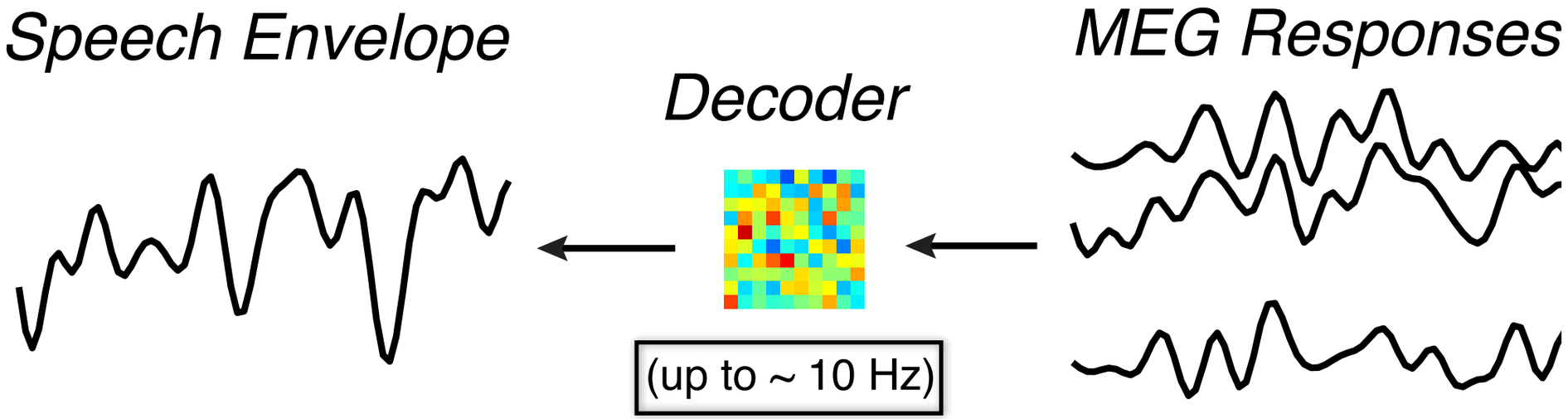


Linear Kernel = STRF

"Spectro-Temporal Response Function"

Ding & Simon, J Neurophysiol (2012)

Neural Reconstruction of Speech Envelope



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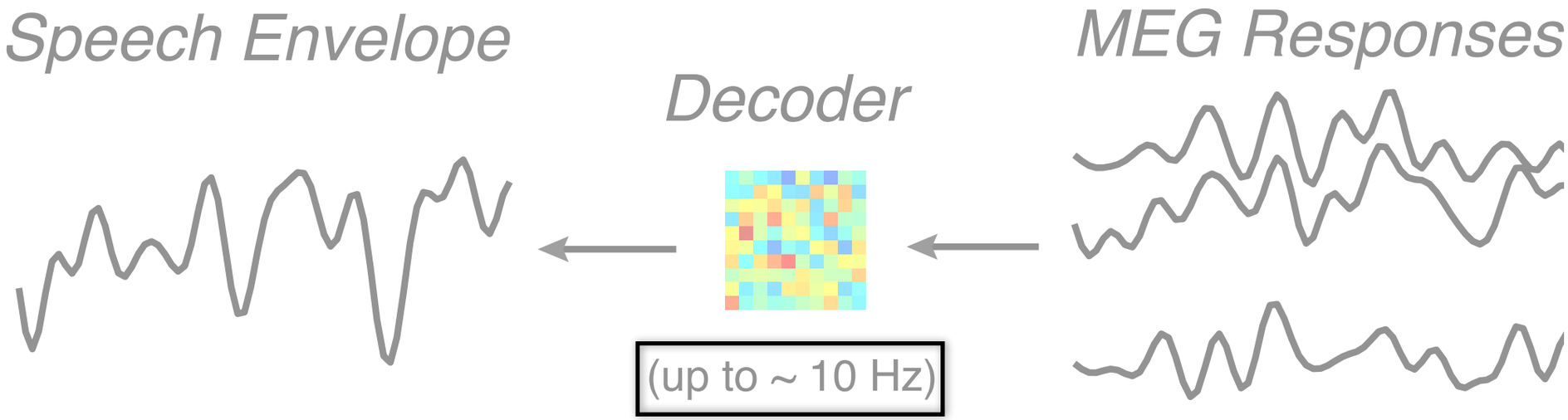
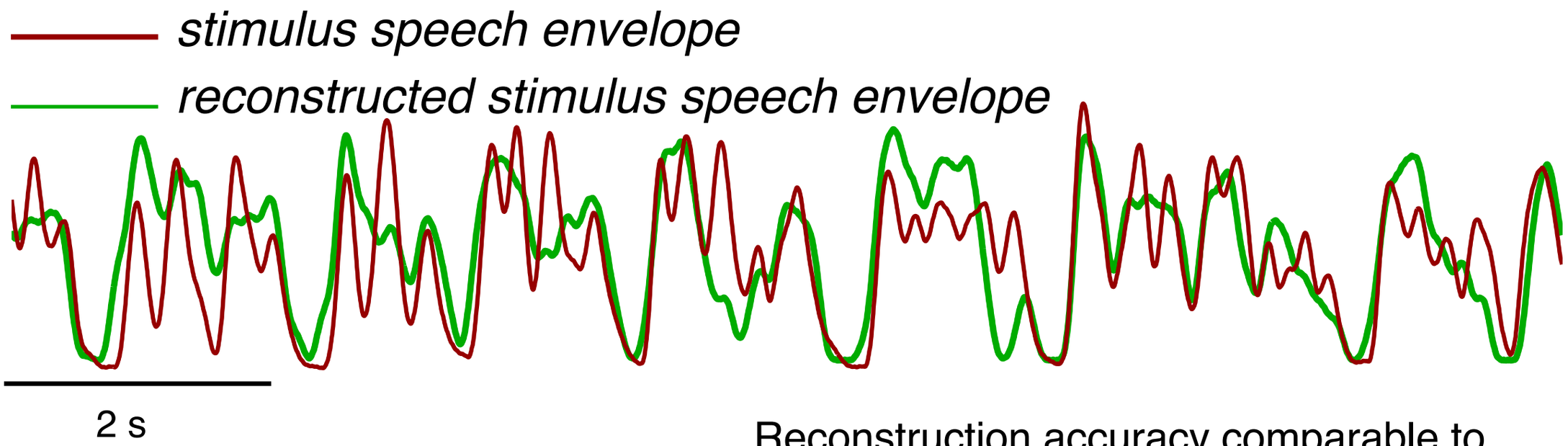
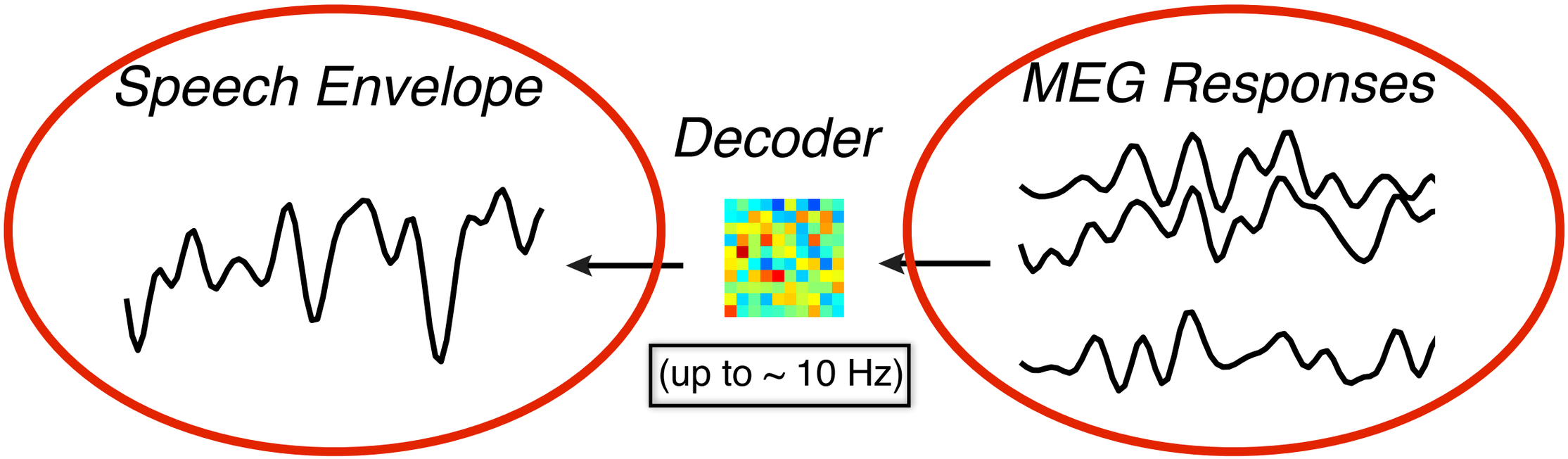


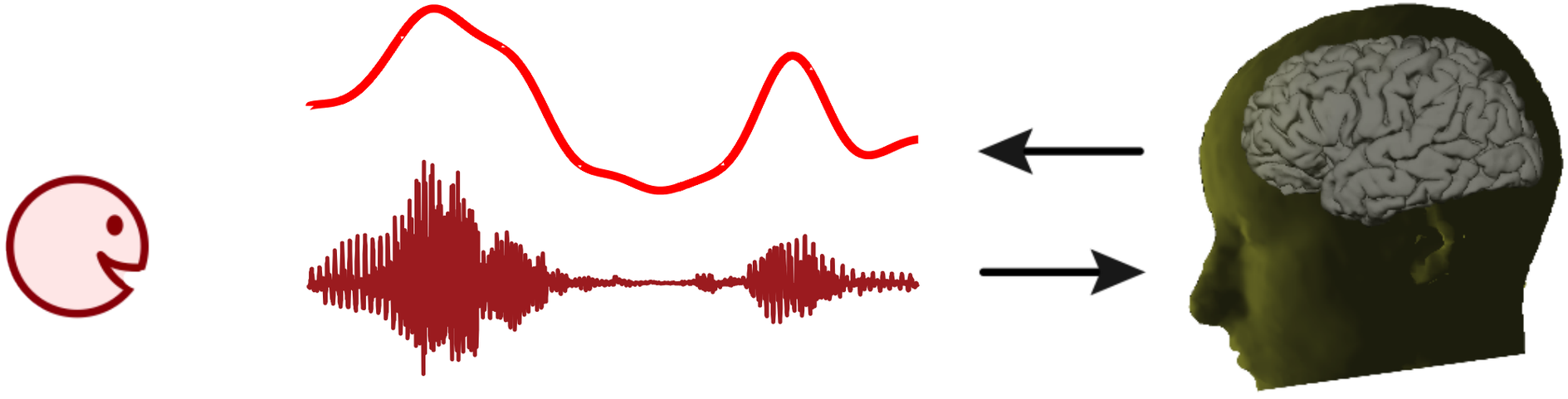


Reconstruction accuracy comparable to single unit & ECoG recordings

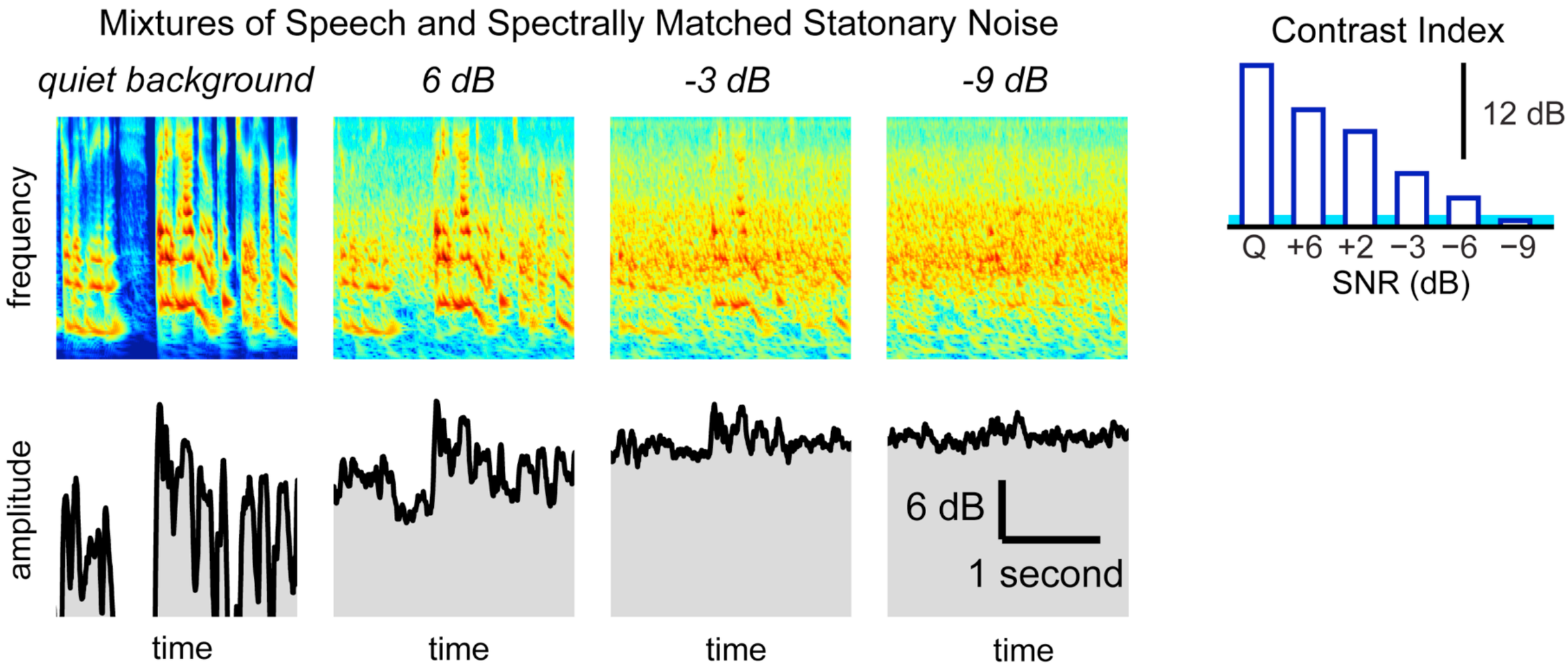
Ding & Simon, J Neurophysiol (2012)
Zion-Golumbic et al., Neuron (2013)


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

Neural Encoding of Speech: Temporal

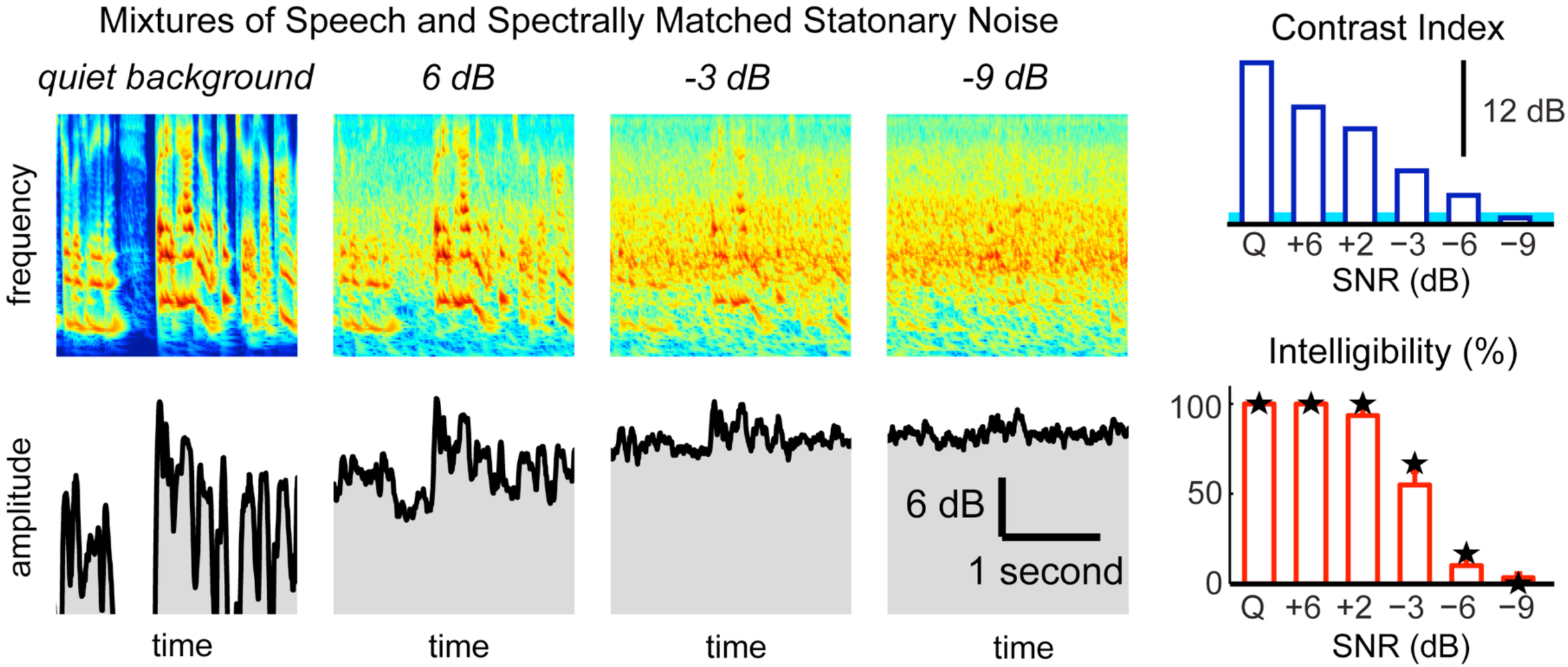


Speech in Noise



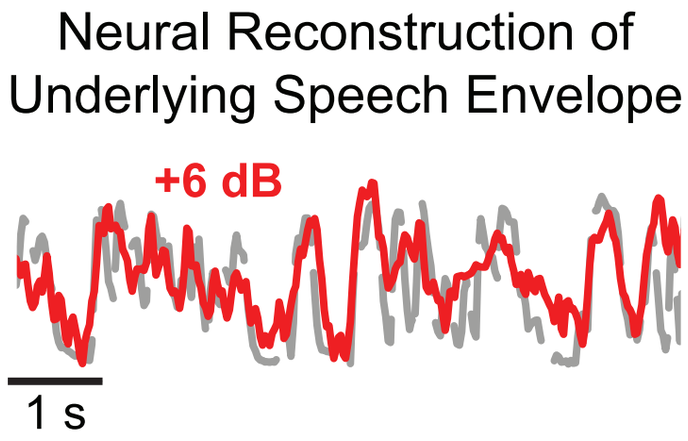
Ding & Simon, J Neuroscience (2013)

Speech in Noise



Ding & Simon, J Neuroscience (2013)

Speech in Noise: Results



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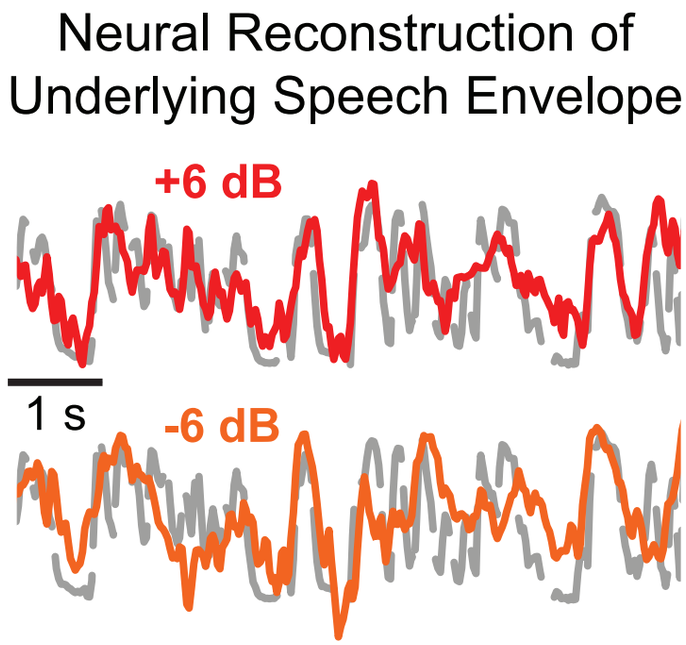

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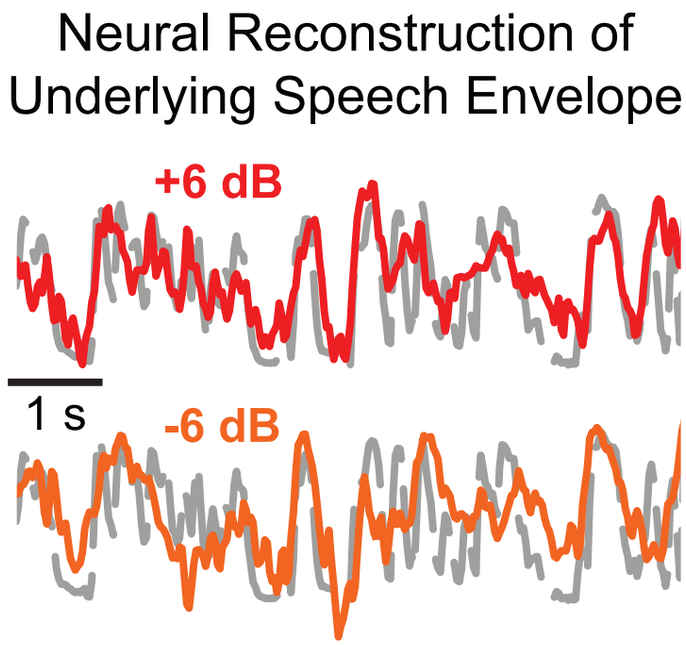

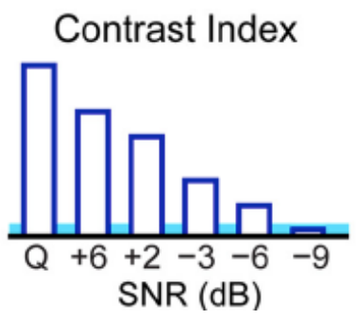

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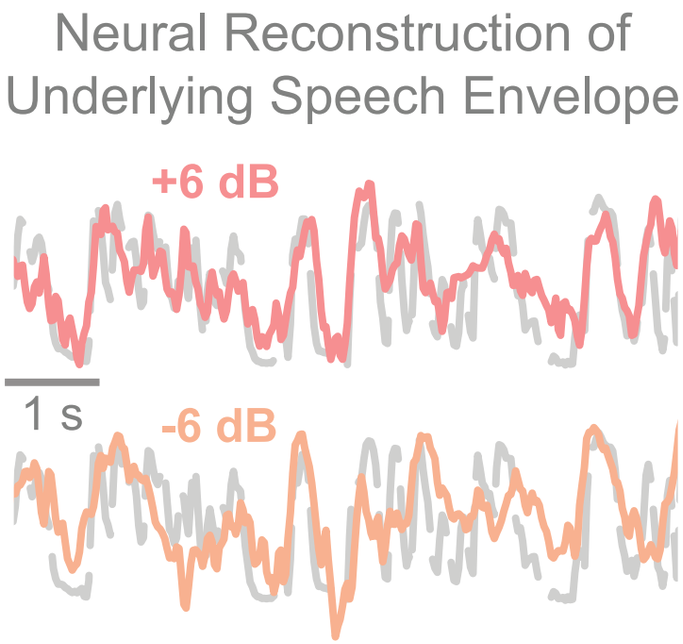

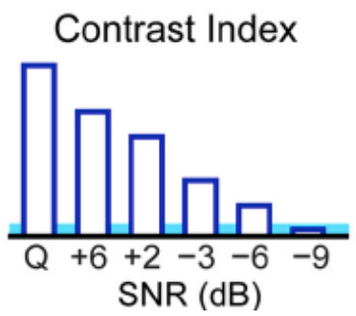

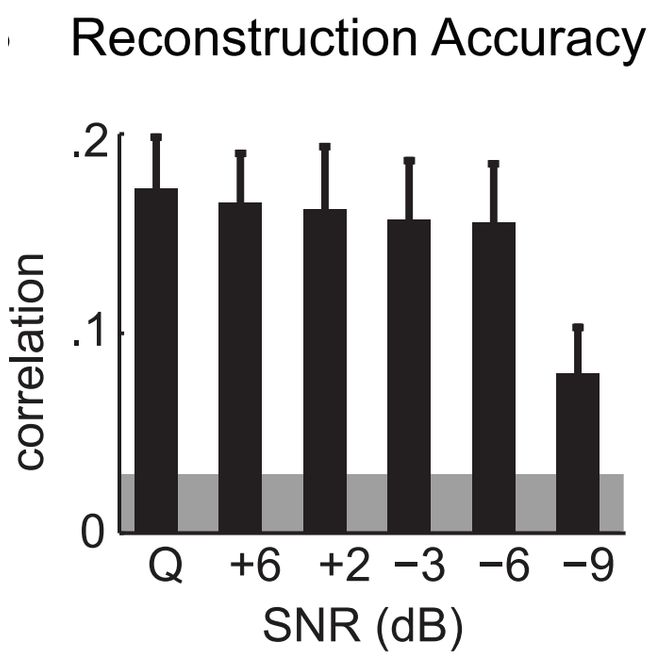

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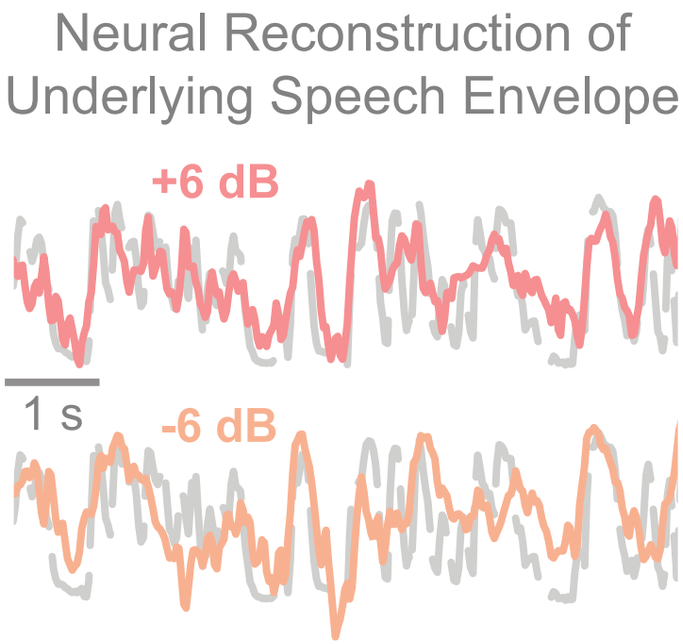

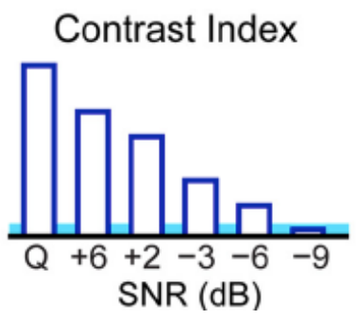

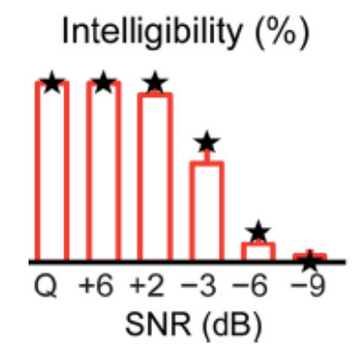

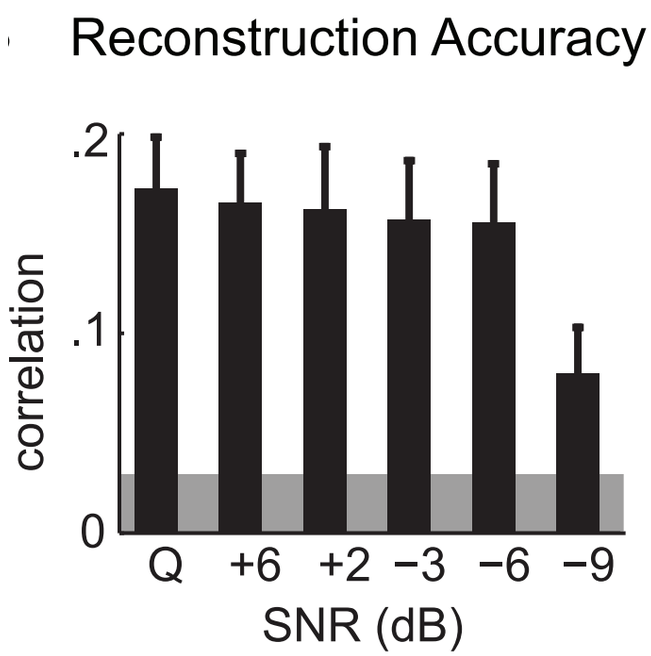

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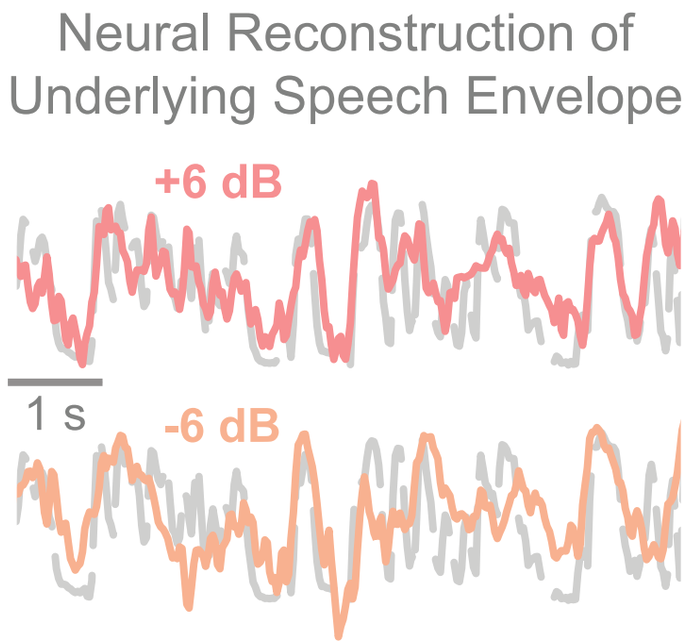
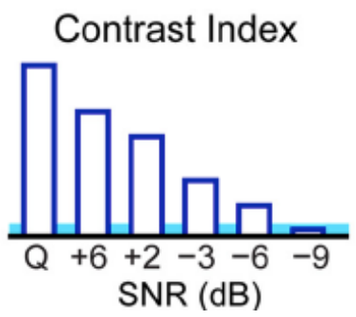
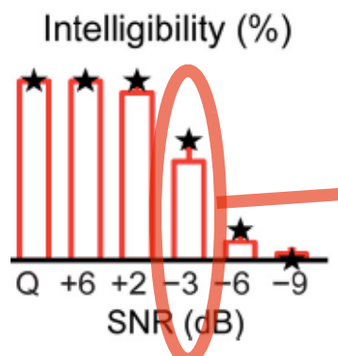
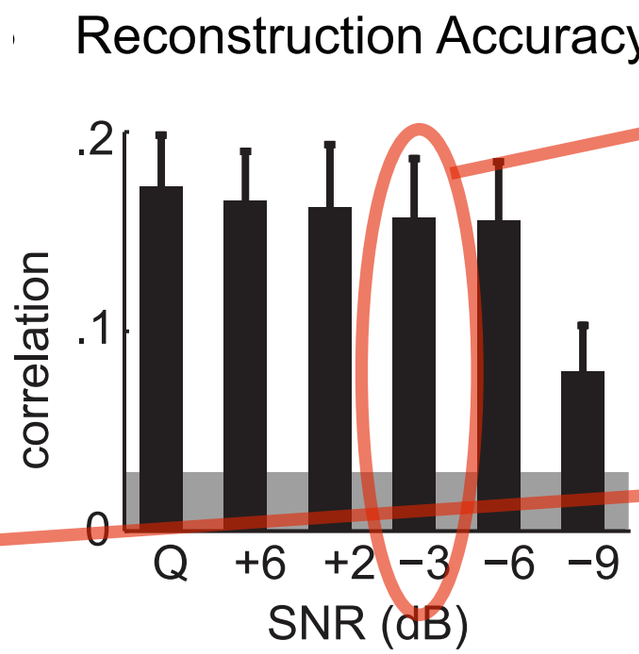
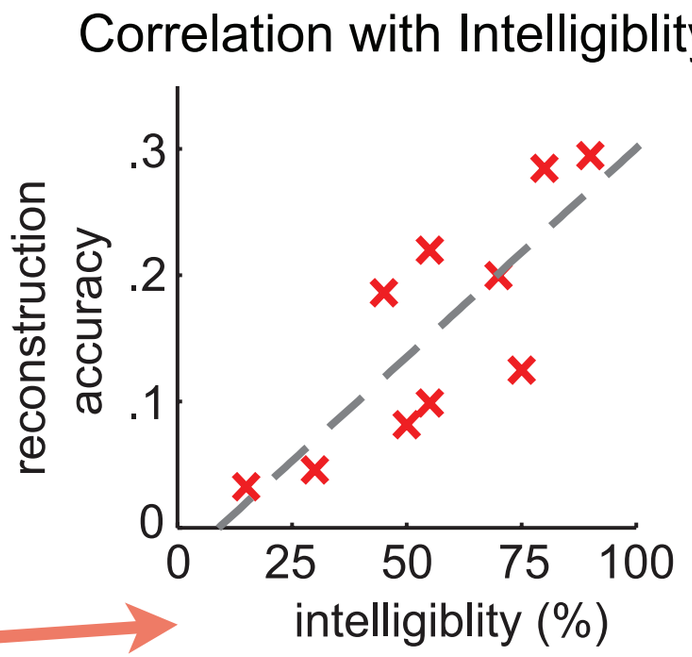










across Subjects

The Cocktail Party

Alex Katz,
The Cocktail Party

The Cocktail Party

Alex Katz,
The Cocktail Party

The Cocktail Party

Alex Katz,
The Cocktail Party

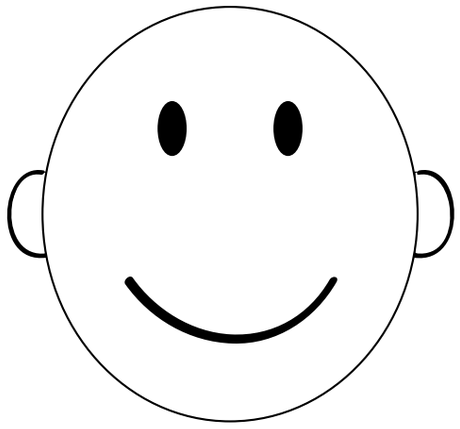
The Cocktail Party

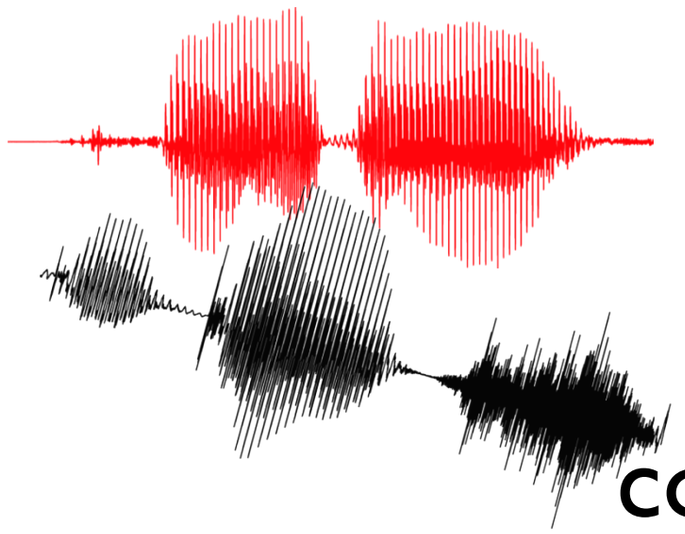
Alex Katz,
The Cocktail Party

The Cocktail Party

Alex Katz,
The Cocktail Party

Experiments

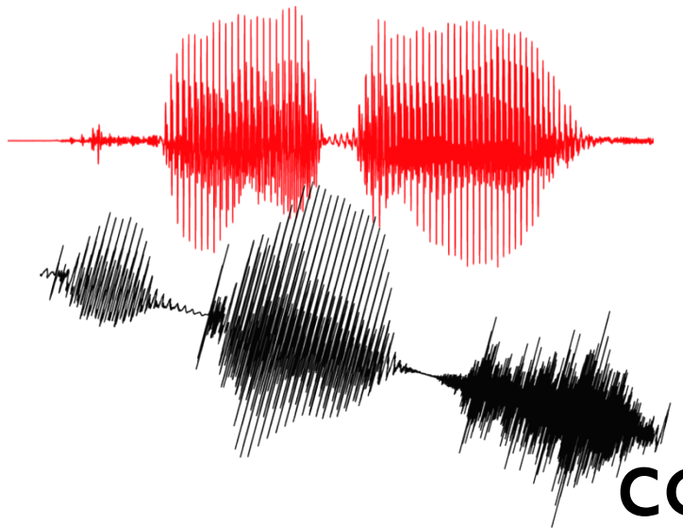




speech

competing speech

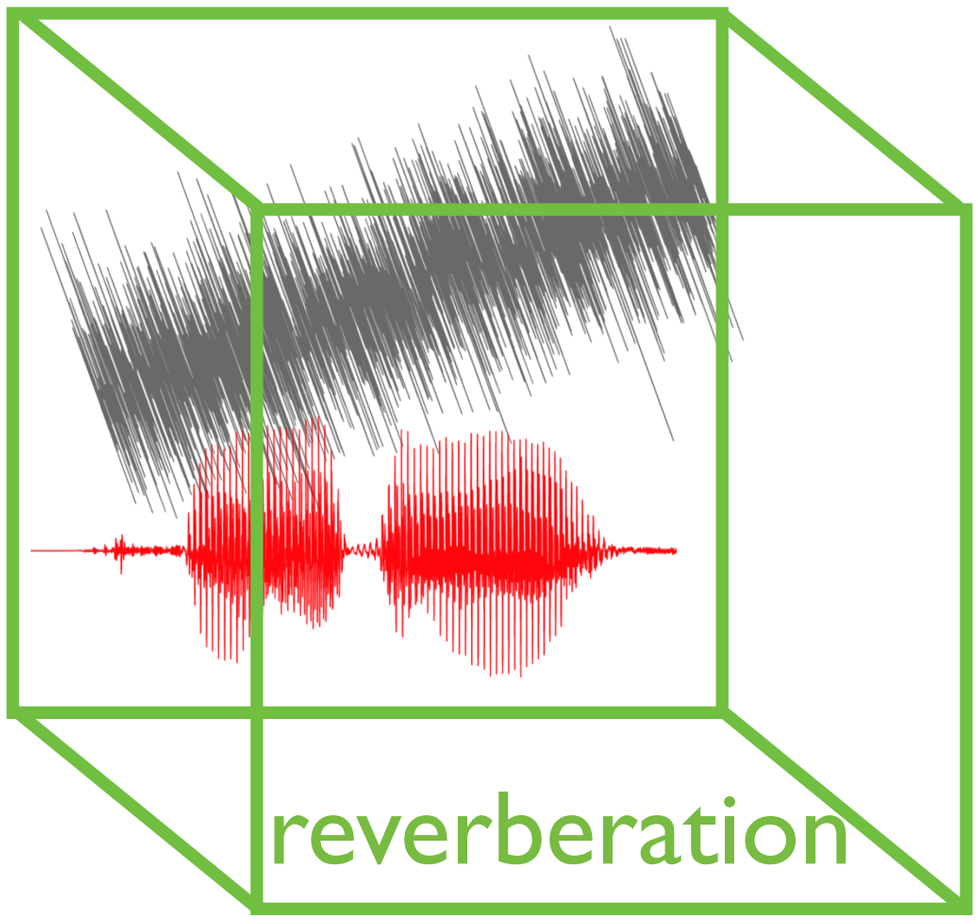
Experiments



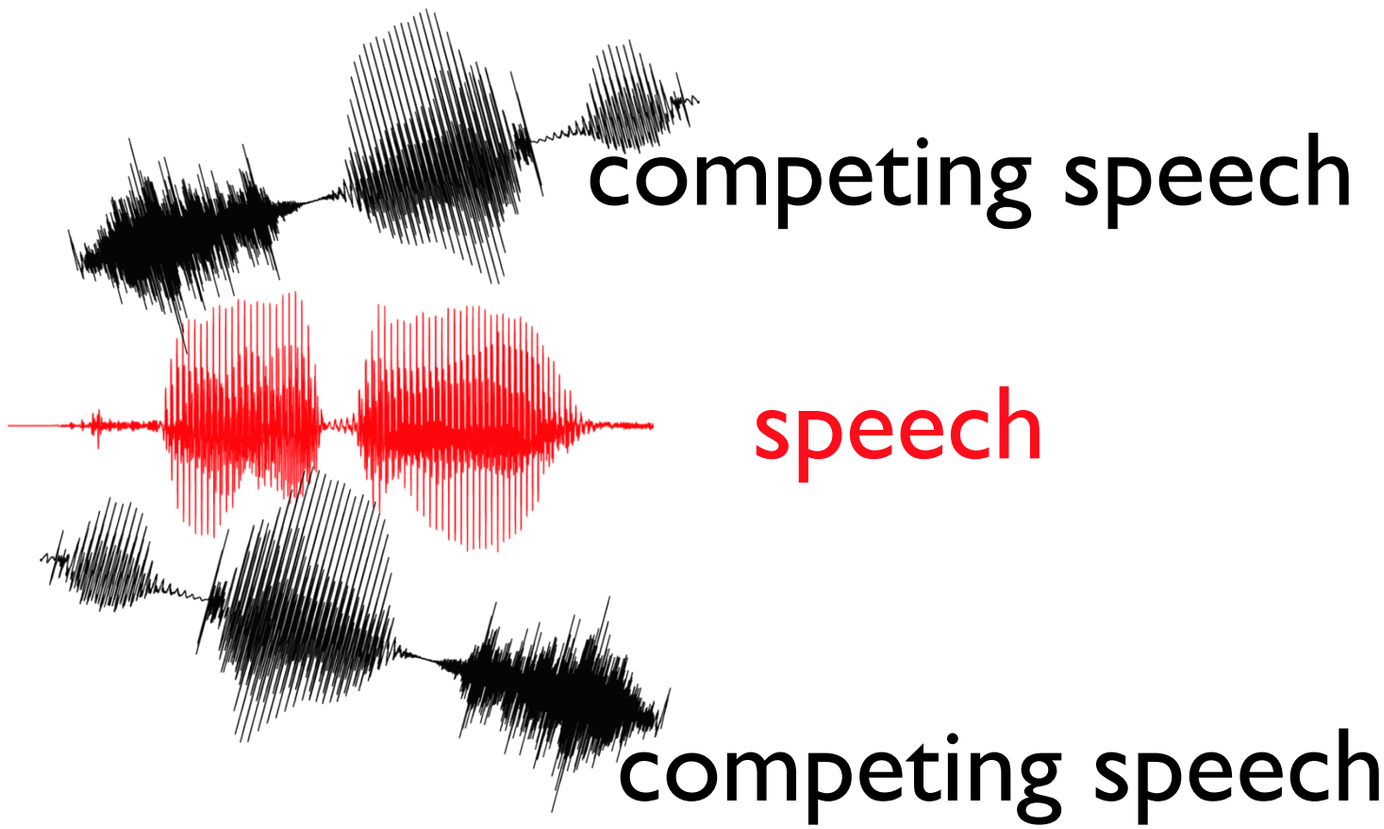
speech

competing speech

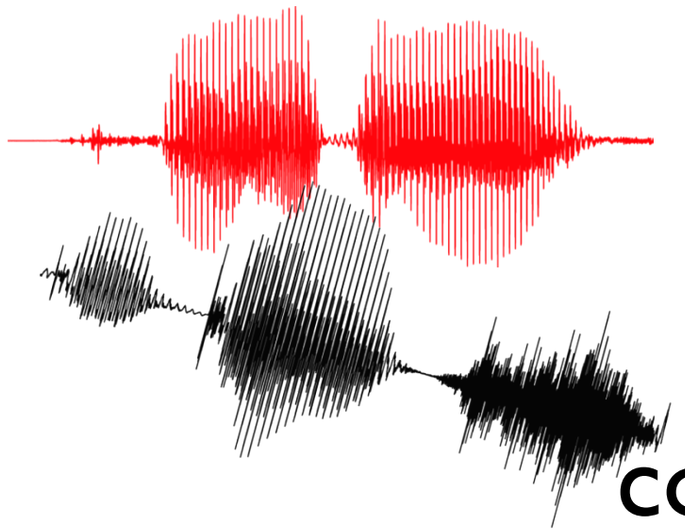
Experiments in Progress



Experiments in Progress



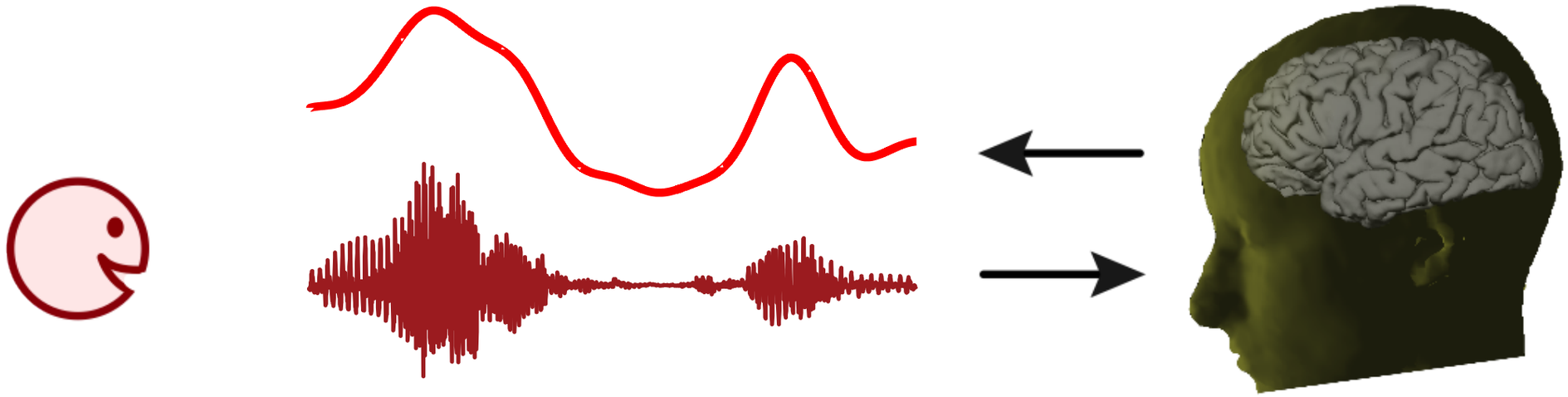
Two Competing Speakers



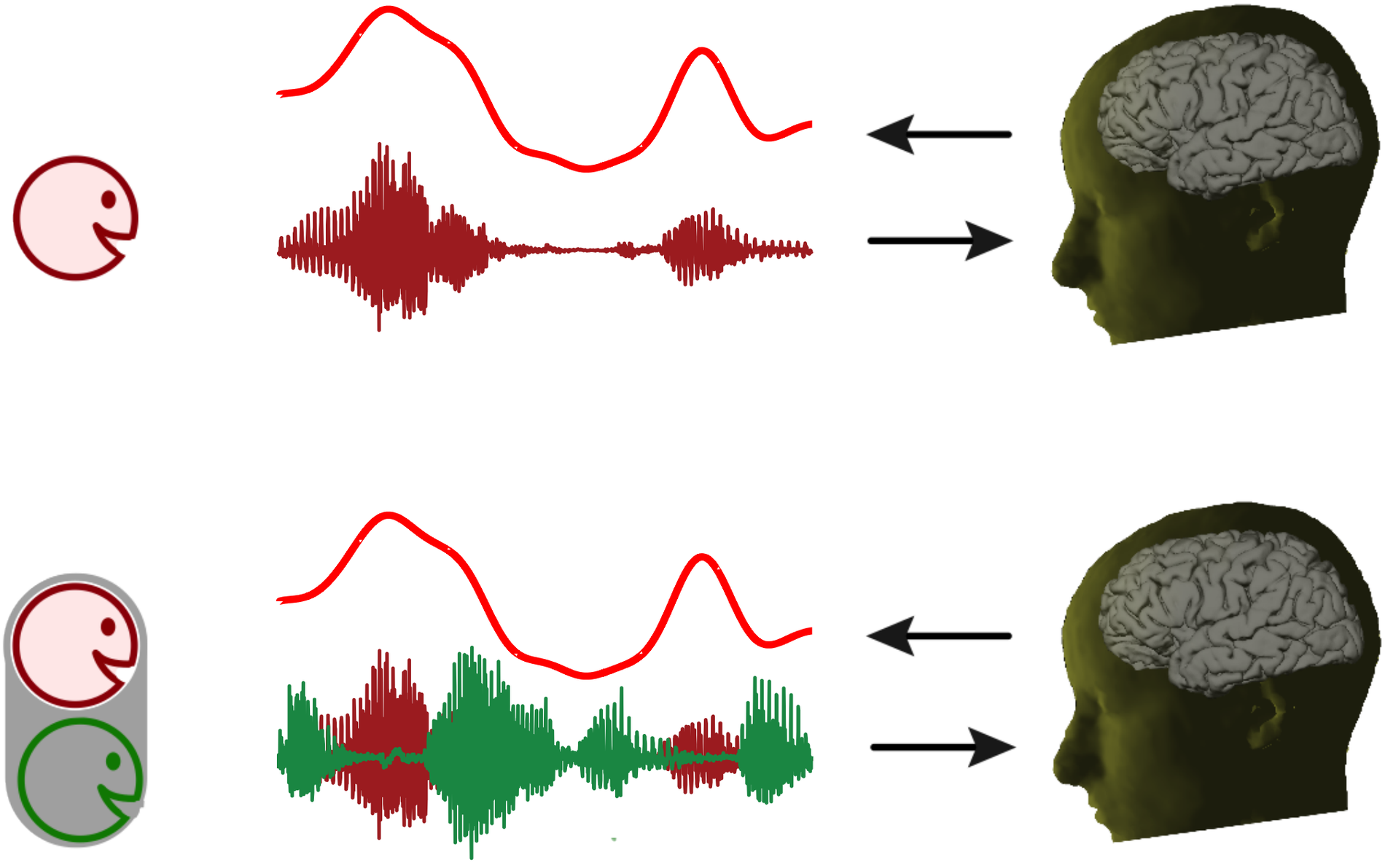
speech

competing speech

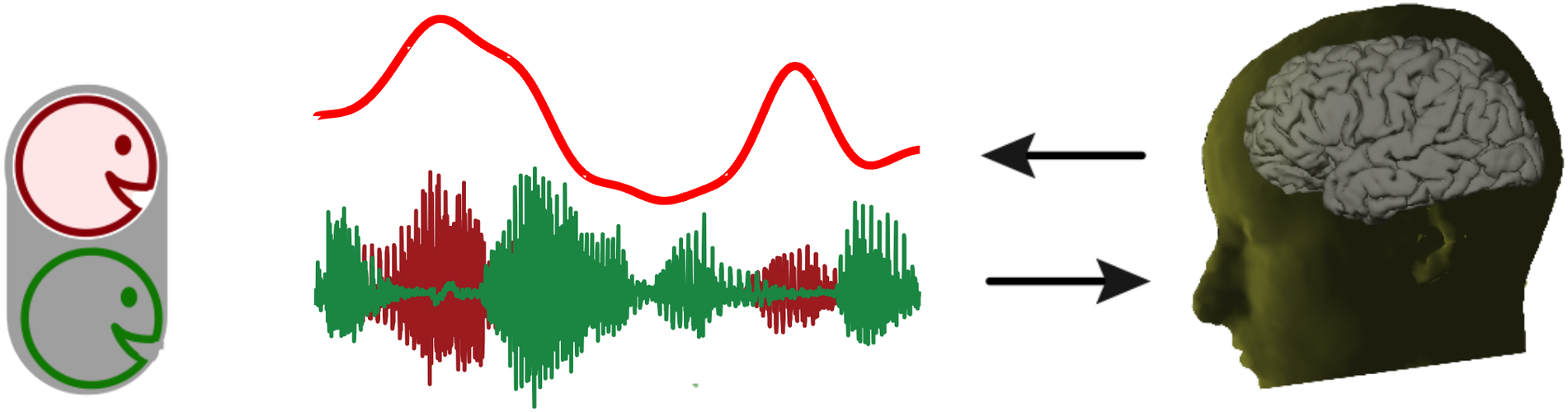
Selective Neural Encoding



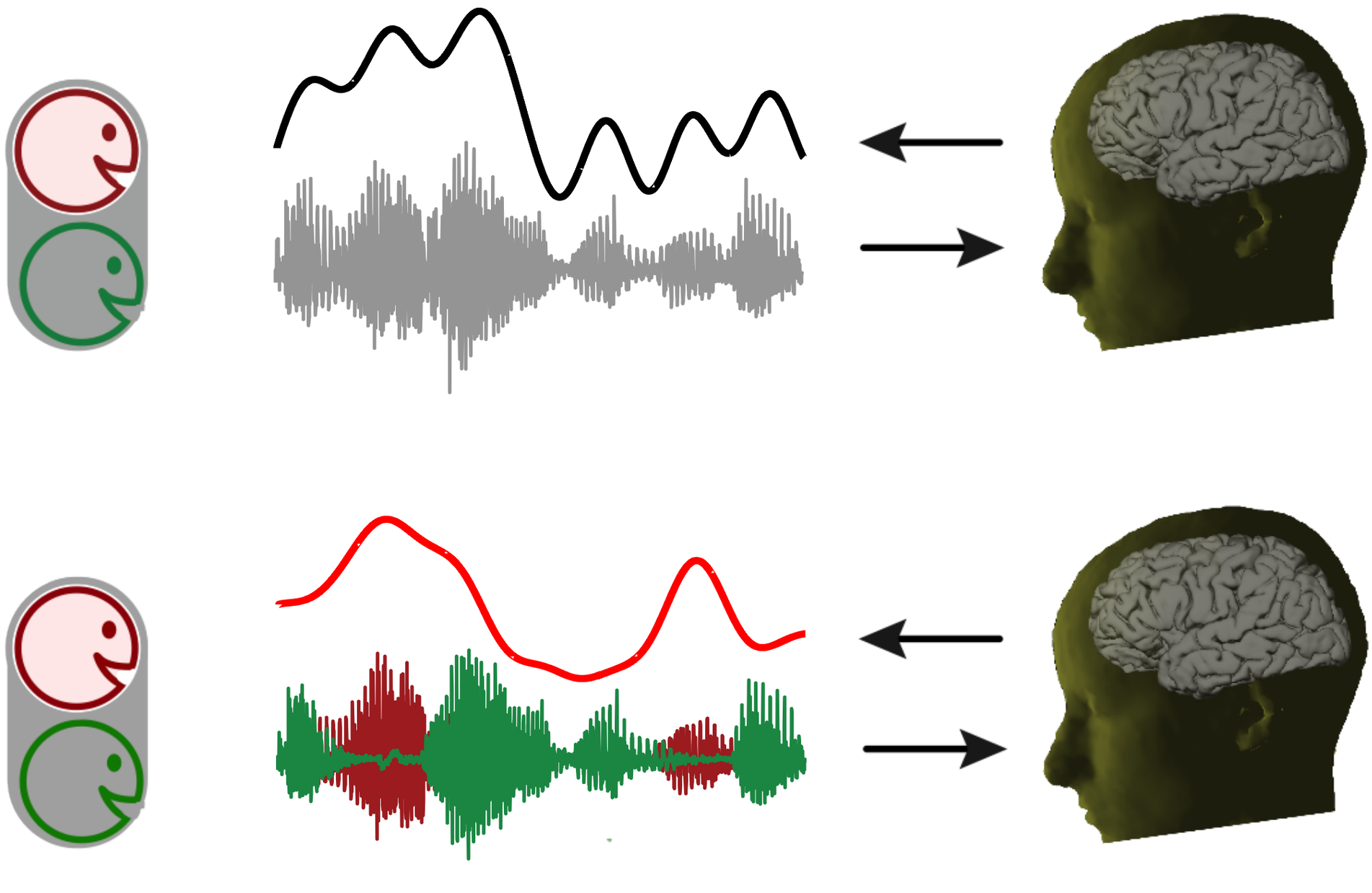
Selective Neural Encoding



Selective Neural Encoding



Unselective vs. Selective Neural Encoding



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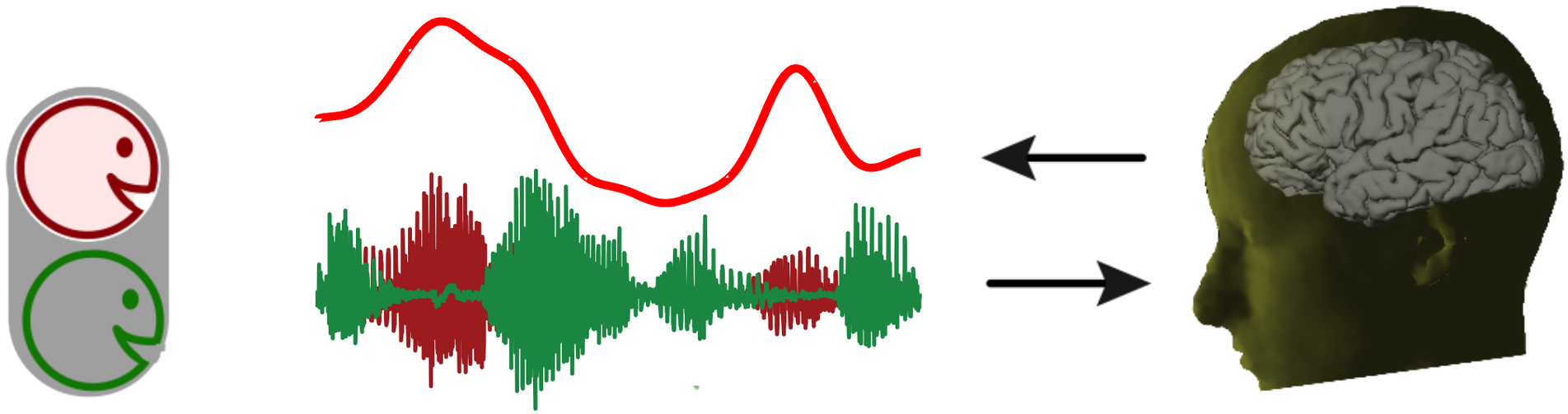
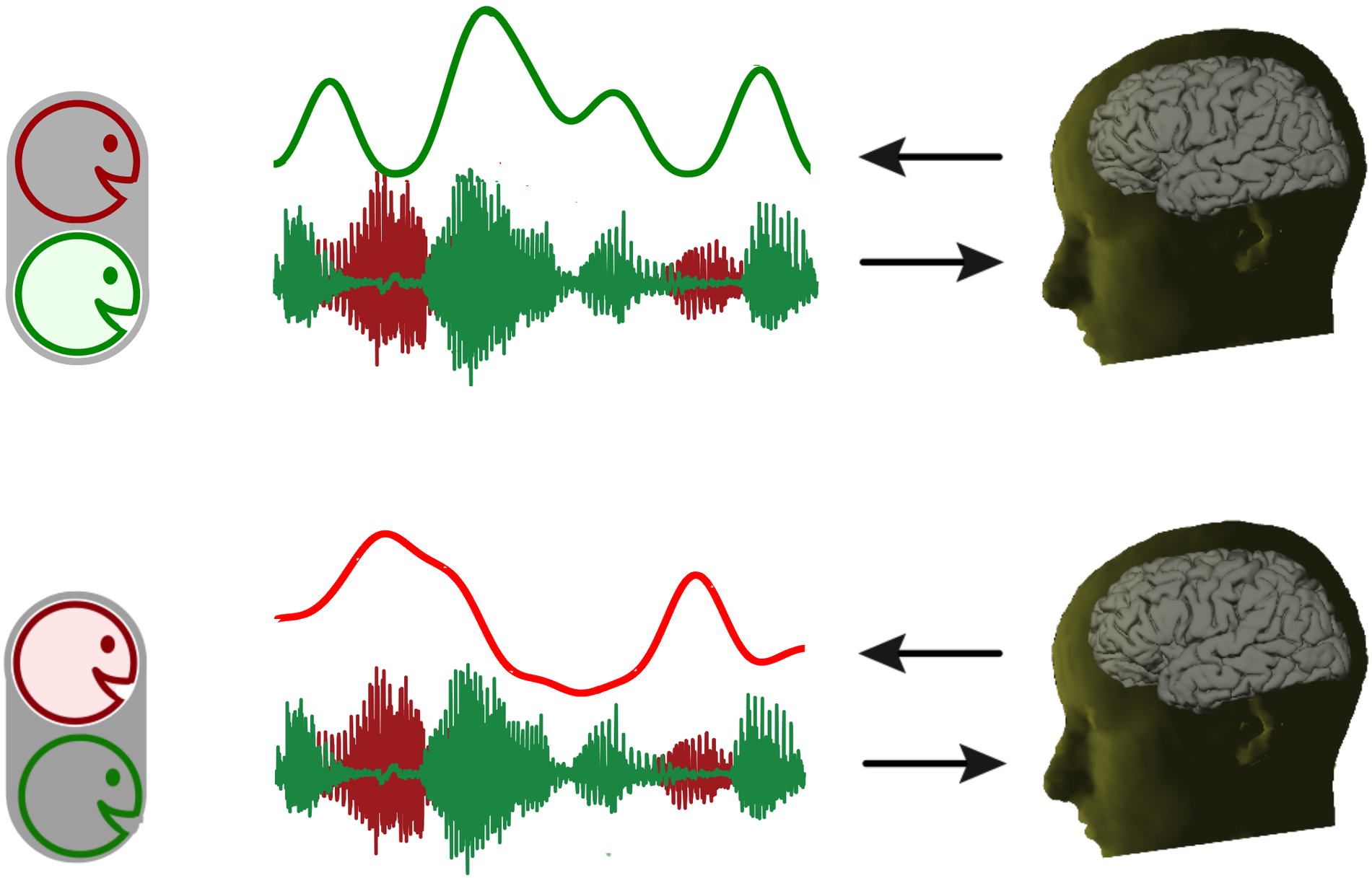
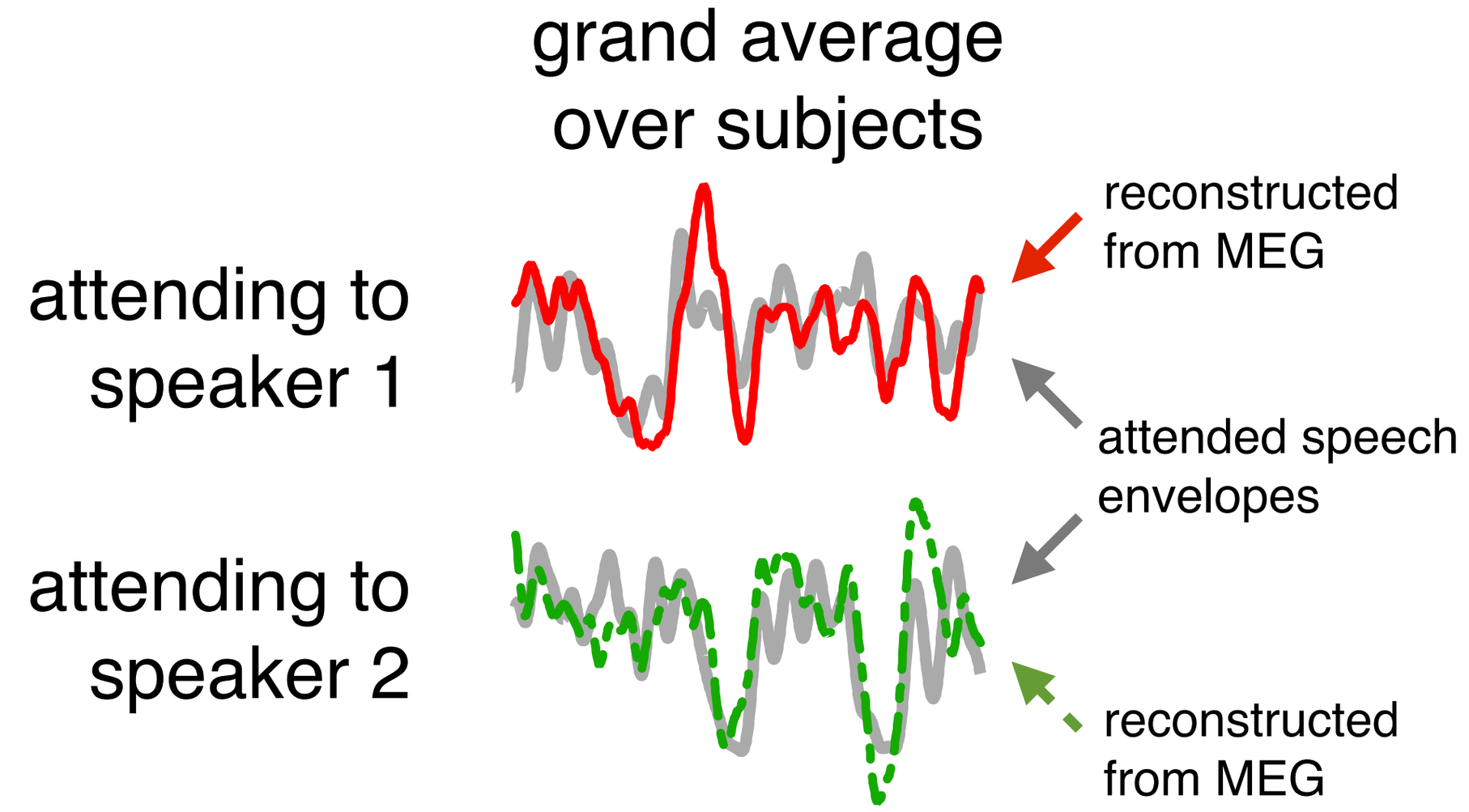


Selective Neural Encoding



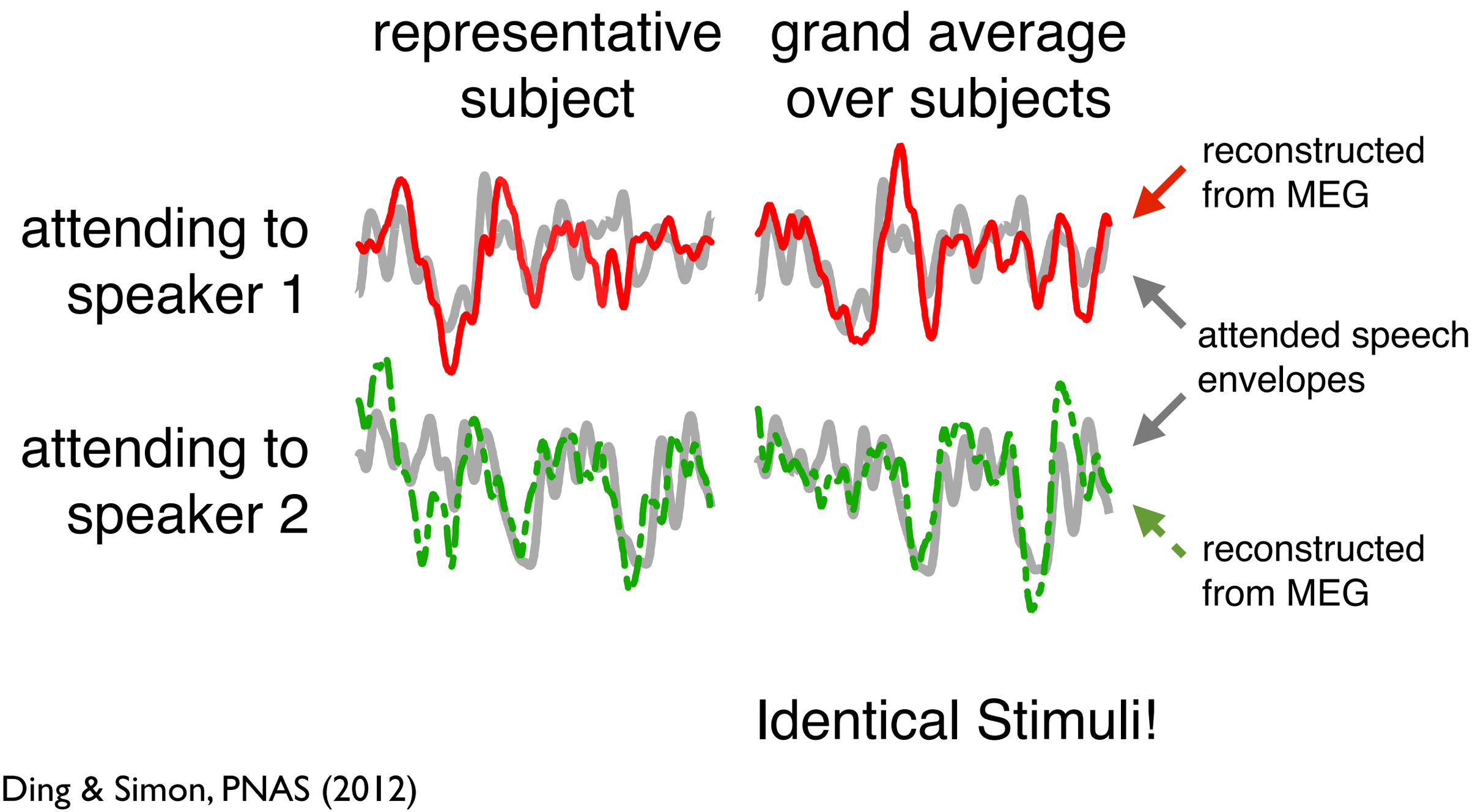
Stream-Specific Representation



Identical Stimuli!

Ding & Simon, PNAS (2012)

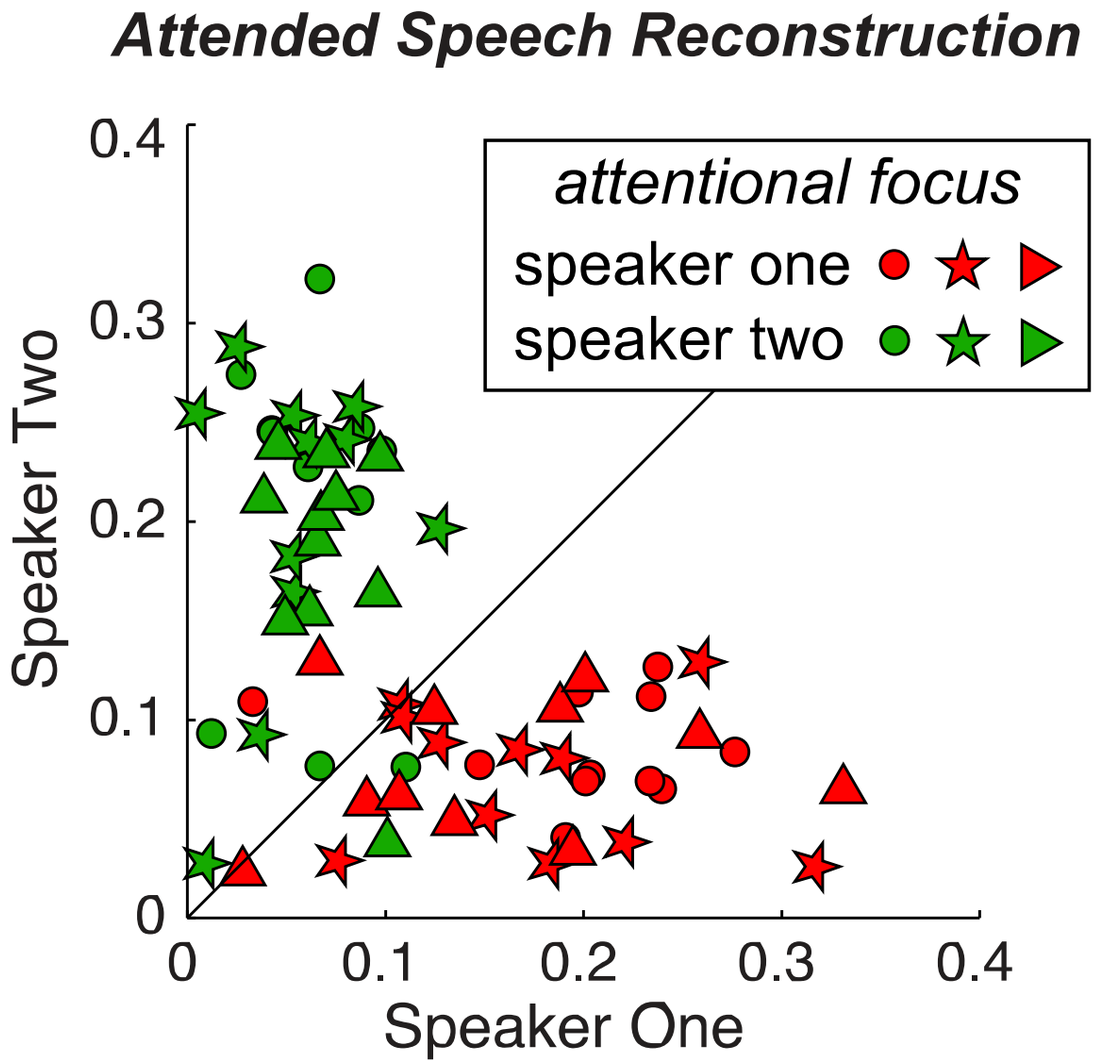
Stream-Specific Representation



Identical Stimuli!

Ding & Simon, PNAS (2012)

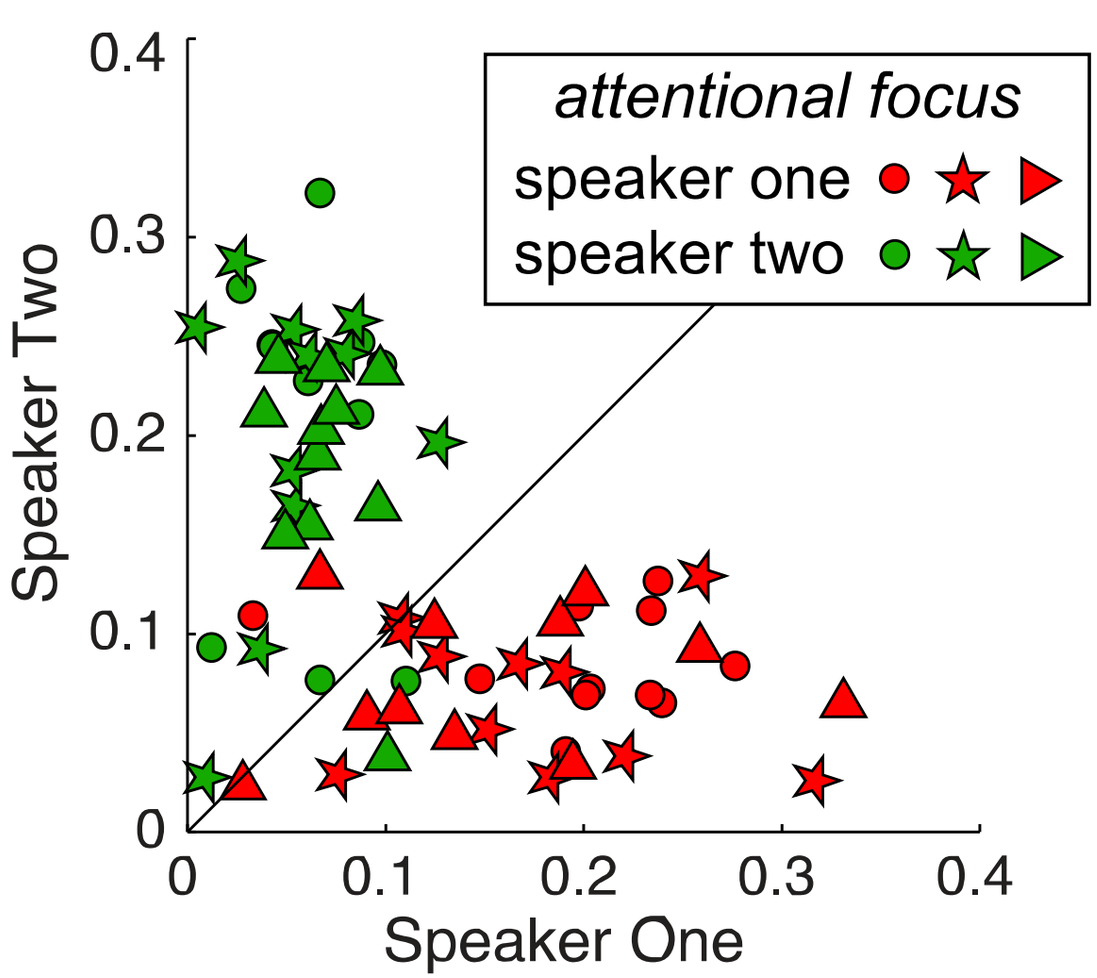
Single Trial Speech Reconstruction



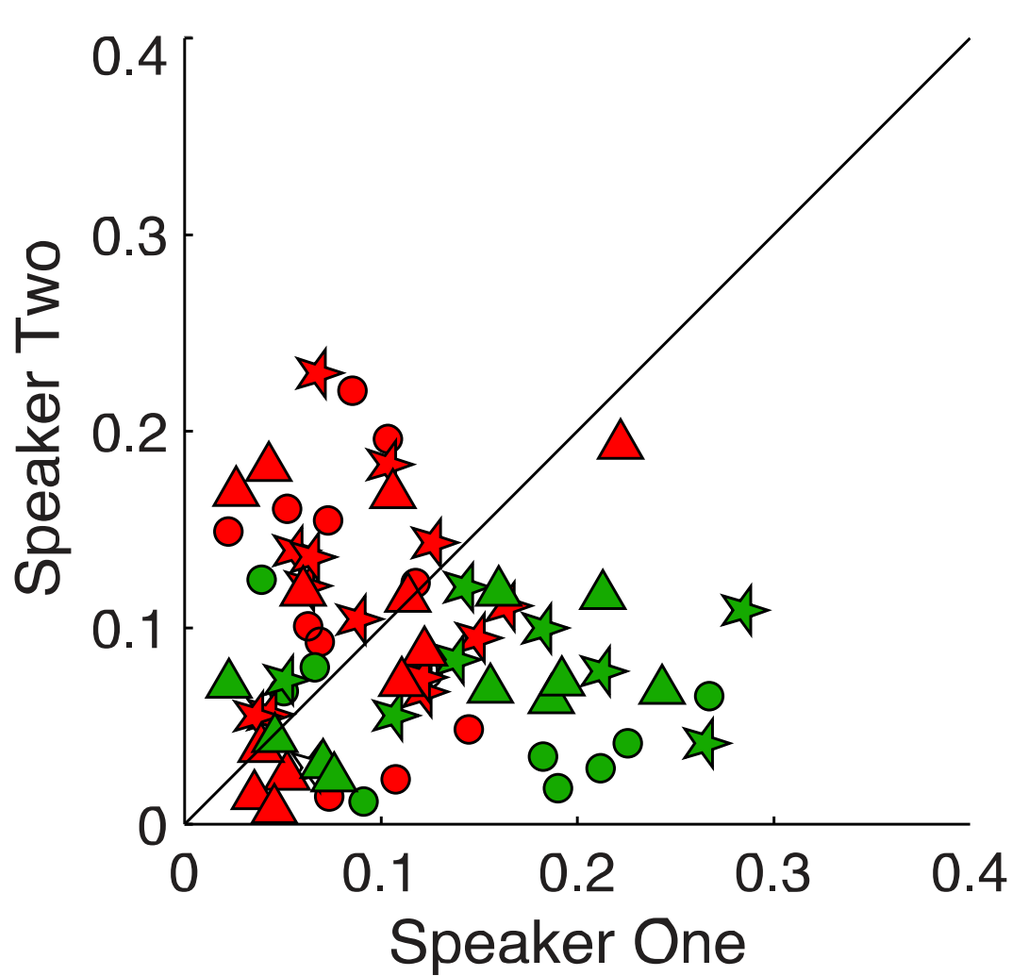
Ding & Simon, PNAS (2012)

Single Trial Speech Reconstruction

Attended Speech Reconstruction

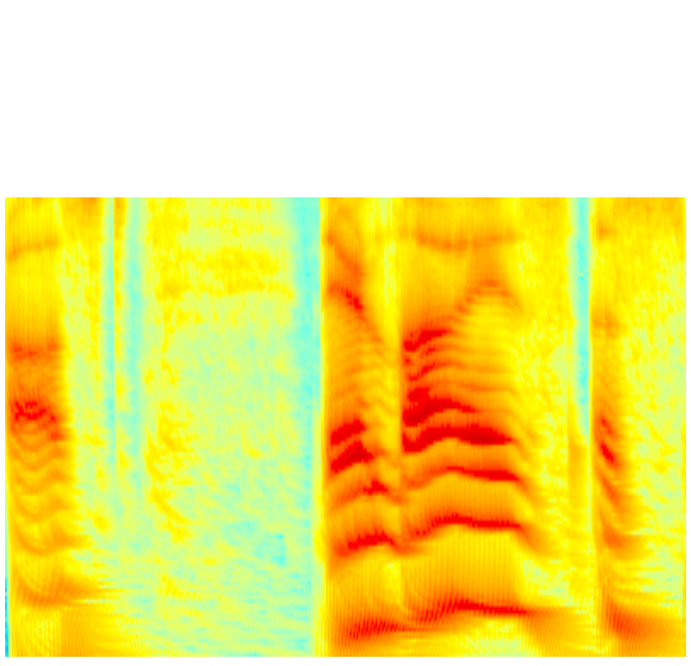


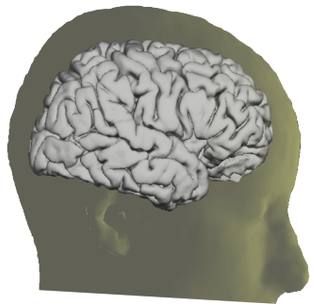
Background Speech Reconstruction

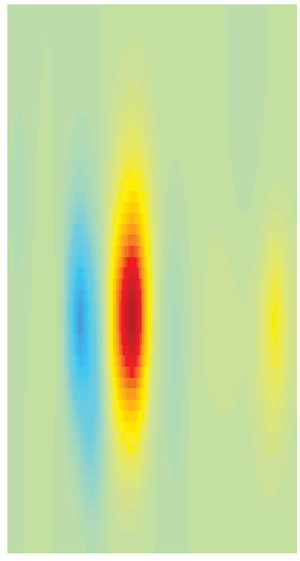


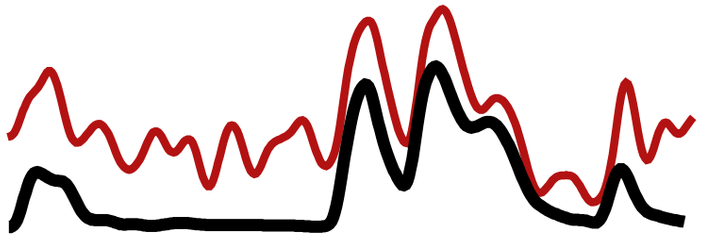
Ding & Simon, PNAS (2013)

Forward STRF Model



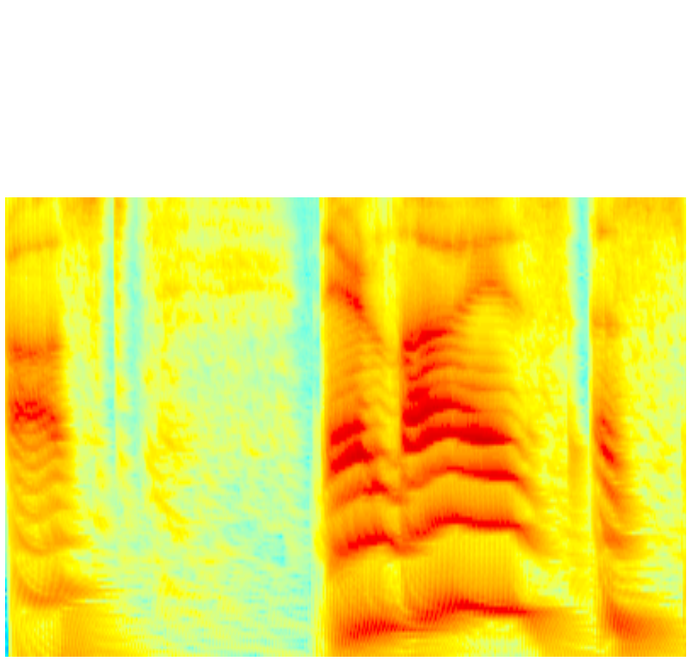


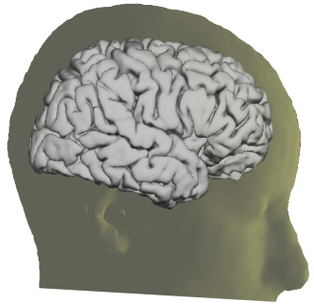


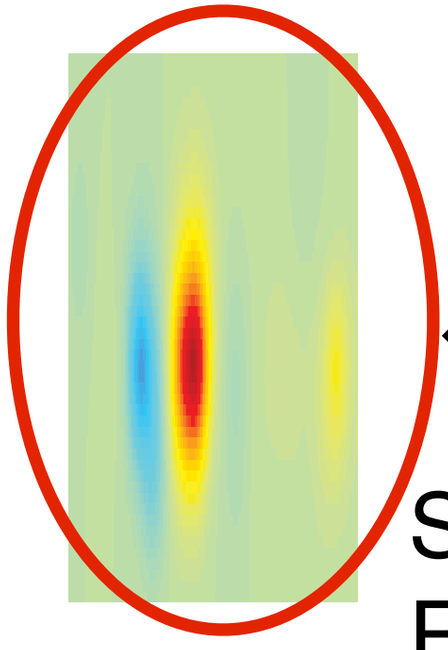


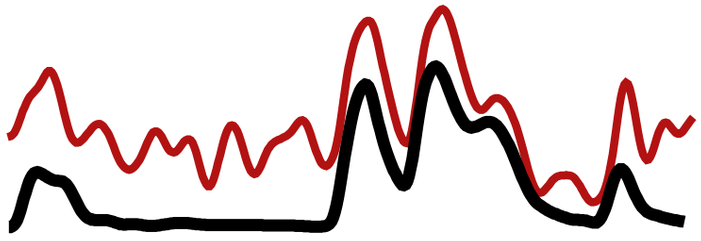
Spectro-Temporal Response Function (STRF)

Forward STRF Model



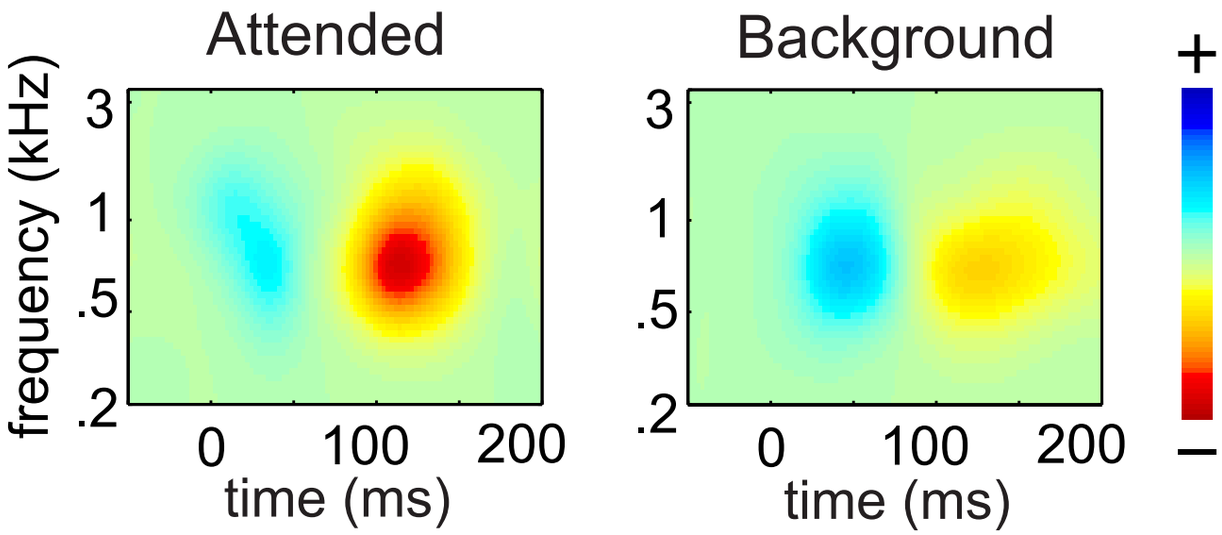






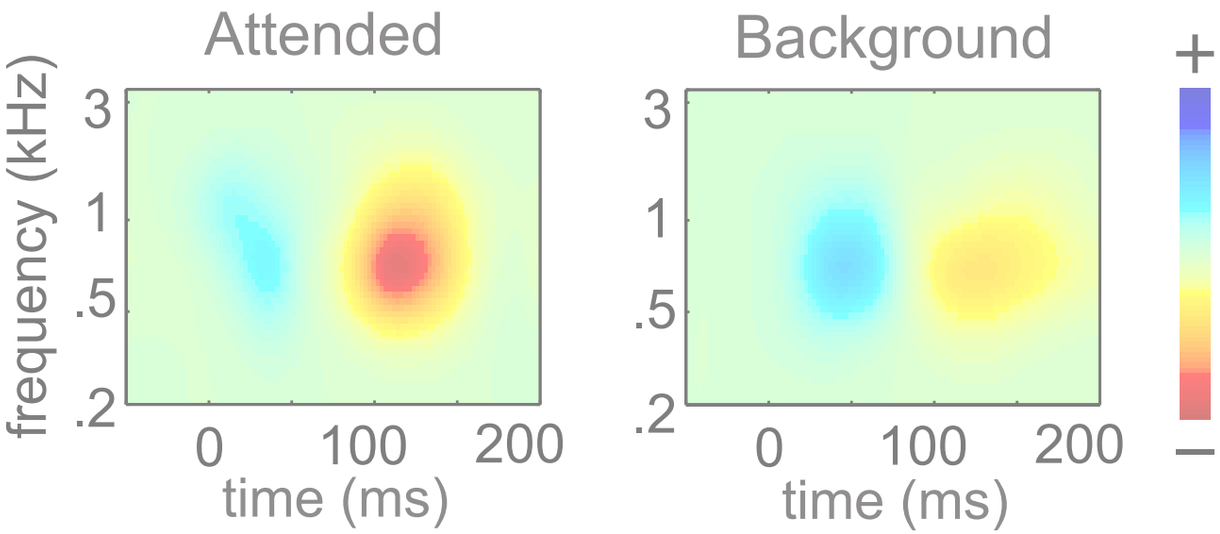
Spectro-Temporal
Response Function
(STRF)

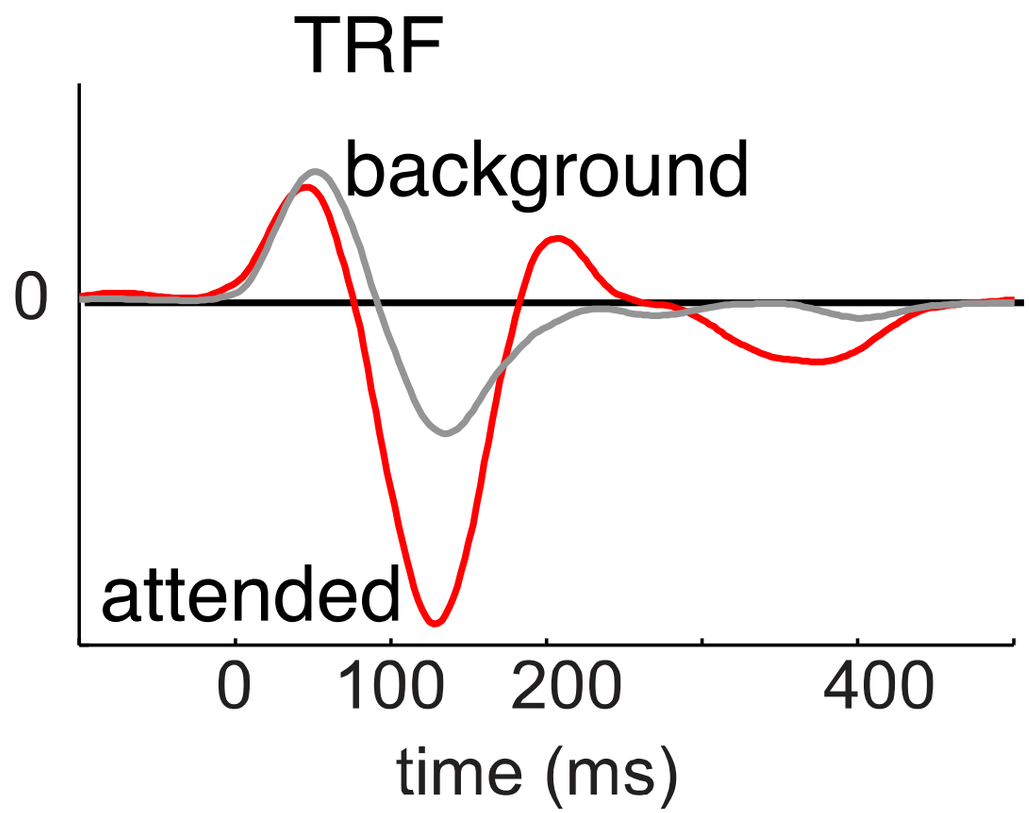
STRF Results



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

STRF Results





- STRF separable (time, frequency)
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- $M50_{STRF}$ positive peak
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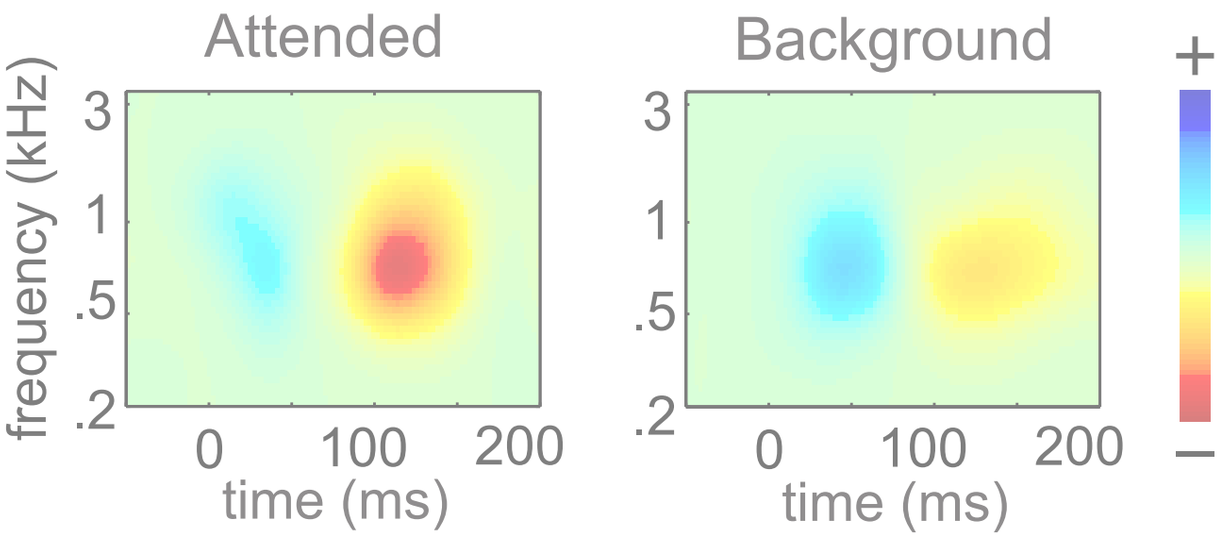
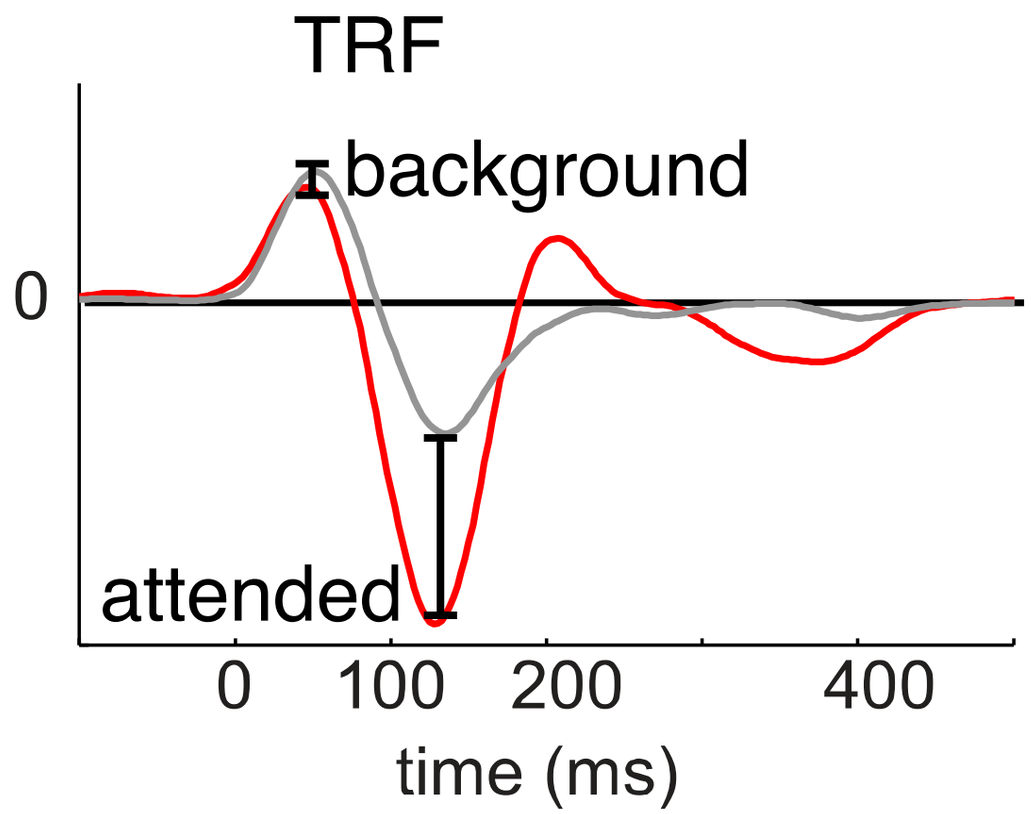
STRF Results





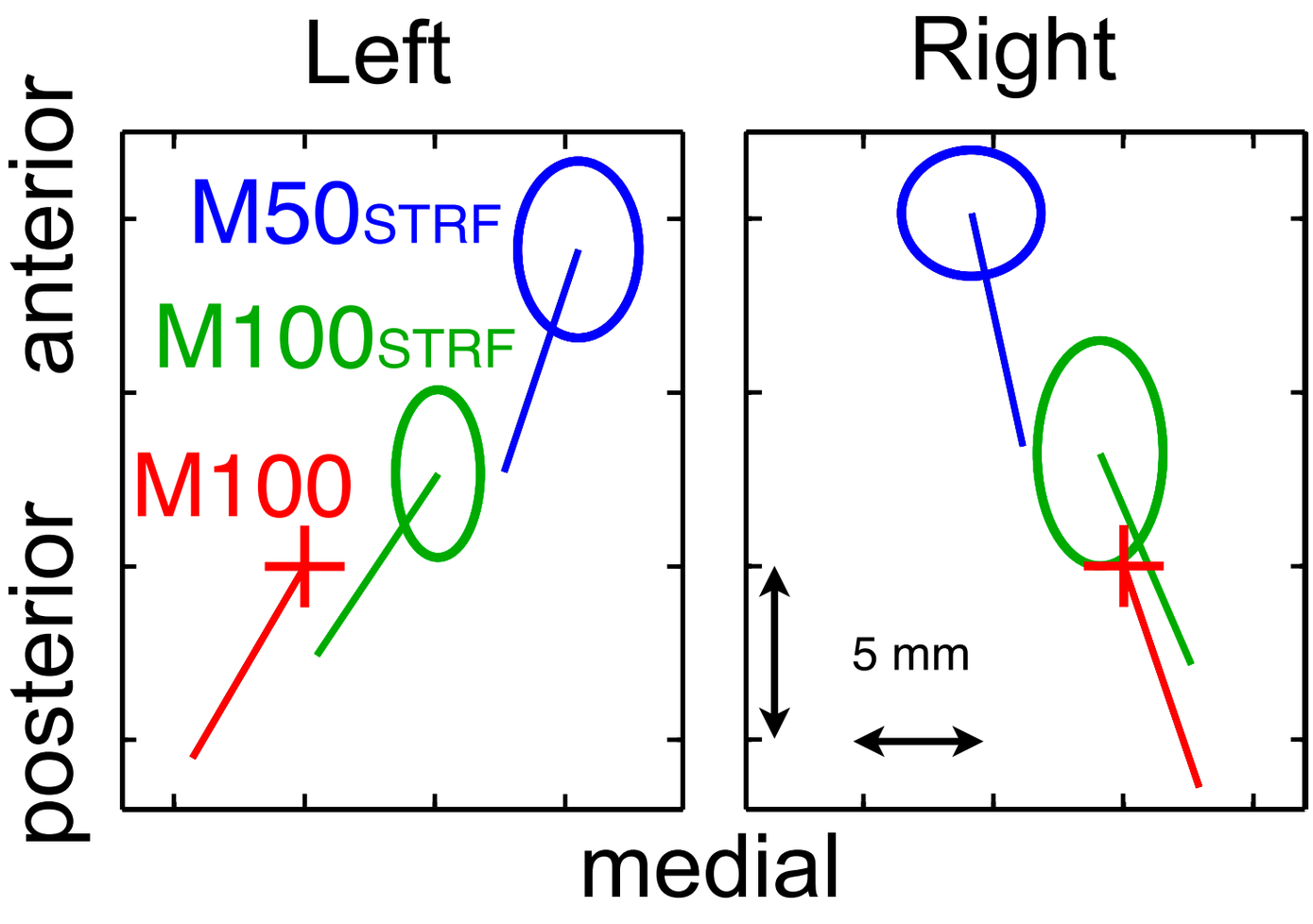
- STRF separable (time, frequency)
- 300 Hz - 2 kHz dominant carriers
- $M50_{STRF}$ positive peak
- $M100_{STRF}$ negative peak
- **$M100_{STRF}$ strongly modulated by attention, *but not $M50_{STRF}$***

Neural Sources

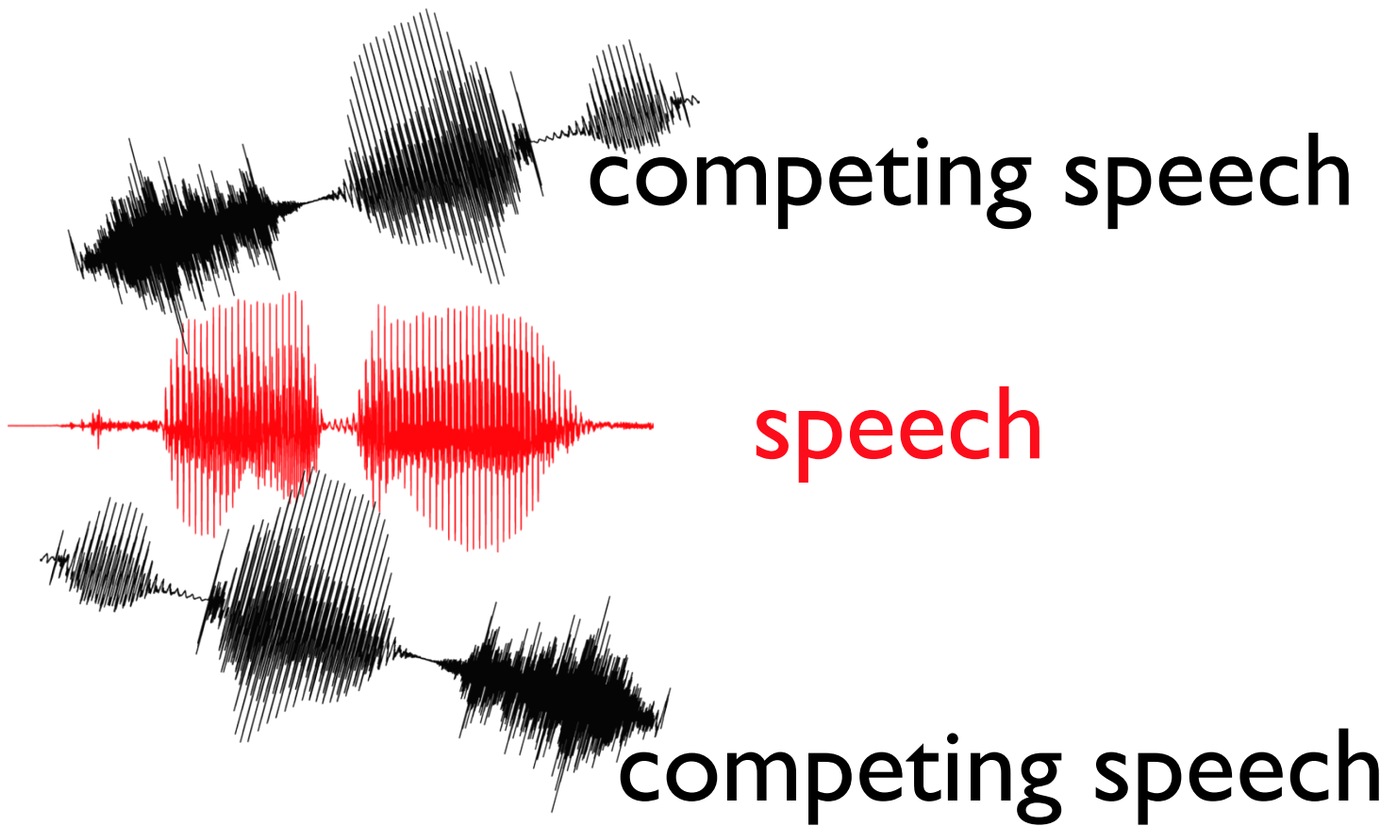
- M100$_{STRF}$ source near (same as?) M100 source: Planum Temporale

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

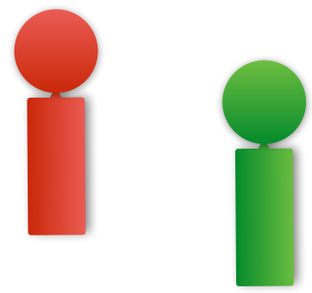
- **PT strongly modulated by attention, *but not HG***

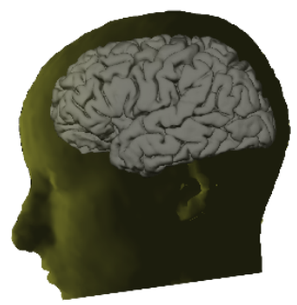


Three Competing Speakers

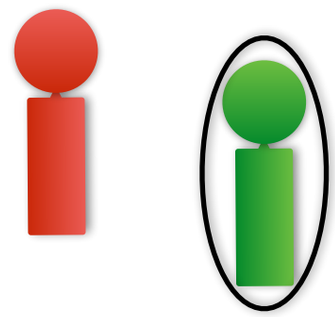


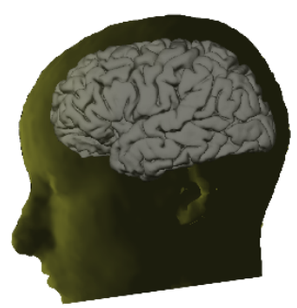
Foreground vs. Background



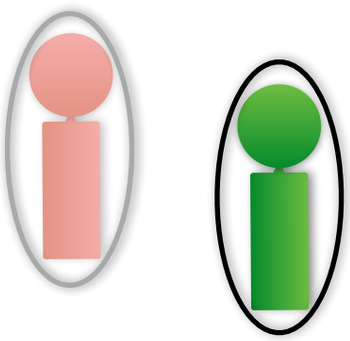


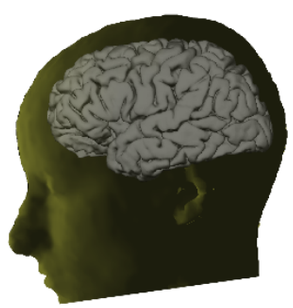
Foreground vs. Background



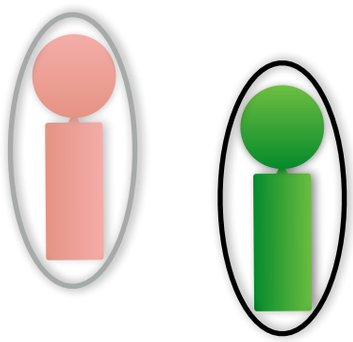


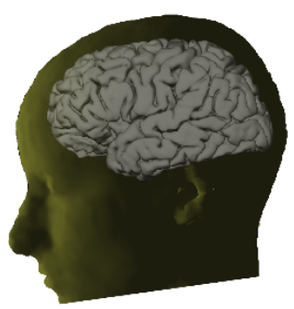
Foreground vs. Background

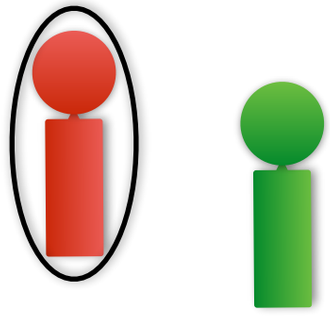




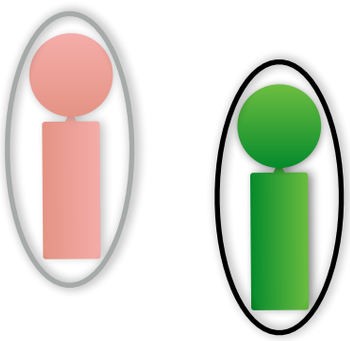
Foreground vs. Background

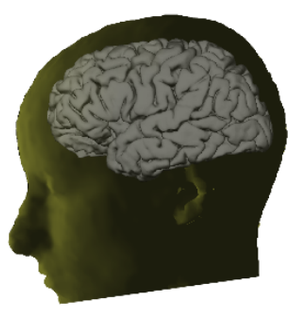


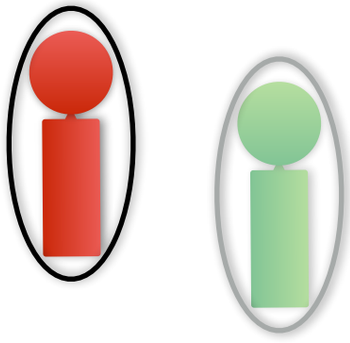




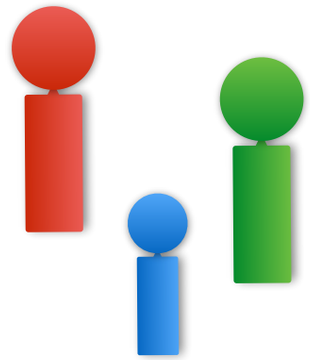
Foreground vs. Background



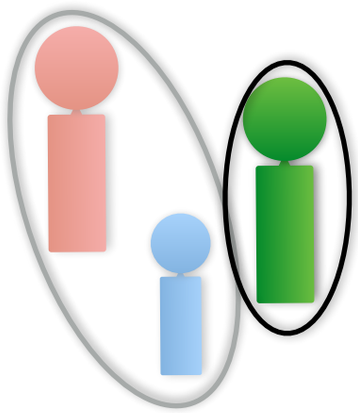


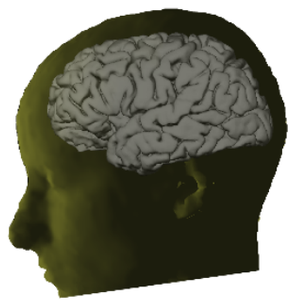


Foreground vs. Background

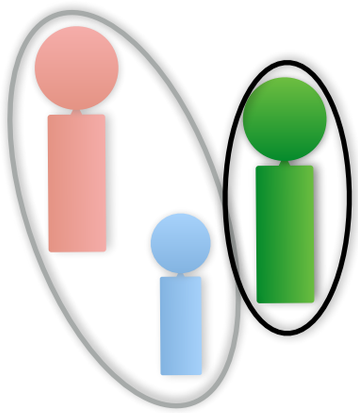


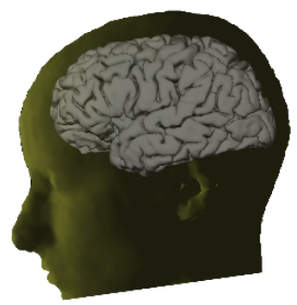
Foreground vs. Background

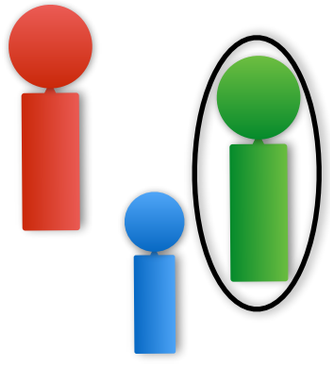




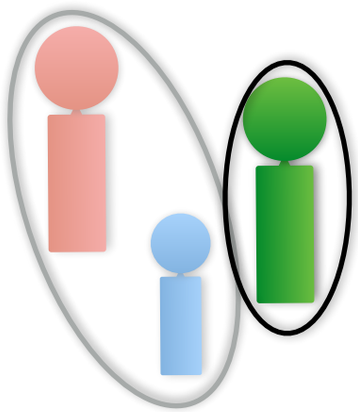
Foreground vs. Background

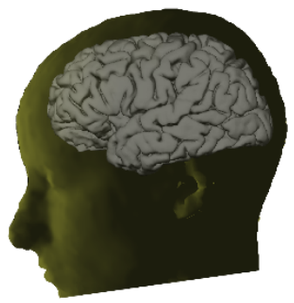


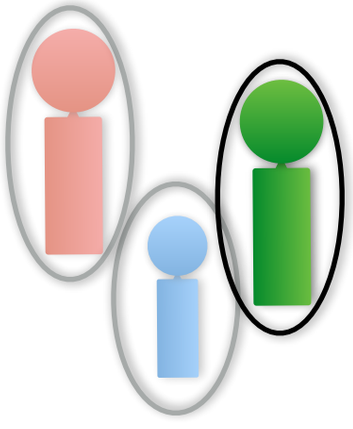




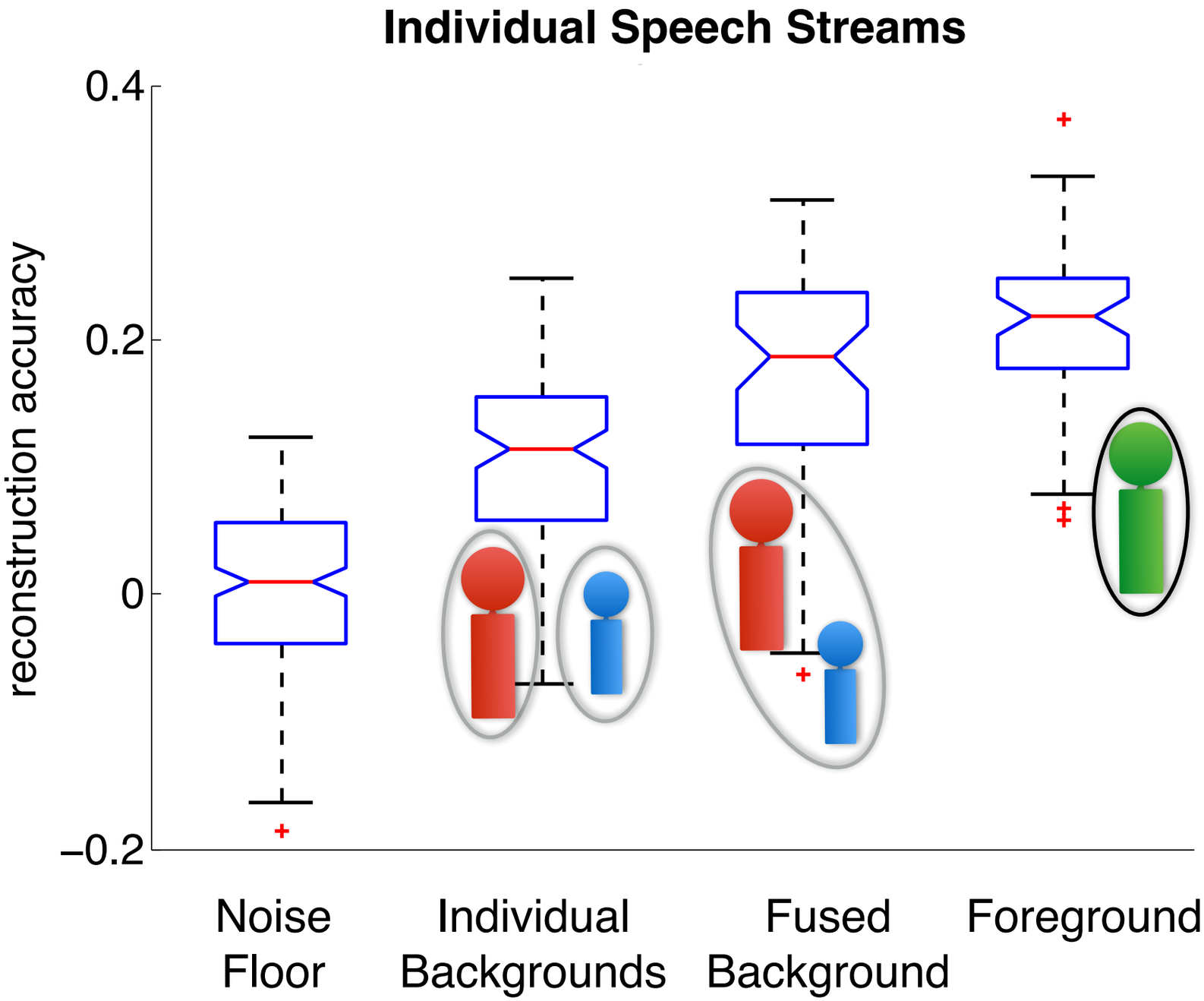
Foreground vs. Background





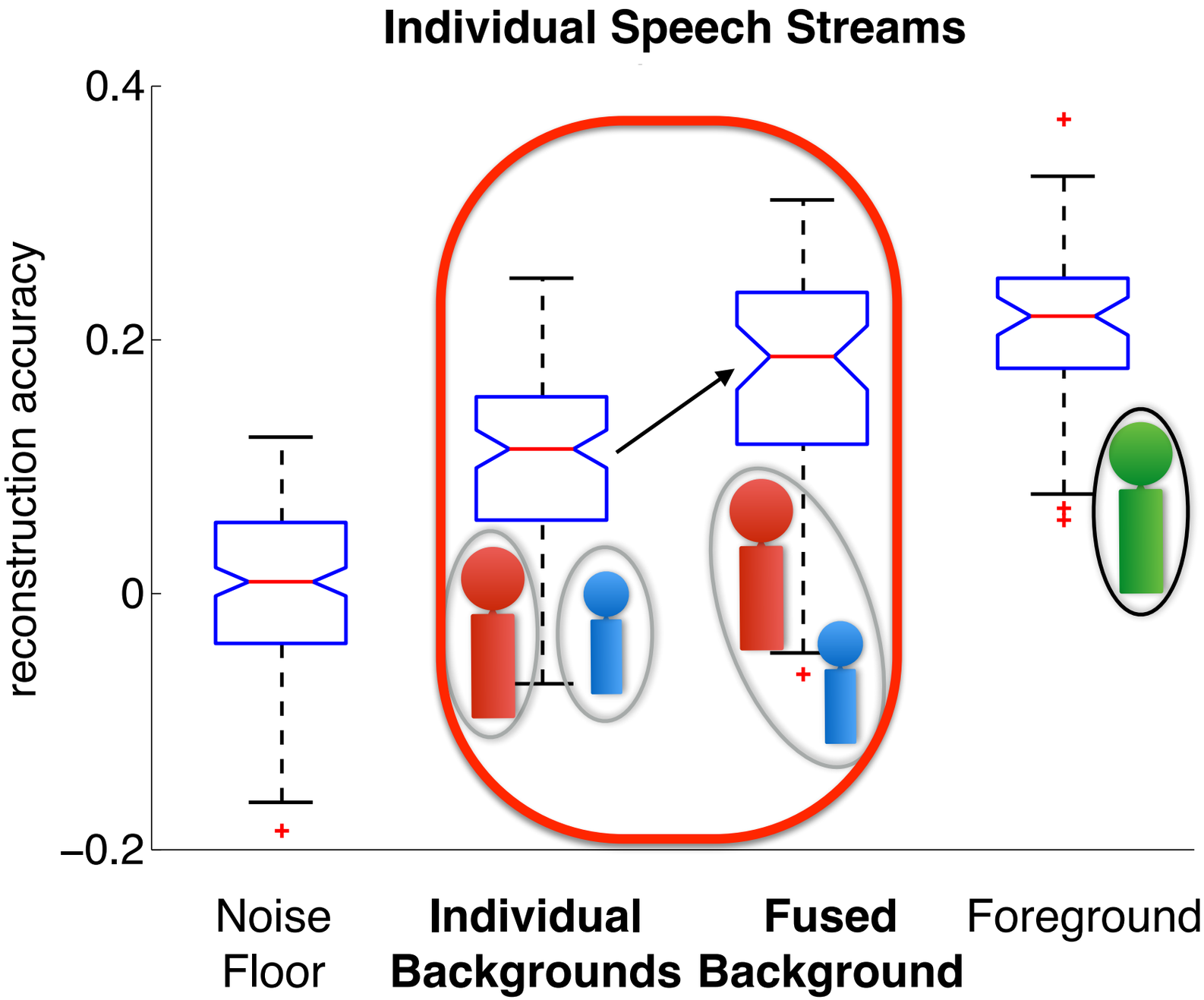


Backgrounds vs. Background



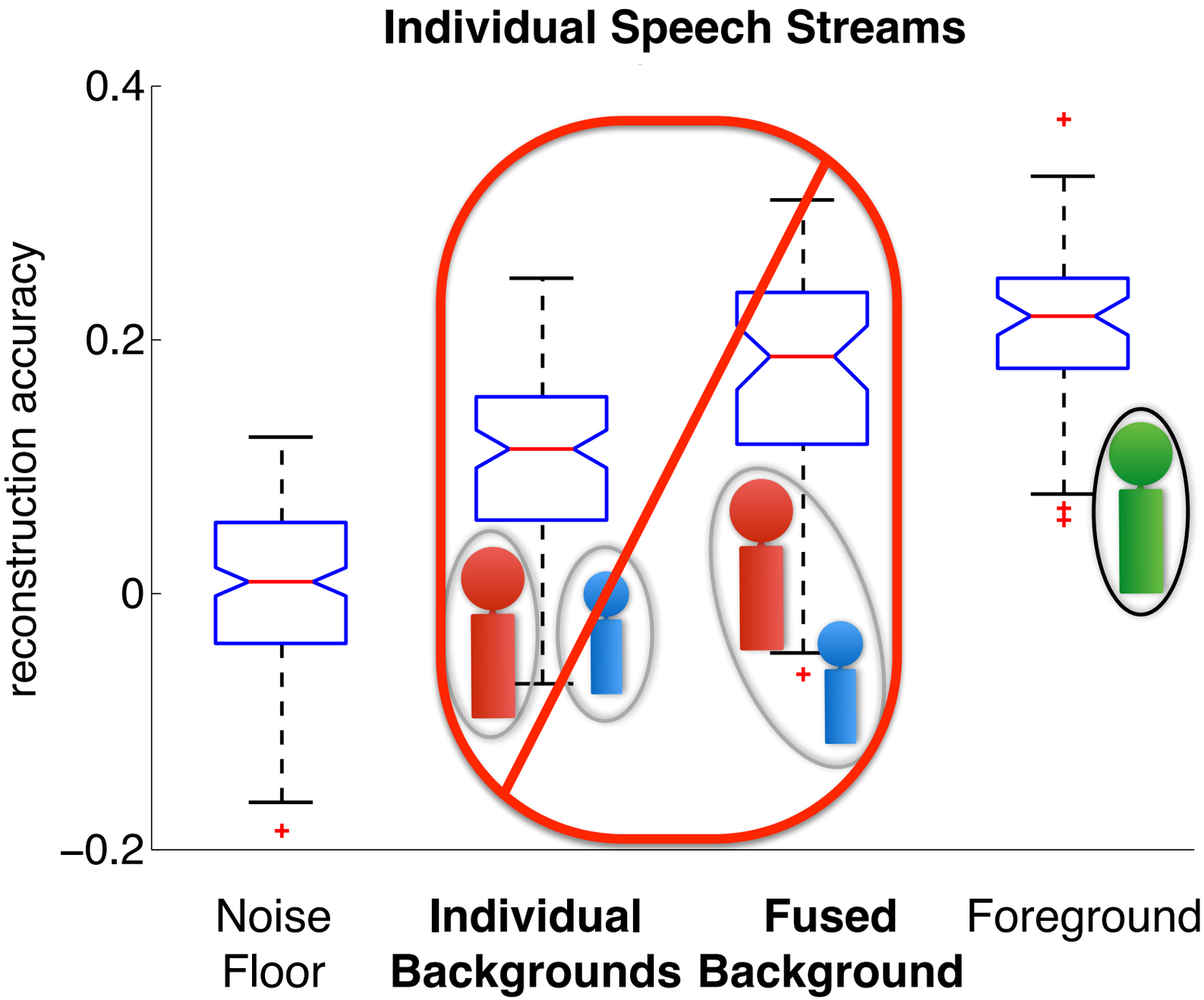
Integration Window over Late Times Only

Backgrounds vs. Background



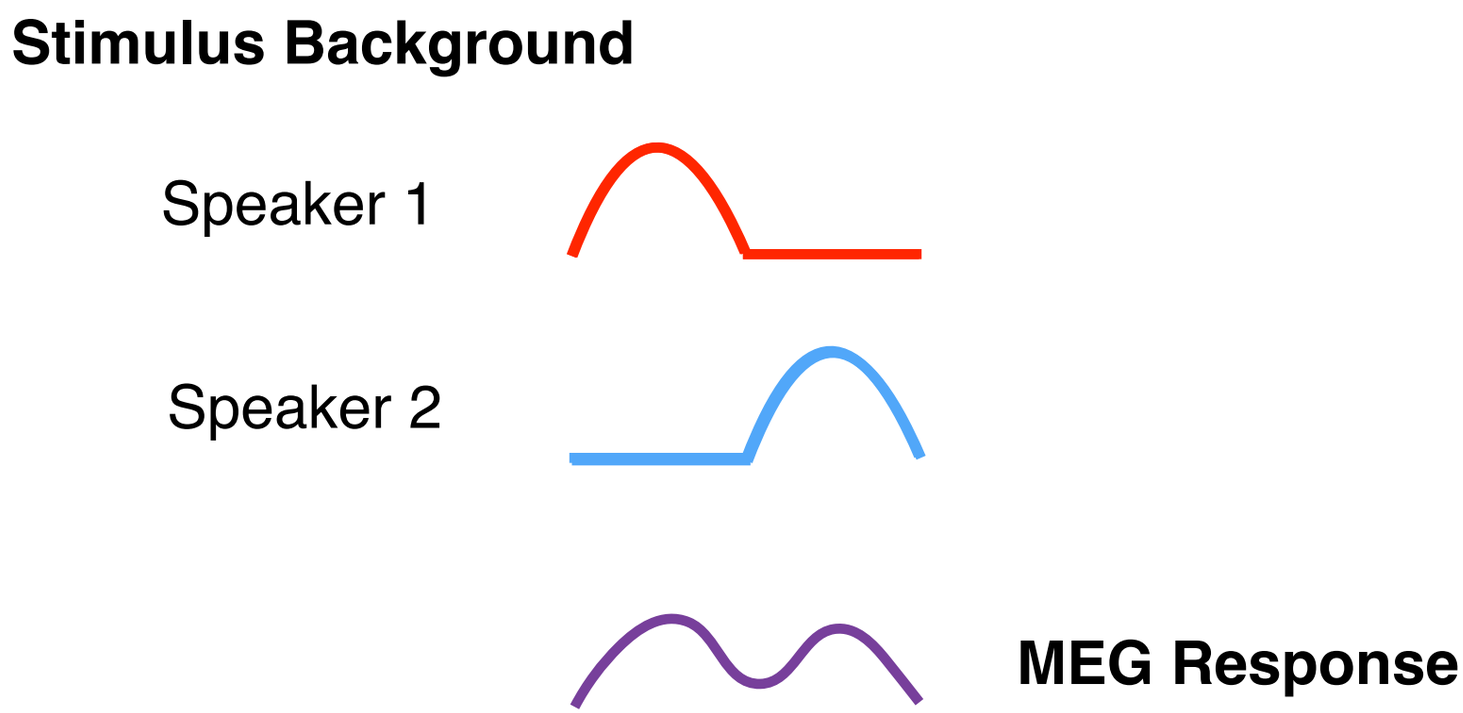
Integration Window over Late Times Only

Backgrounds vs. Background

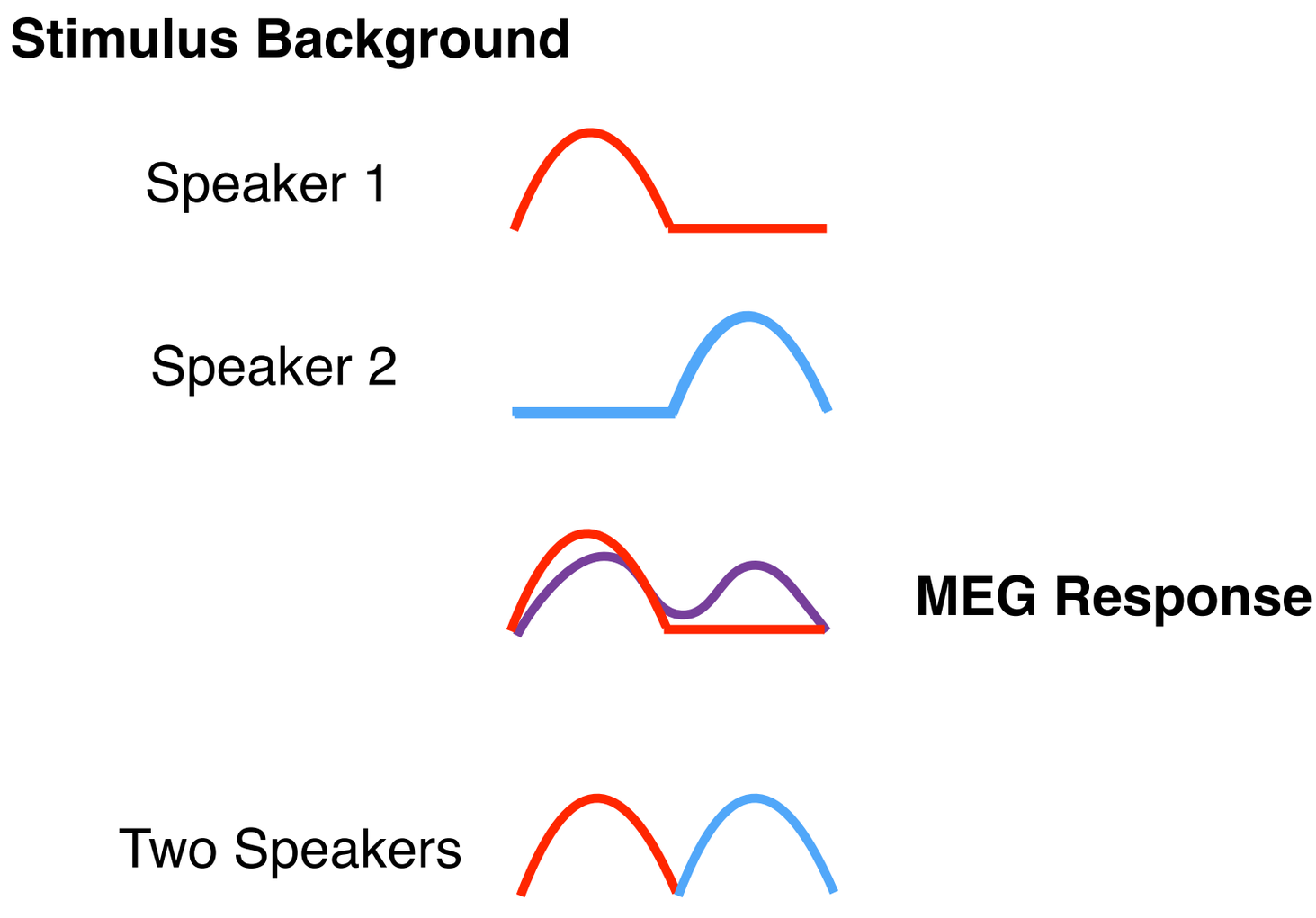


Integration Window over Late Times Only

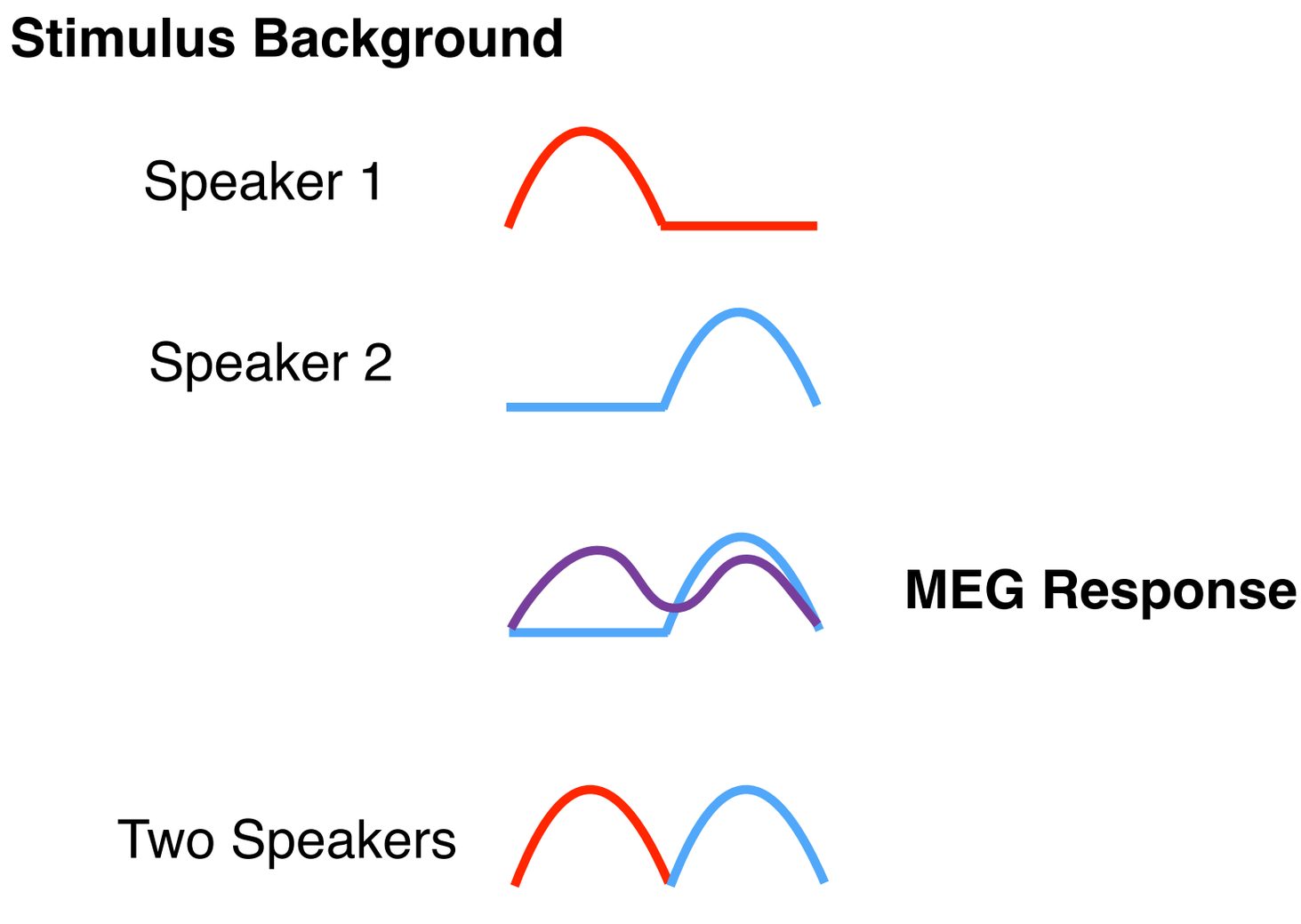
Backgrounds vs. Background
Why not?



Backgrounds vs. Background
Why not?



Backgrounds vs. Background
Why not?

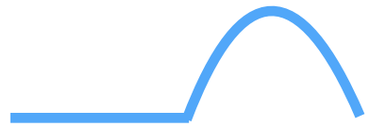


Backgrounds vs. Background
Why not?

Stimulus Background

Speaker 1

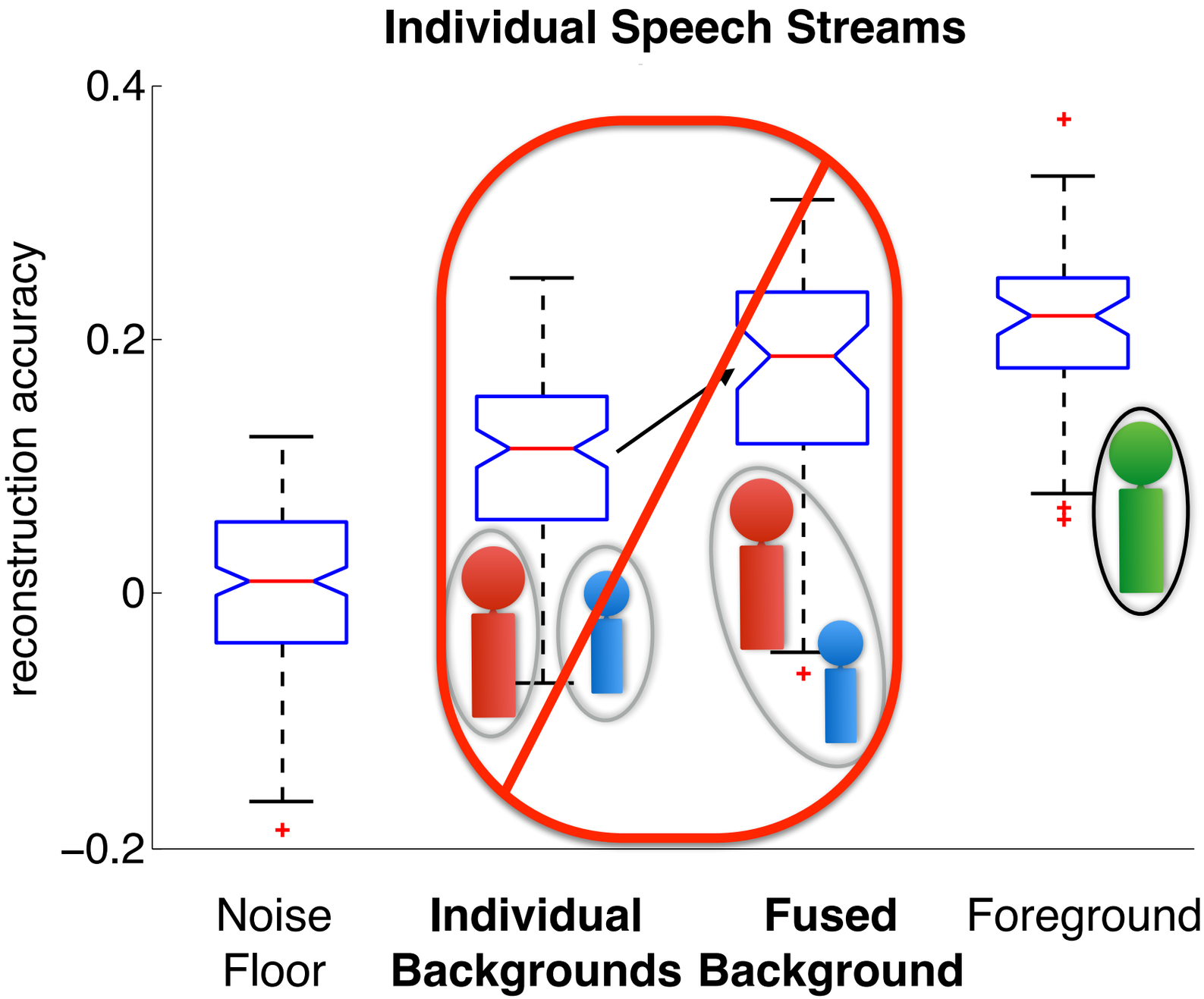
Speaker 2



MEG Response

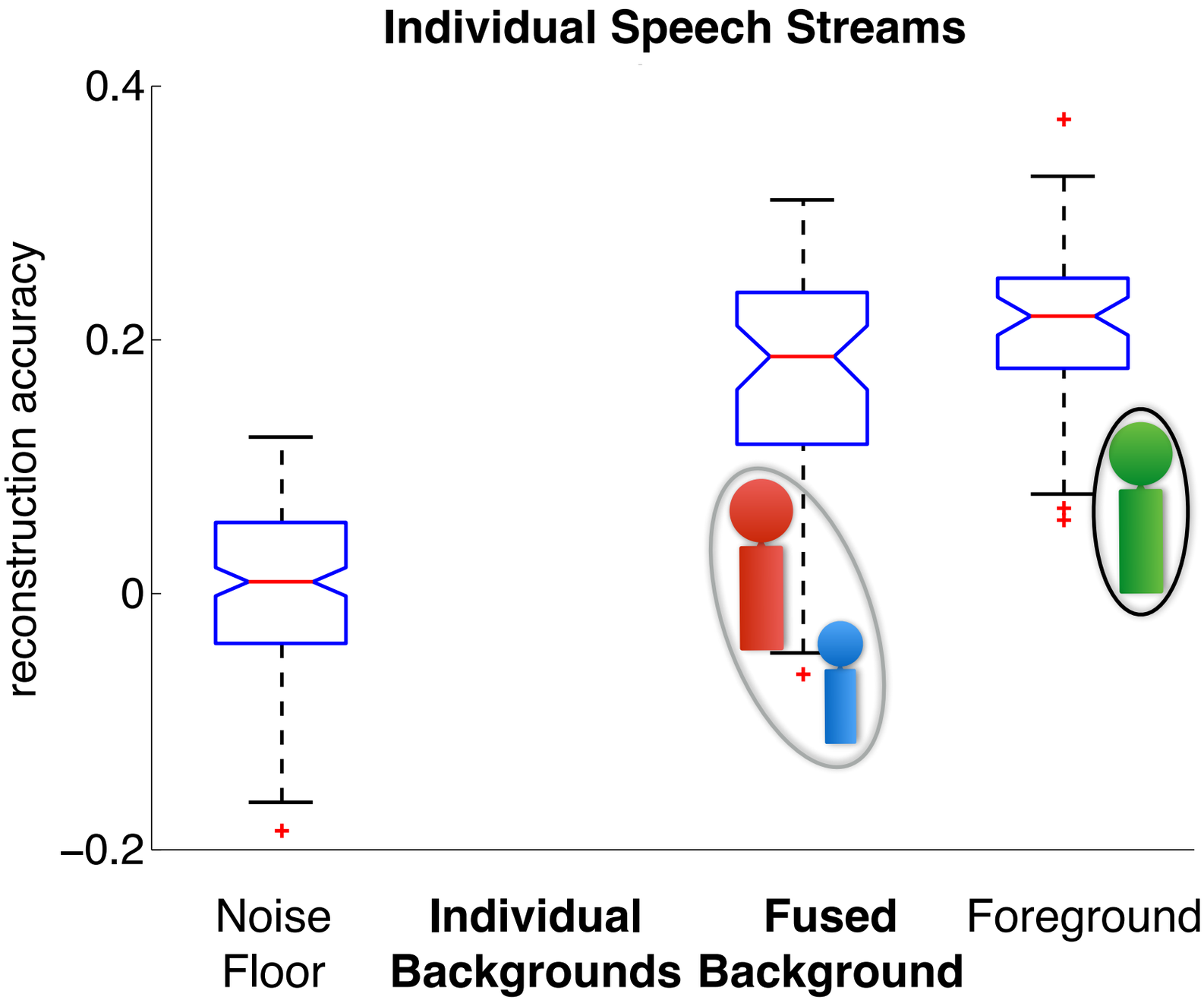
Two Speakers

Backgrounds vs. Background



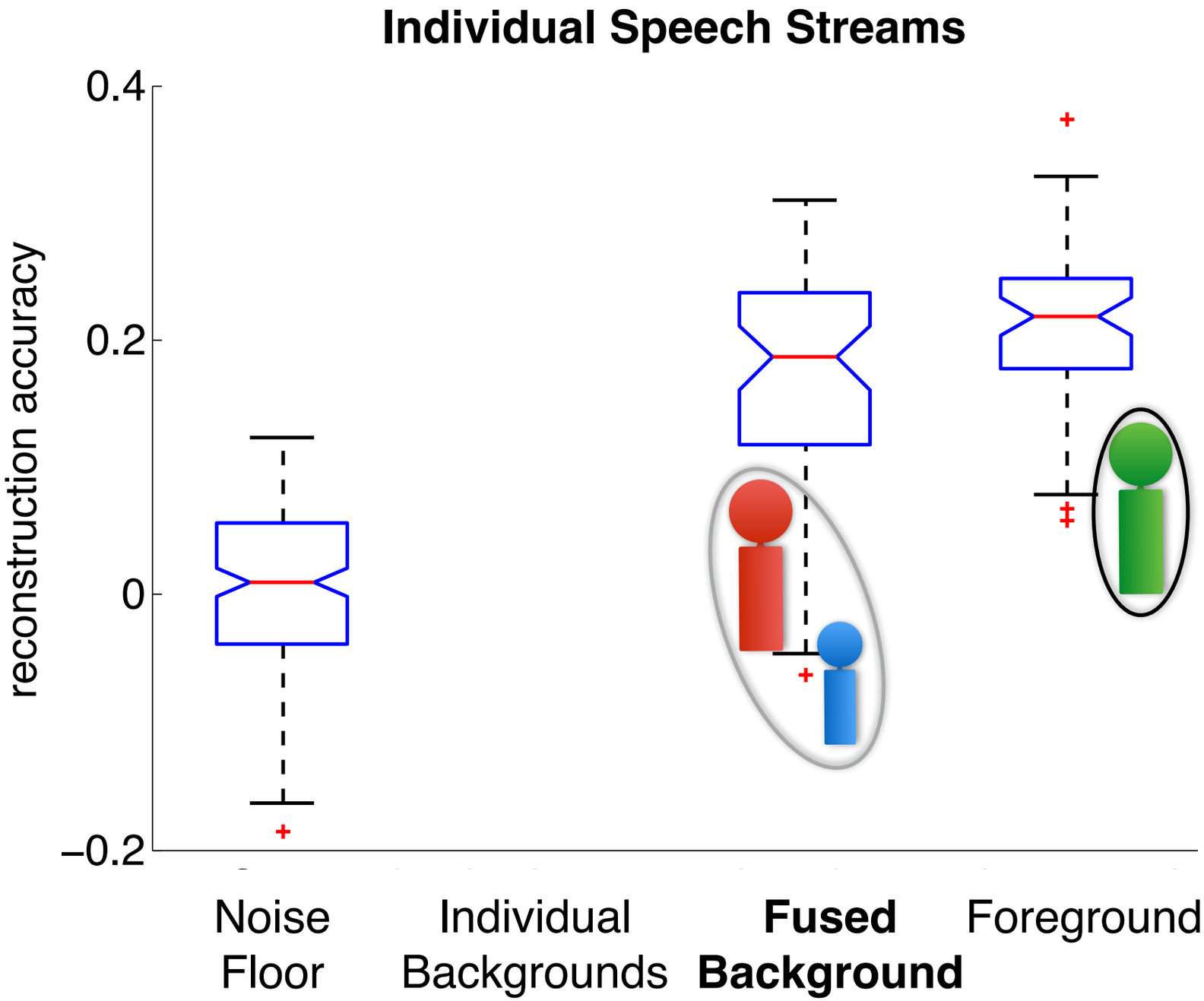
Integration Window over Late Times Only

Backgrounds vs. Background



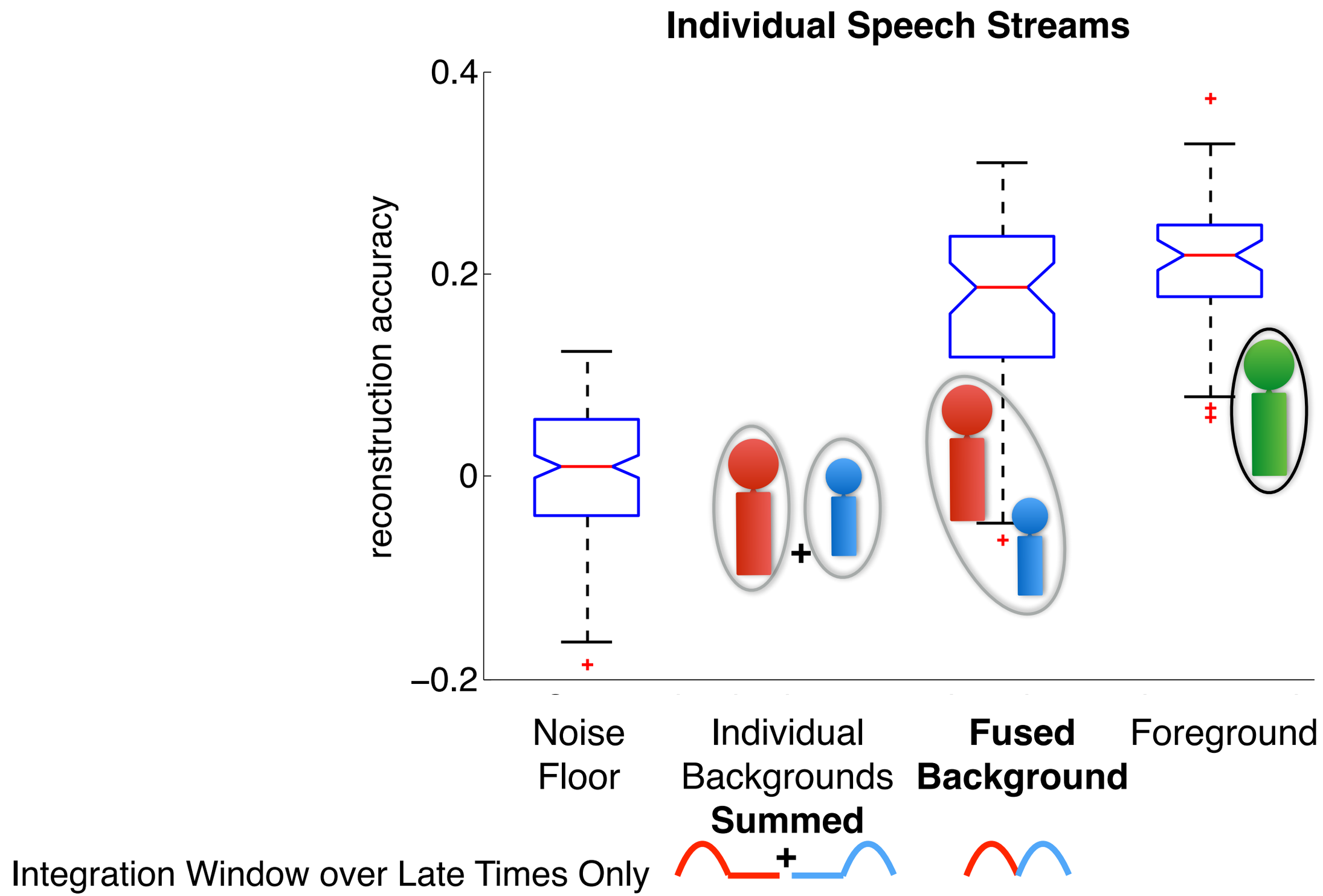
Integration Window over Late Times Only

Backgrounds vs. Background

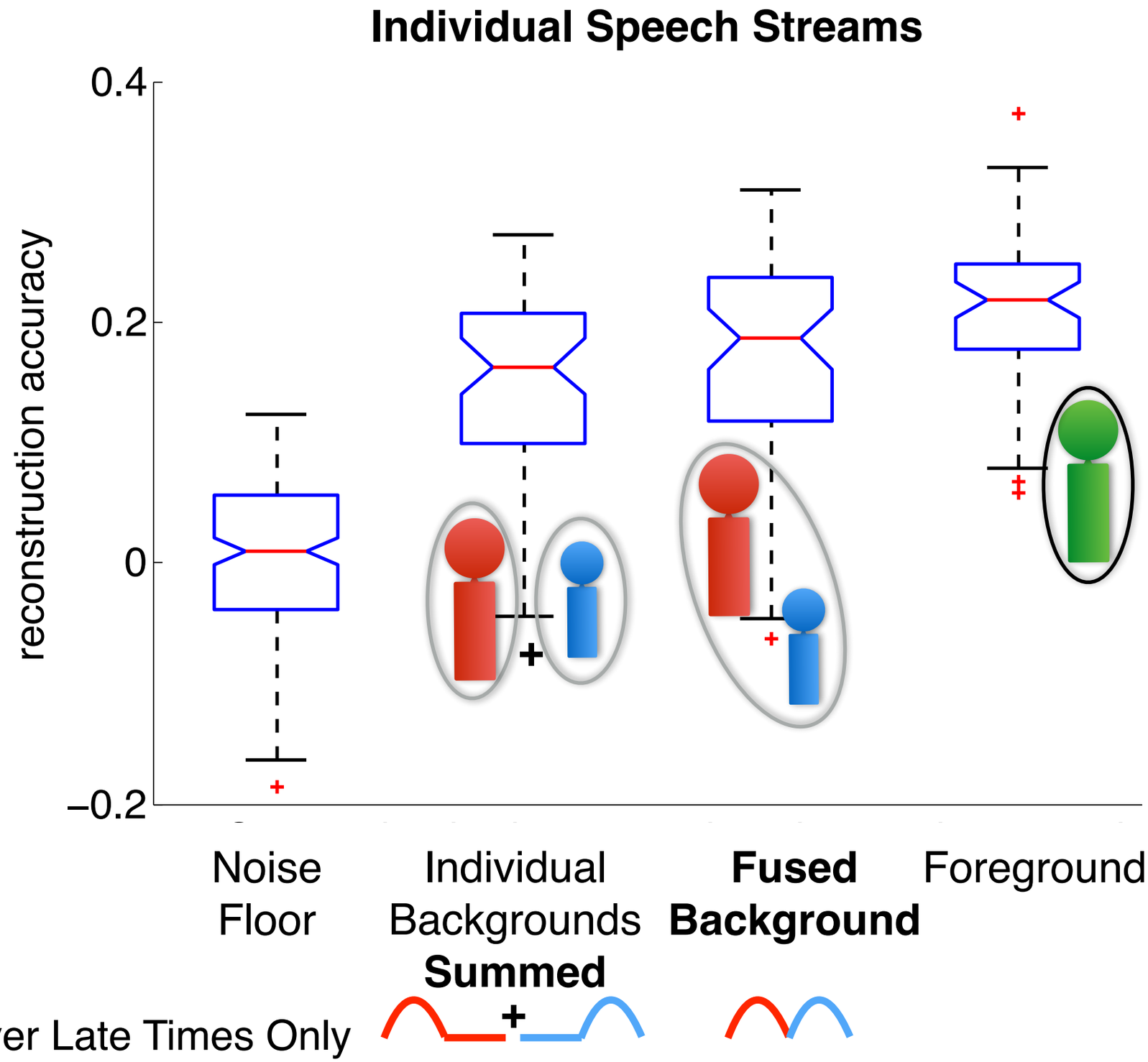


Integration Window over Late Times Only

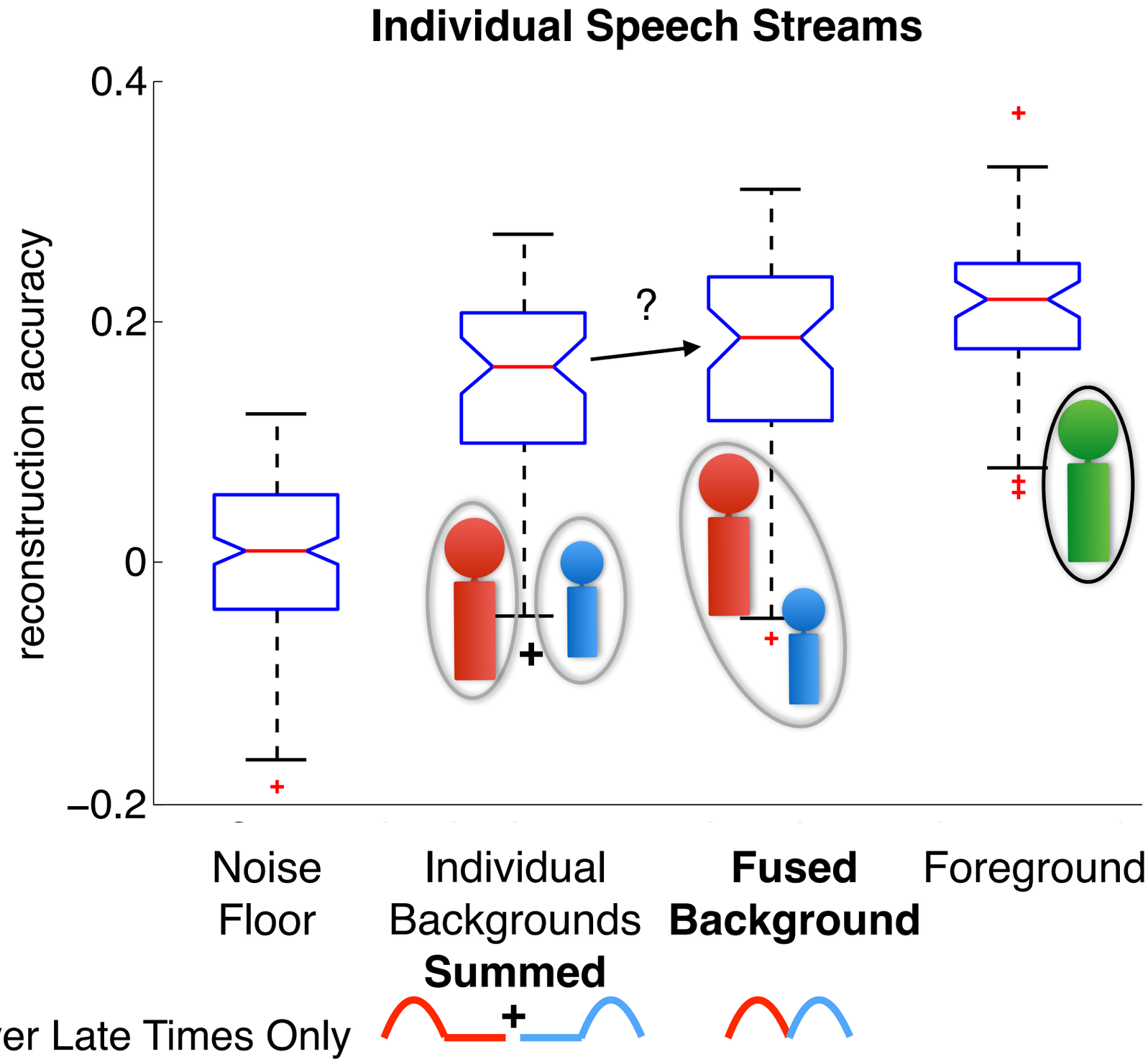
Backgrounds vs. Background



Backgrounds vs. Background

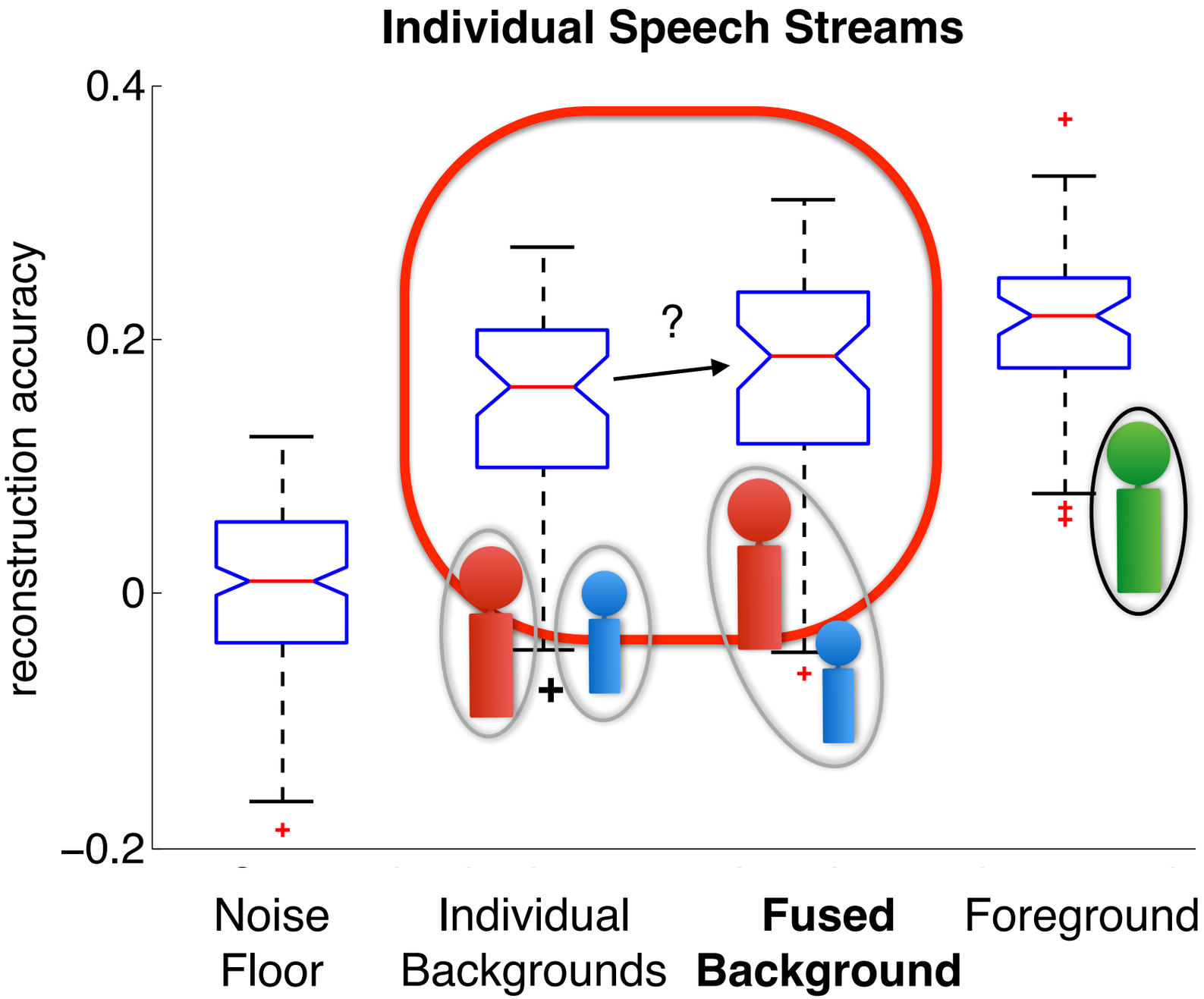


Backgrounds vs. Background



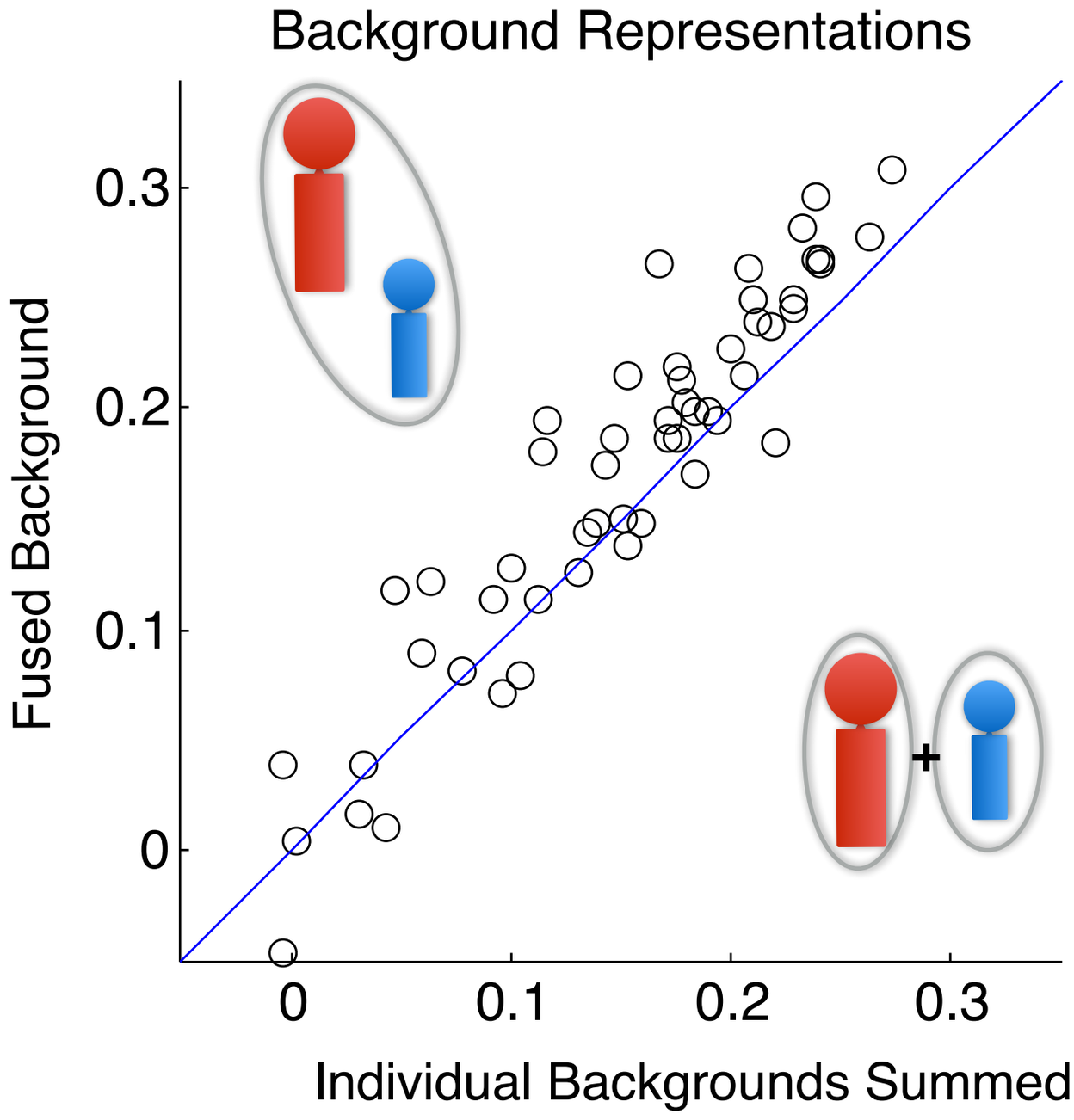
Integration Window over Late Times Only

Backgrounds vs. Background



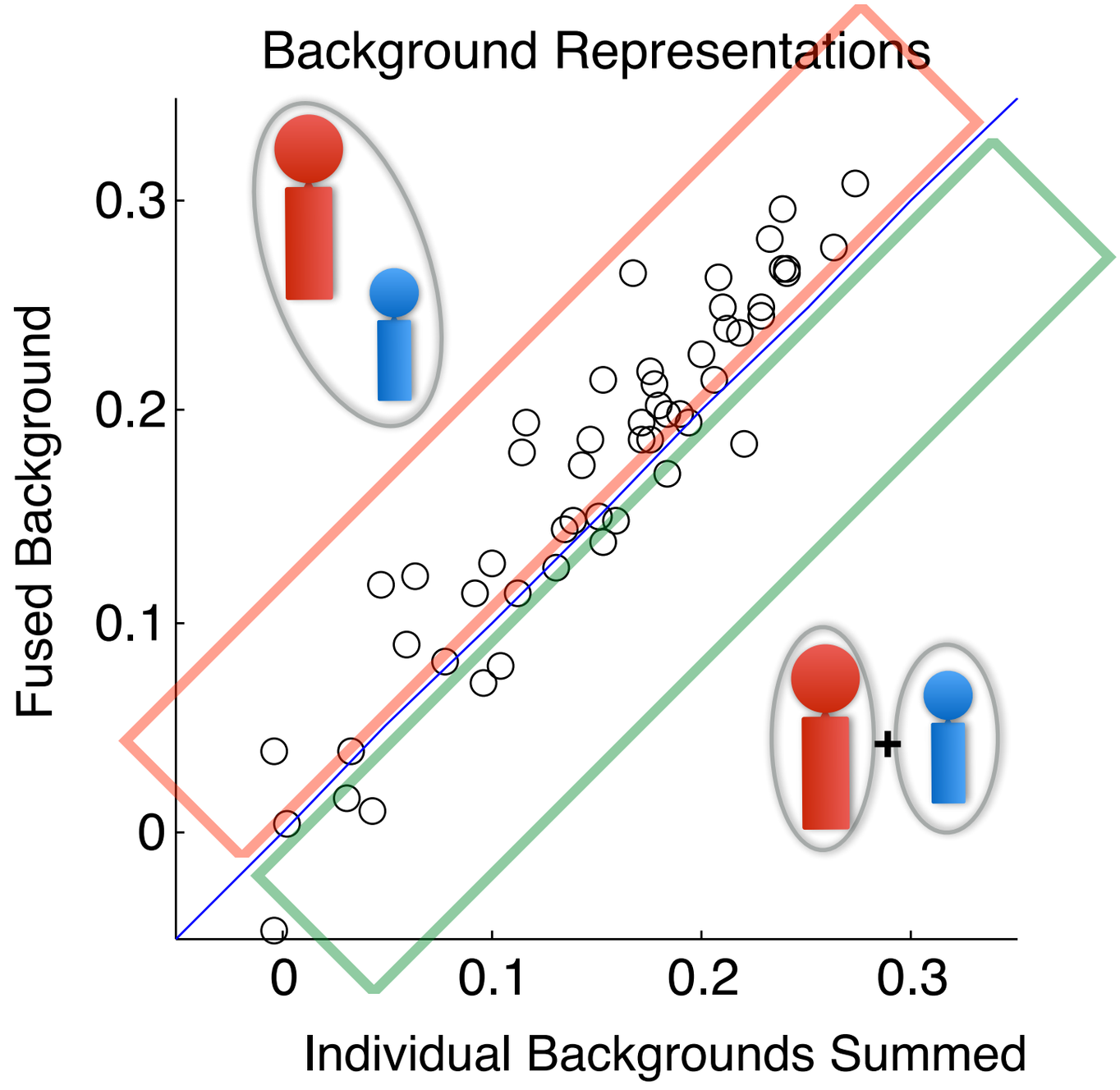
Integration Window over Late Times Only

Backgrounds vs. Background



Integration Window over Late Times Only

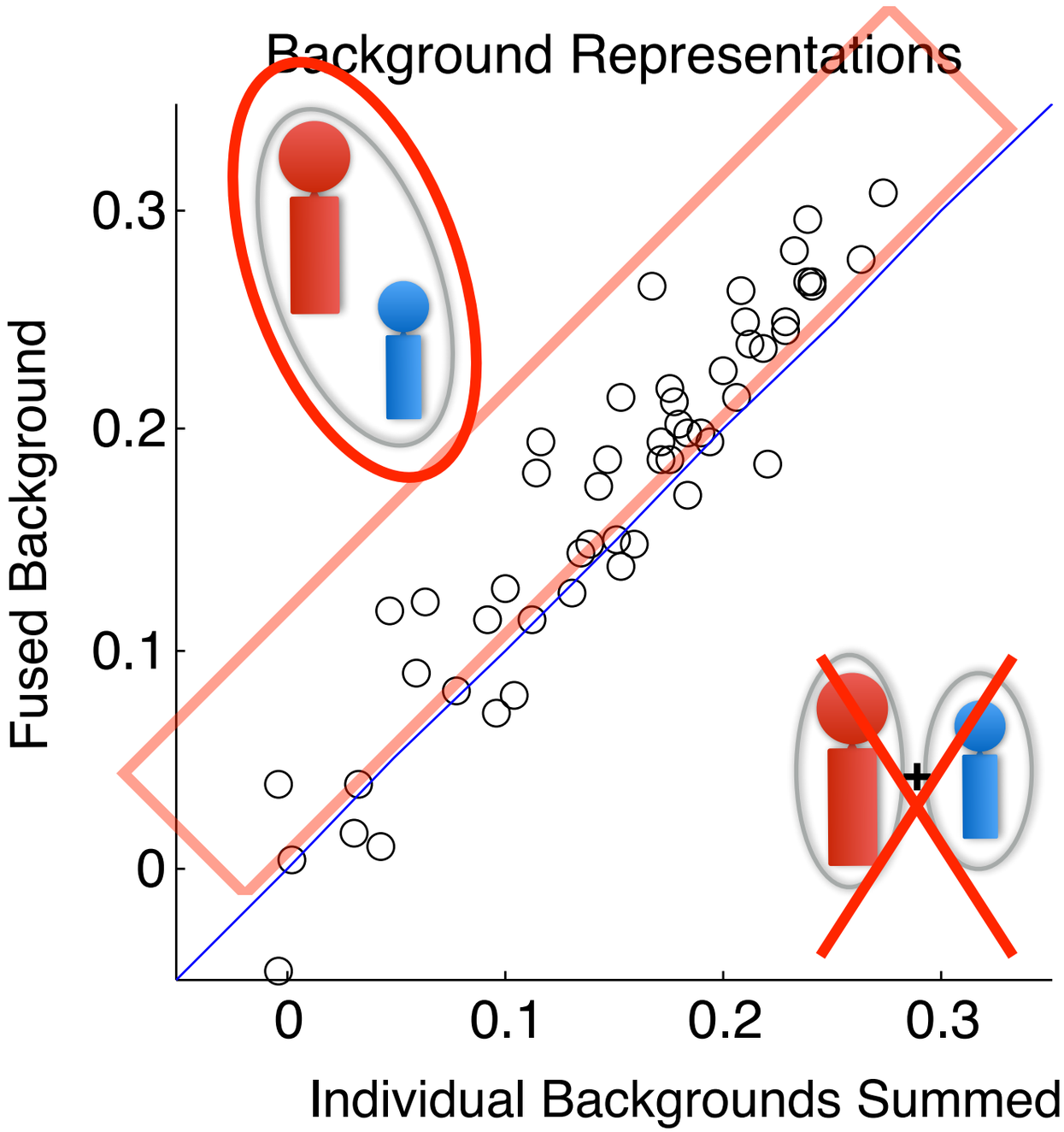
Backgrounds vs. Background



Integration Window over Late Times Only

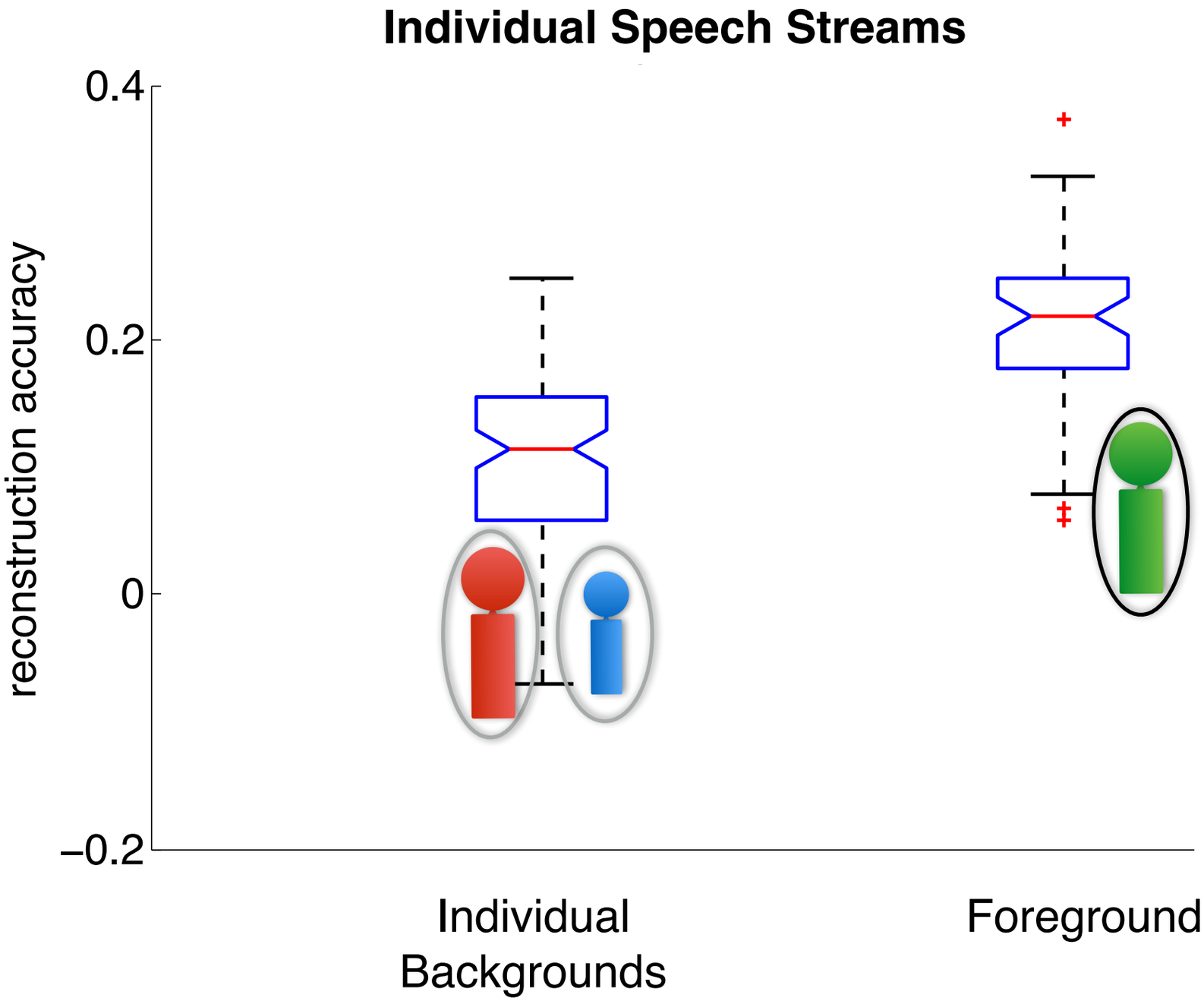
Backgrounds vs. Background

High latency areas (PT) represent ***fused*** background with better fidelity than ***individual*** backgrounds (p = 1.3E-05)



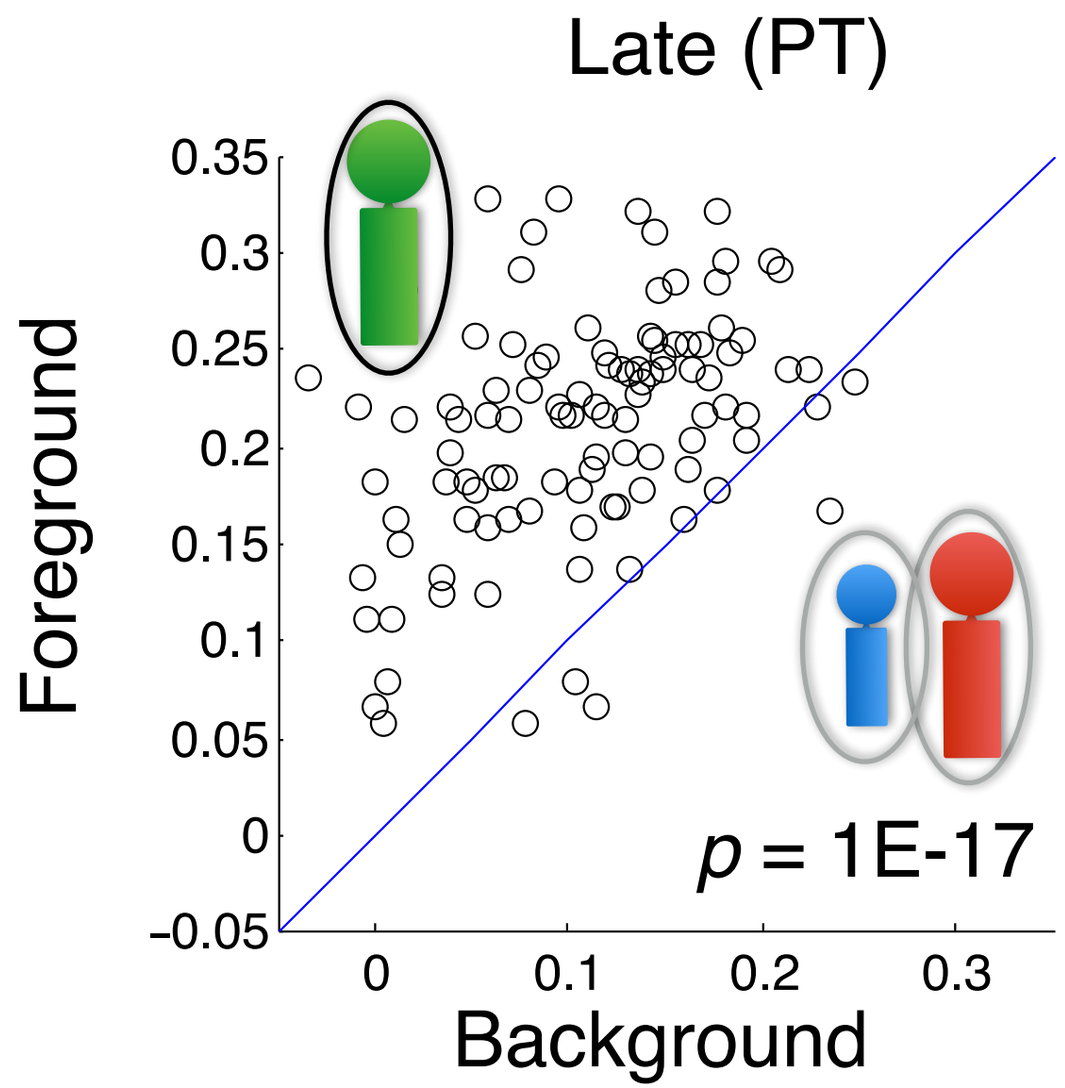
Integration Window over Late Times Only

Foreground vs. Background



Integration Window over Late Times Only

Foreground vs. Background
Early vs. Late



Foreground vs. Background
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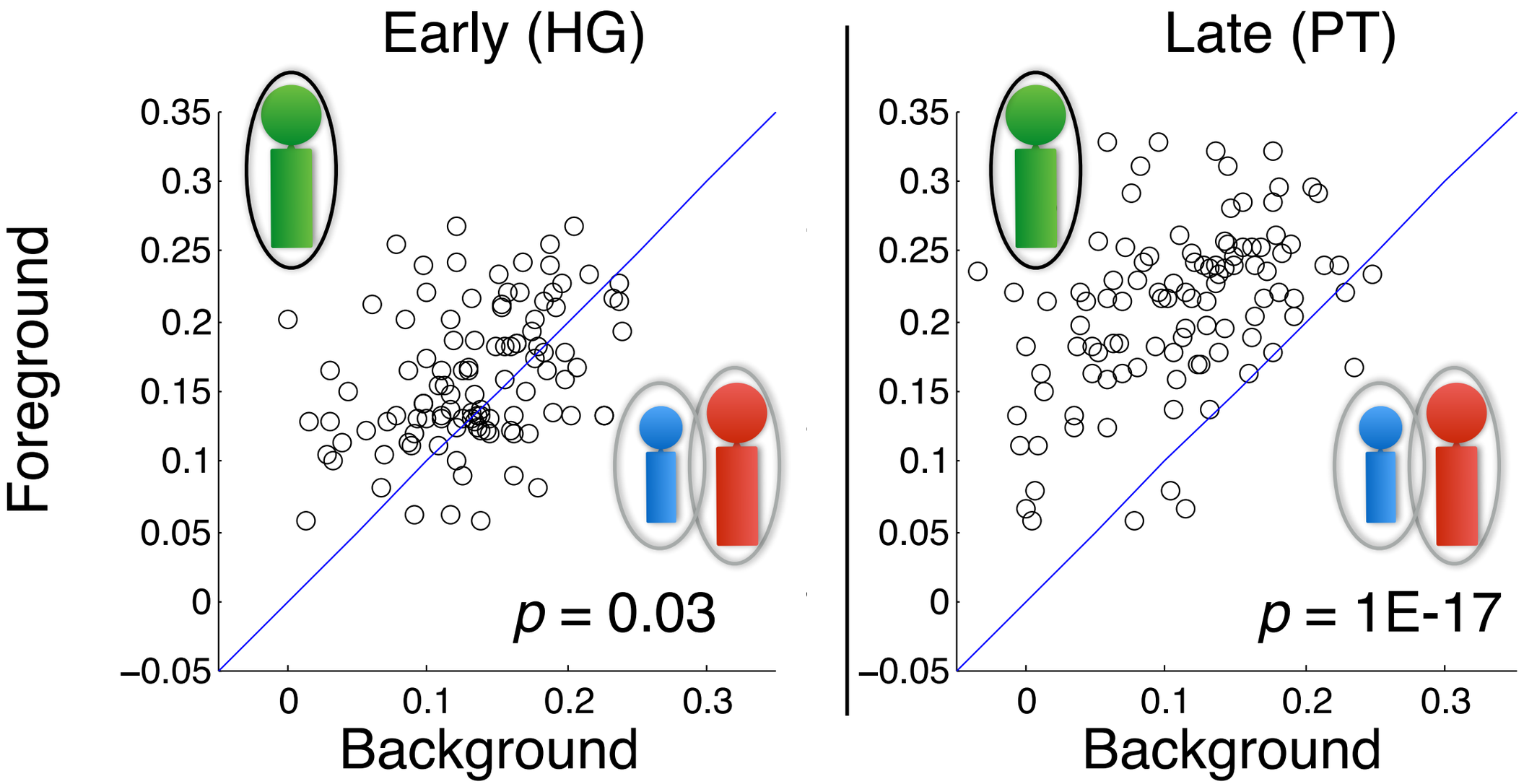

Foreground vs. Background
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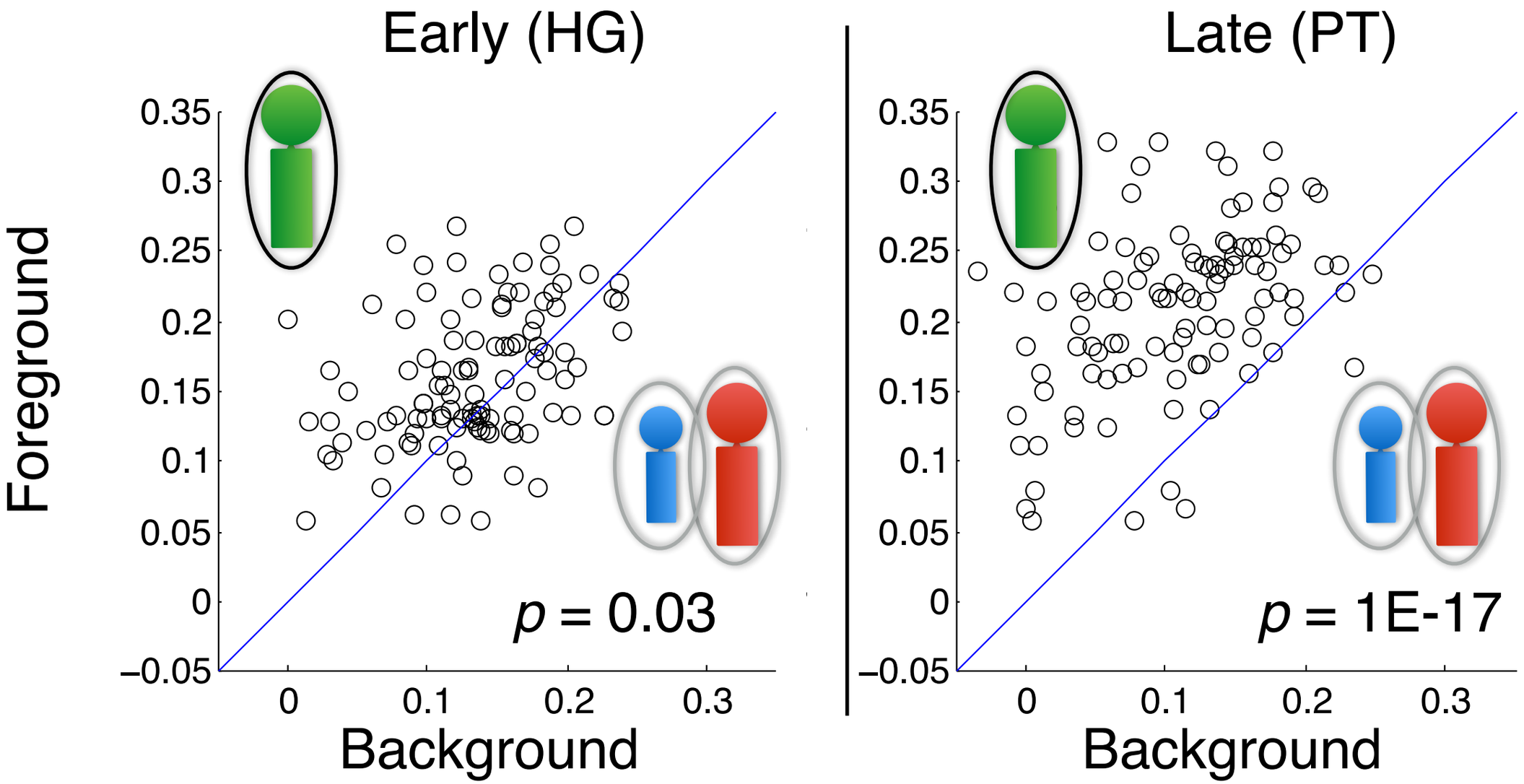

HG represents attended and unattended speech with *almost* equal fidelity

Summary

- Cortical representations of speech
  - ✓ representation of envelope (up to ~10 Hz)
- Object representation at 100 ms latency (PT), but not by 50 ms (HG)
- Consistent with being neural representations of auditory perceptual object
- Preliminary evidence for
  - ✓ PT: additional fused background representation
  - ✓ HG: almost equal representations

Thank You