Neural Representations of Cocktail Party Speech in Human Auditory Cortex

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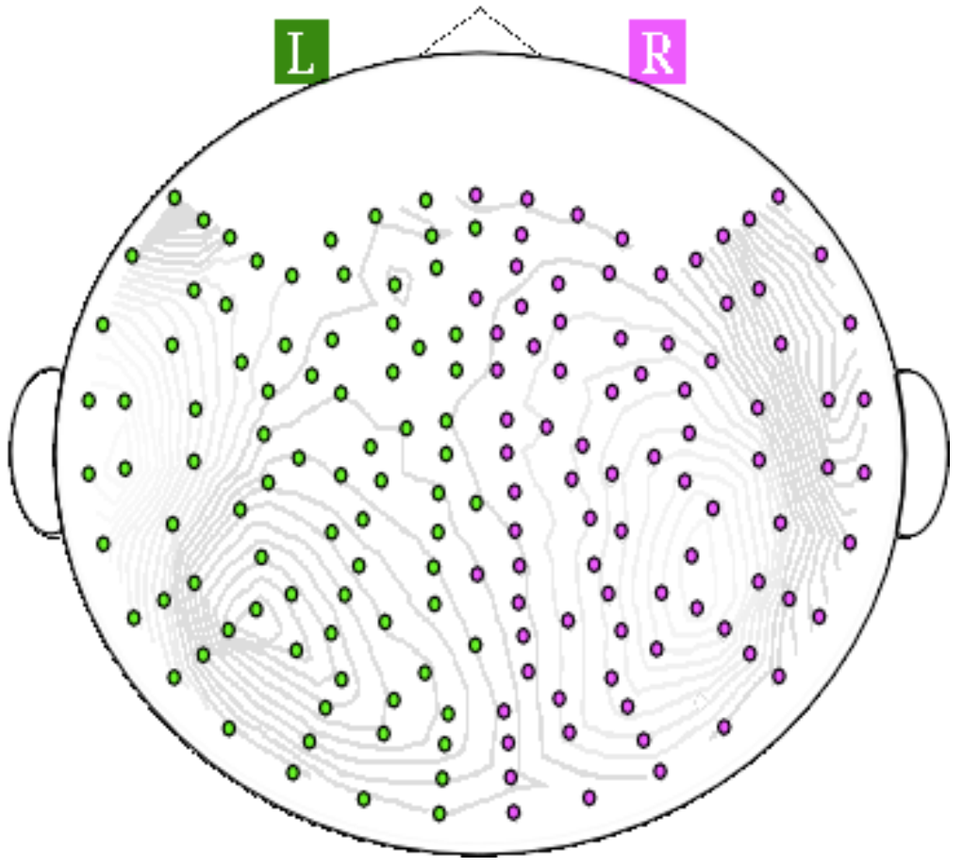
Outline

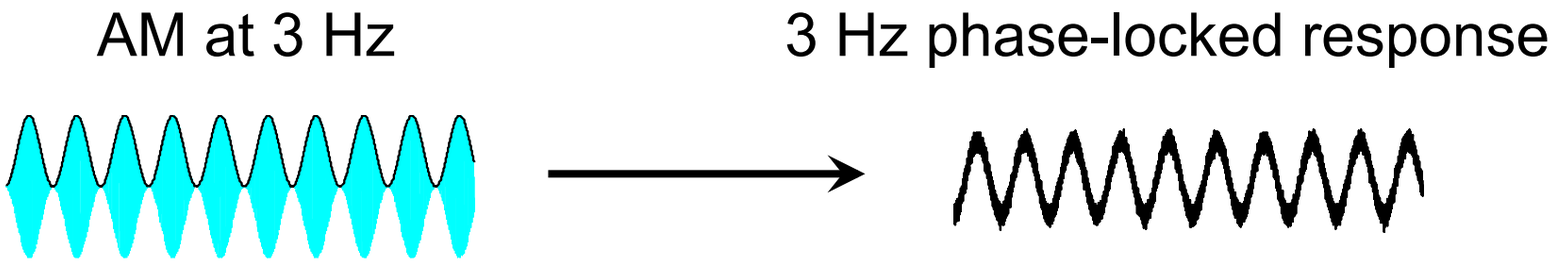
- Cortical Representations of Speech (via MEG)
  - *Encoding vs. Decoding*
- Cortical Representations of Speech in Noise
- Cortical Representations of "Cocktail Party" Speech
- Effects of Aging on Cortical Representations of "Cocktail Party" Speech
- Cortical Representations of Internal Speech

Magnetoencephalography (MEG)

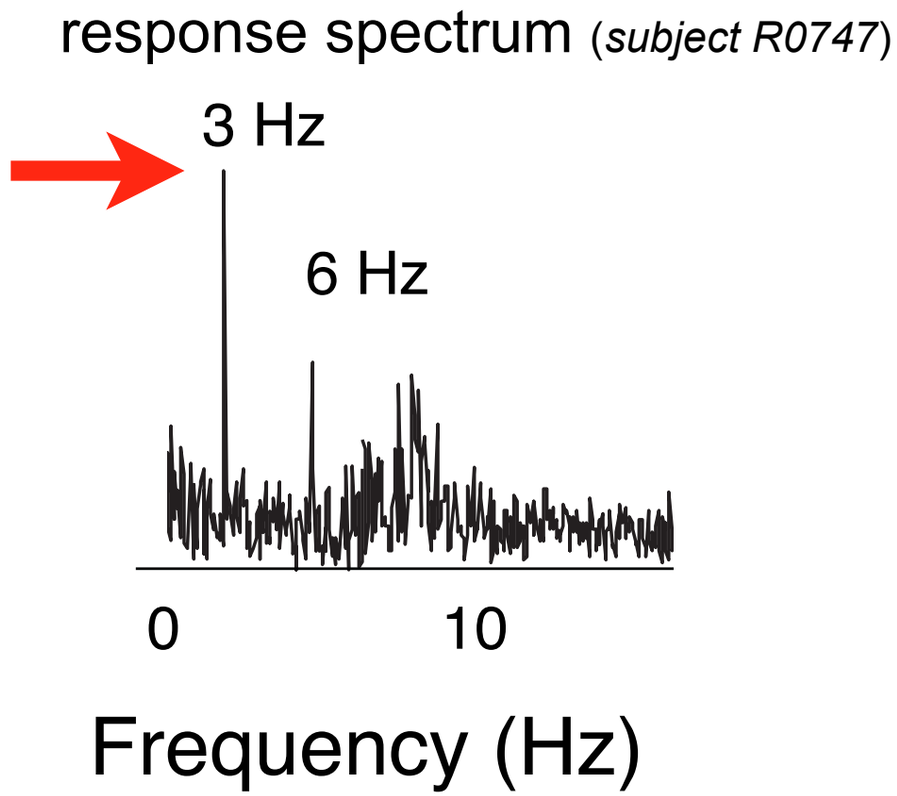
- Non-invasive, Passive, Silent Neural Recordings of Cortex
- Simultaneous Whole-Head Recording (~200 sensors)
- Sensitivity
  - high: ~100 fT (10^{-13} Tesla)
  - low: ~10^4 – ~10^6 neurons
- Temporal Resolution: ~1 ms
- Spatial Resolution
  - coarse: ~1 cm
  - ambiguous



MEG Phase-Locked Responses to Slow Acoustic Modulations

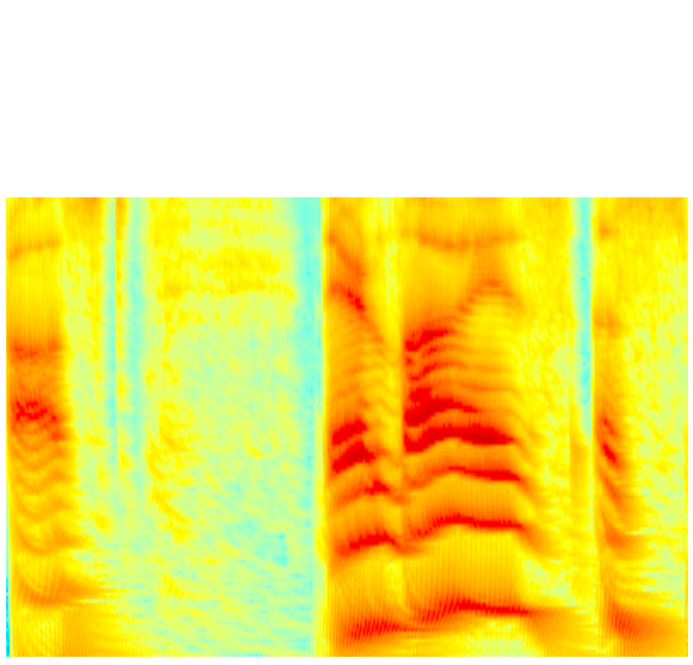


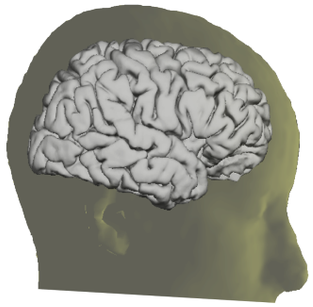
MEG activity is phase-locked to temporal modulations of sound



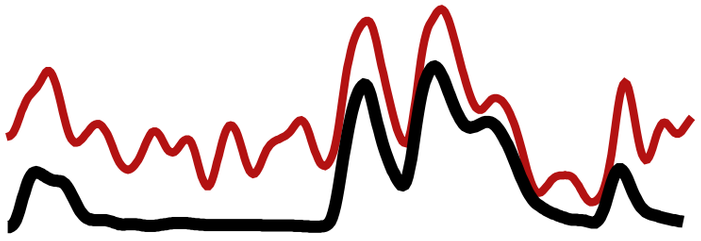
Ding & Simon, J Neurophysiol (2009)
Wang et al., J Neurophysiol (2012)

MEG Responses to Speech Modulations

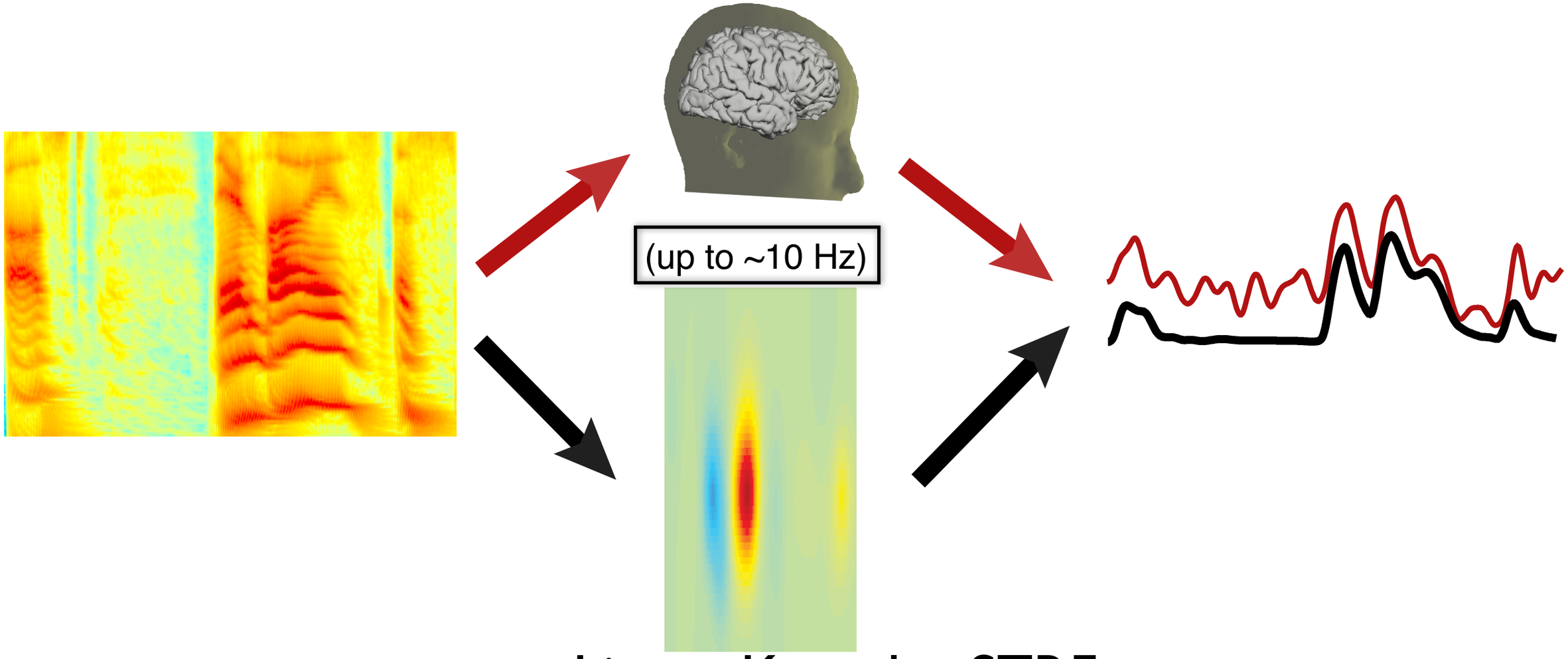




Auditory Model



MEG Responses Predicted by STRF Model

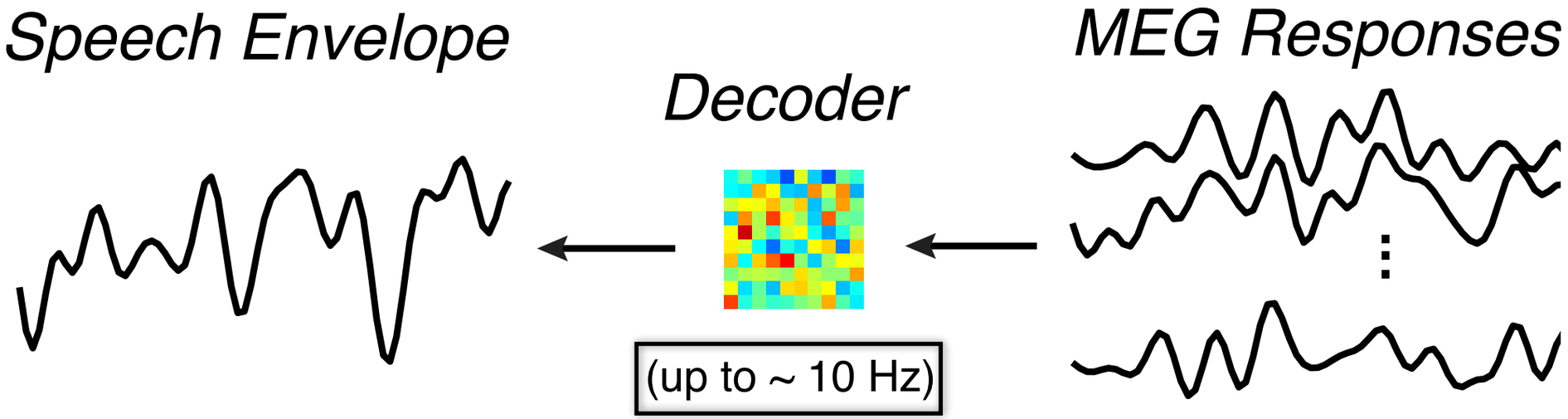


Linear Kernel = STRF

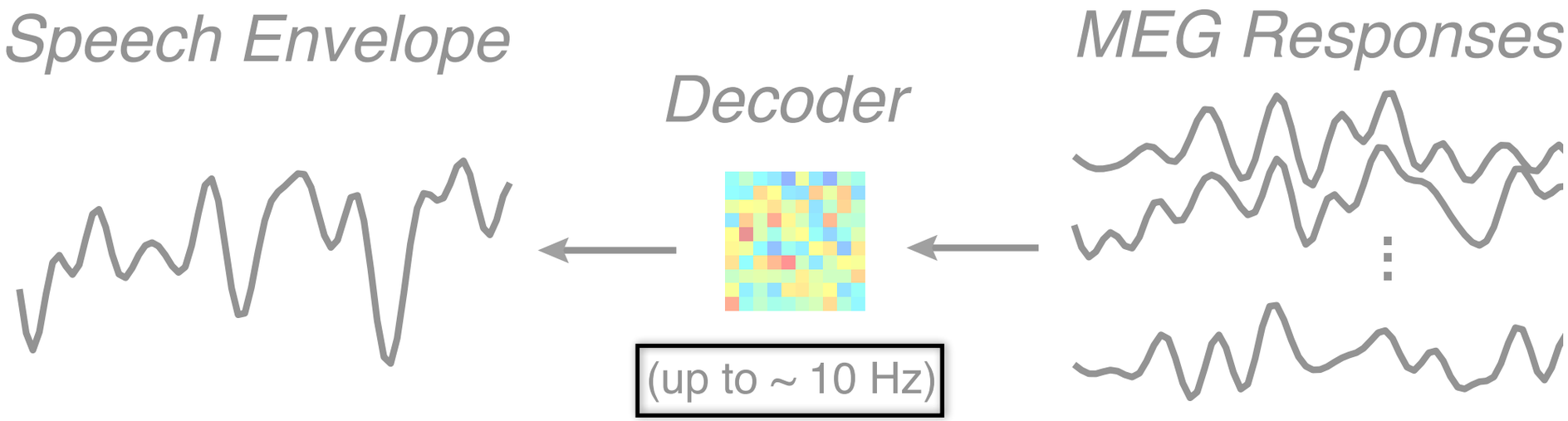
"Spectro-Temporal Response Function"

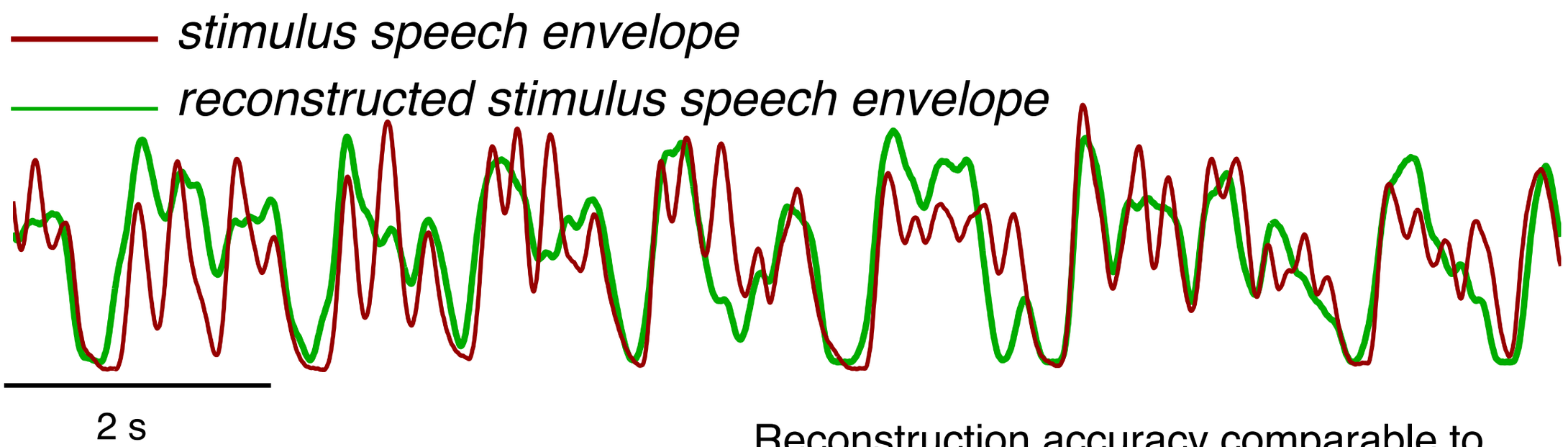
Ding & Simon, J Neurophysiol (2012)

Neural Reconstruction of Speech Envelope



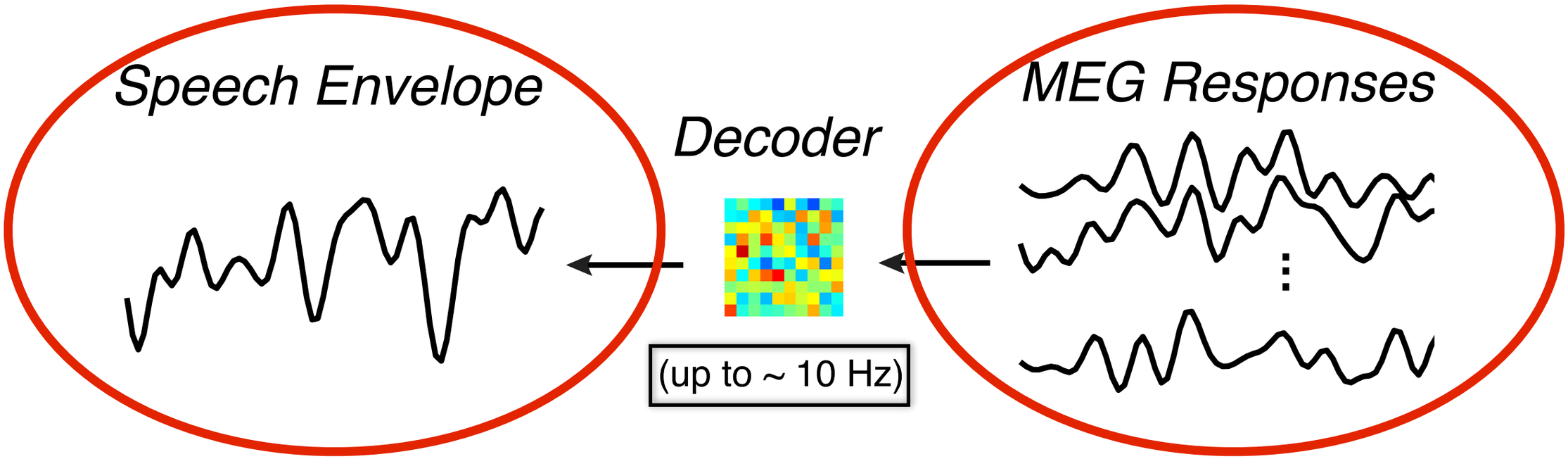
Neural Reconstruction of Speech Envelope



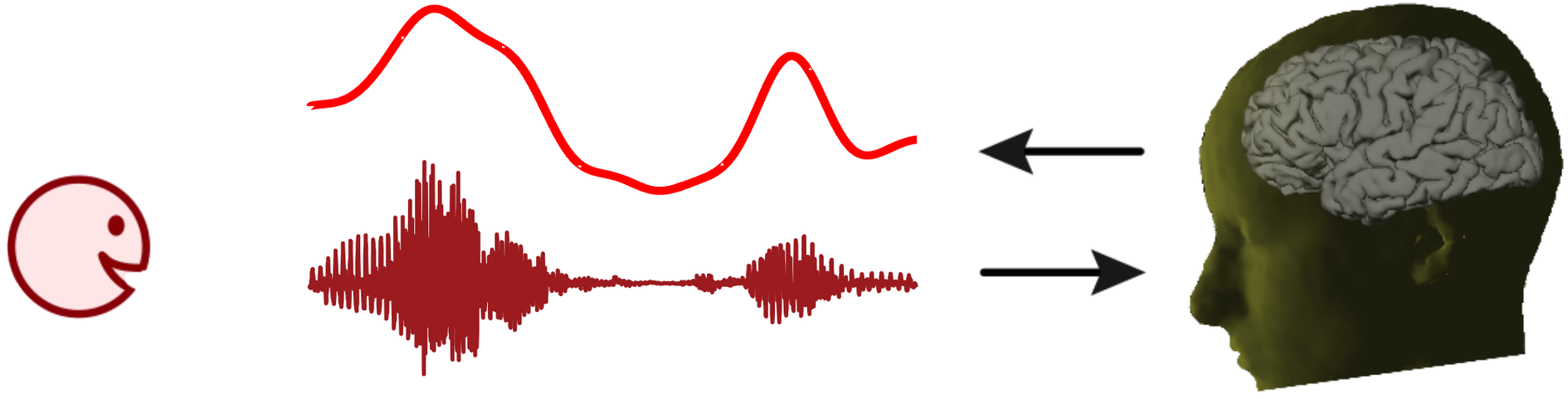


Reconstruction accuracy comparable to single unit & ECoG recordings

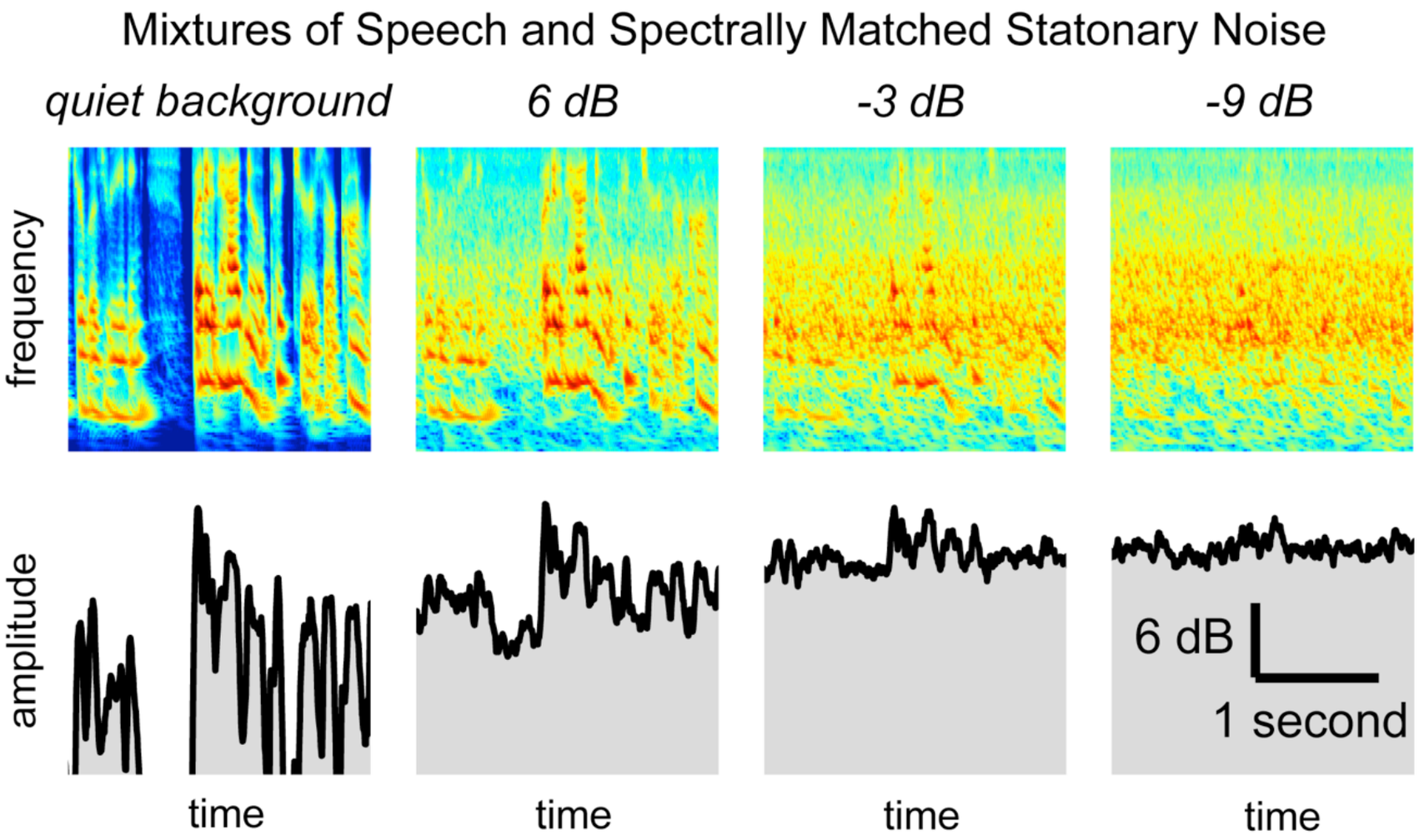
Ding & Simon, J Neurophysiol (2012)
Zion-Golumbic et al., Neuron (2013)

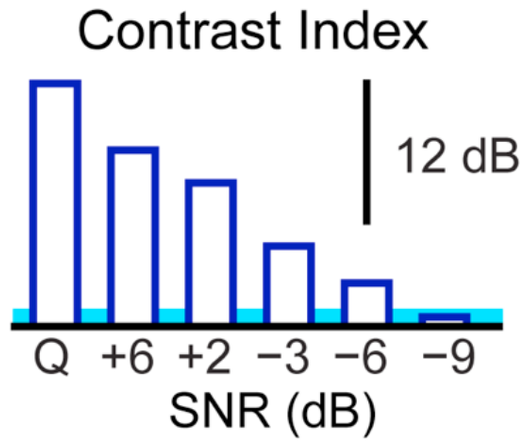

Speech Envelope
Decoder
MEG Responses
(up to ~ 10 Hz)

Neural Representation of Speech: Temporal



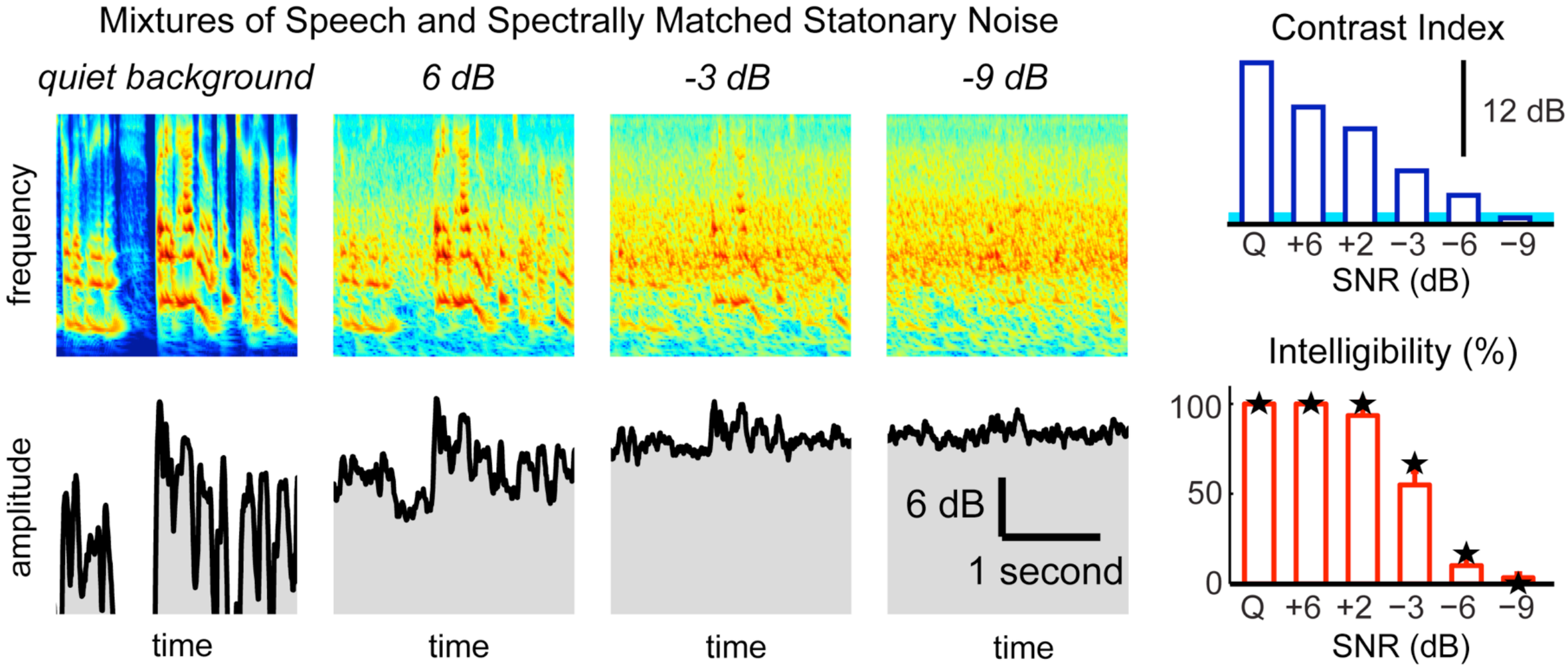
Speech in Stationary Noise





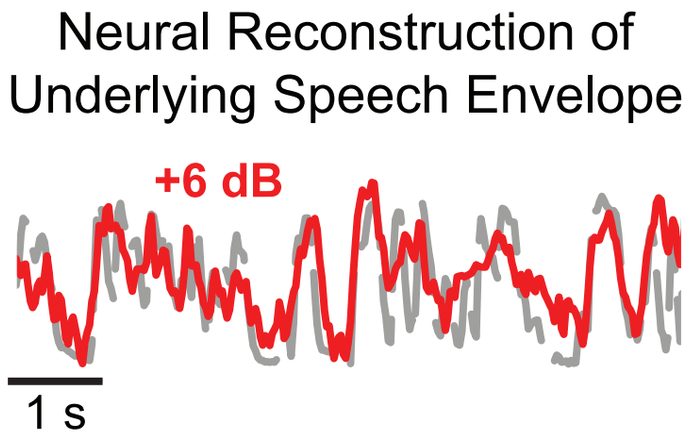
Ding & Simon, J Neuroscience (2013)

Speech in Stationary Noise



Ding & Simon, J Neuroscience (2013)

Speech in Noise: Results



Ding & Simon, J Neuroscience (2013)

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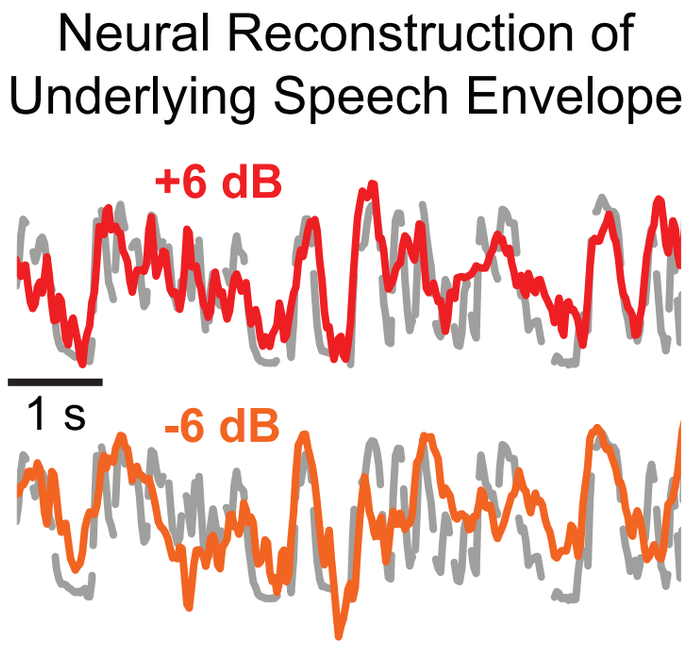
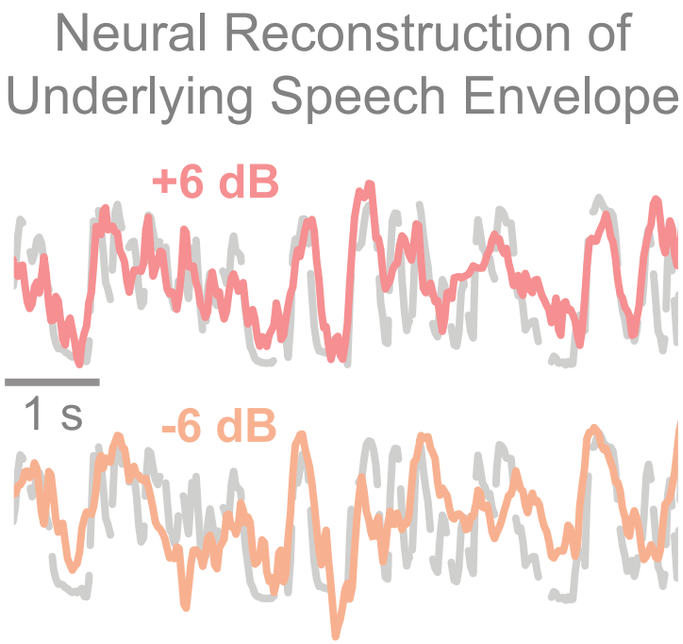
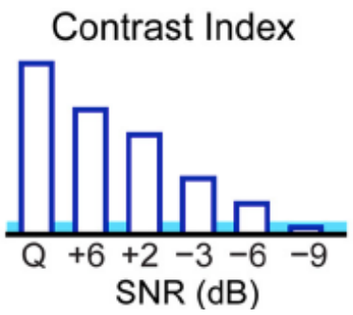
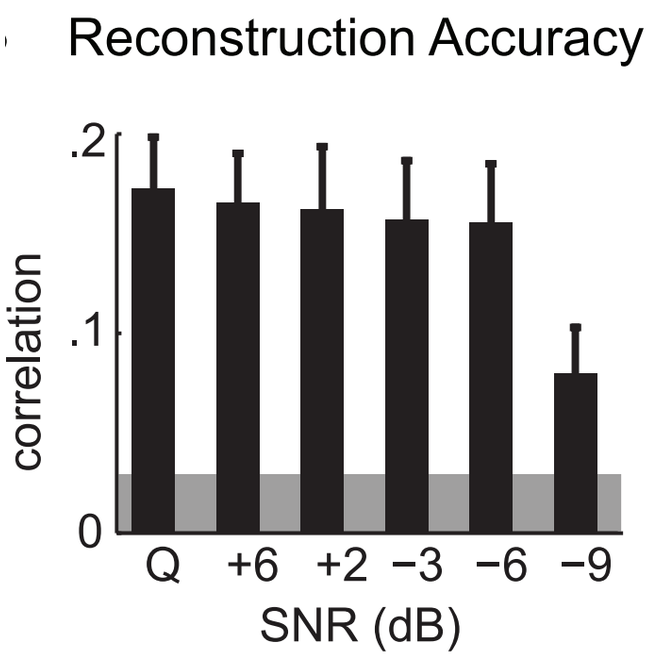


Ding & Simon, J Neuroscience (2013)

Speech in Noise: Results







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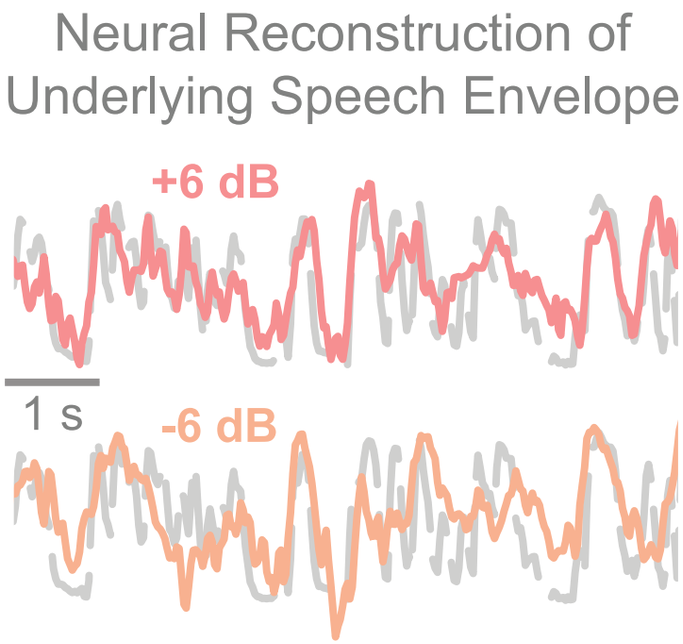
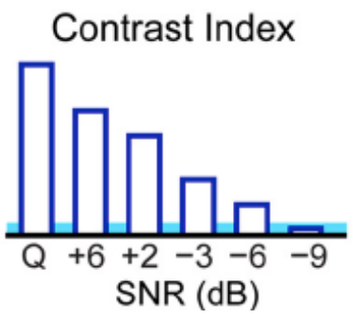
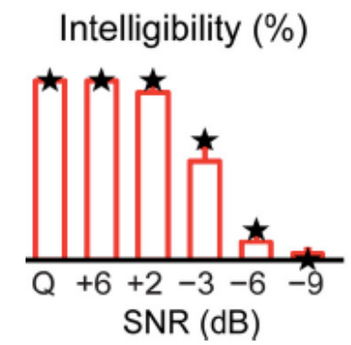
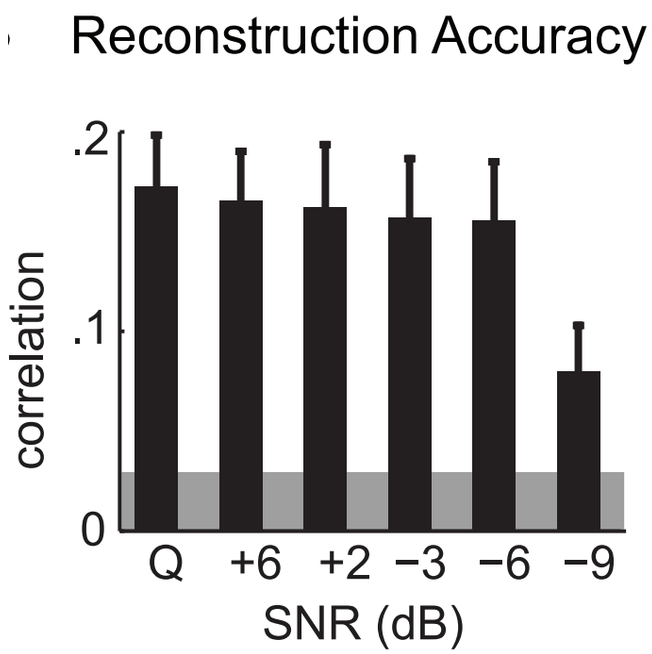
Speech in Noise: Results









Ding & Simon, J Neuroscience (2013)

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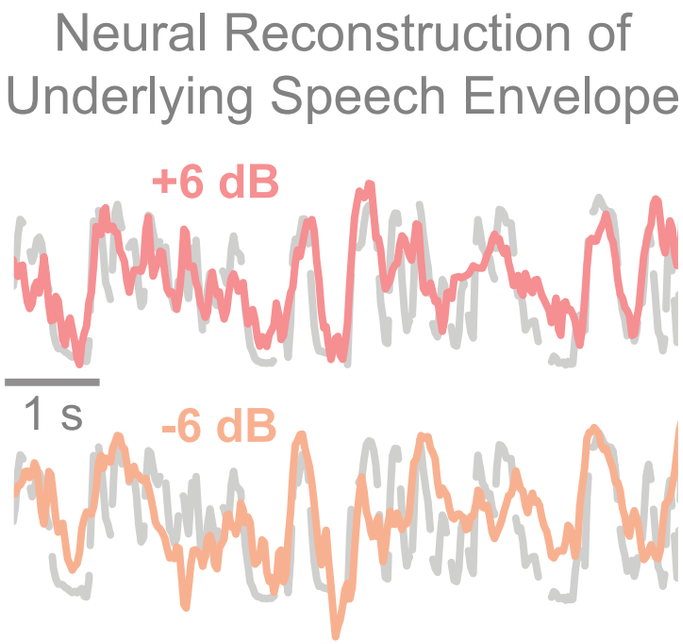
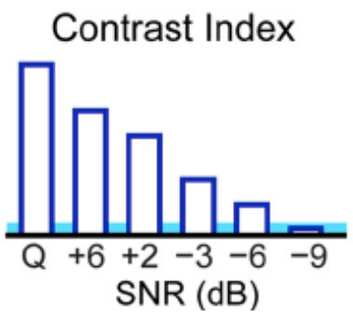
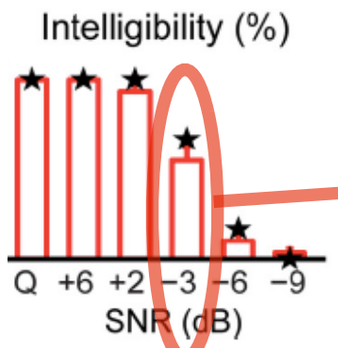
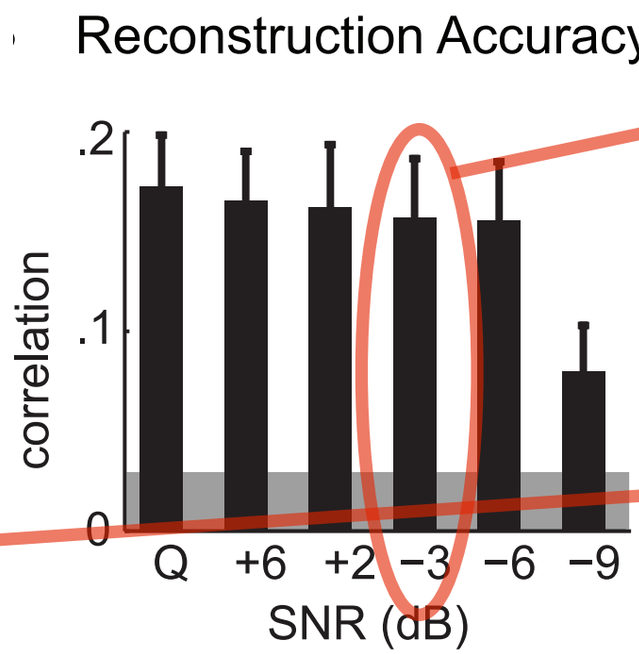
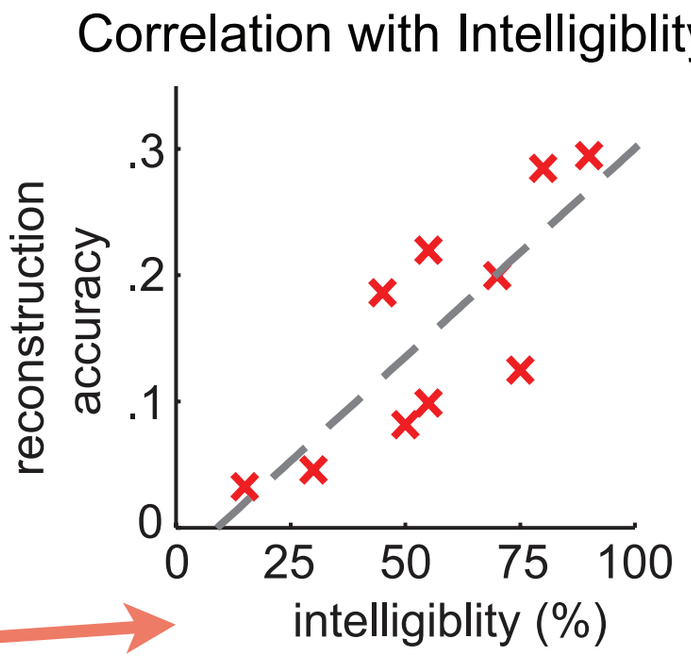






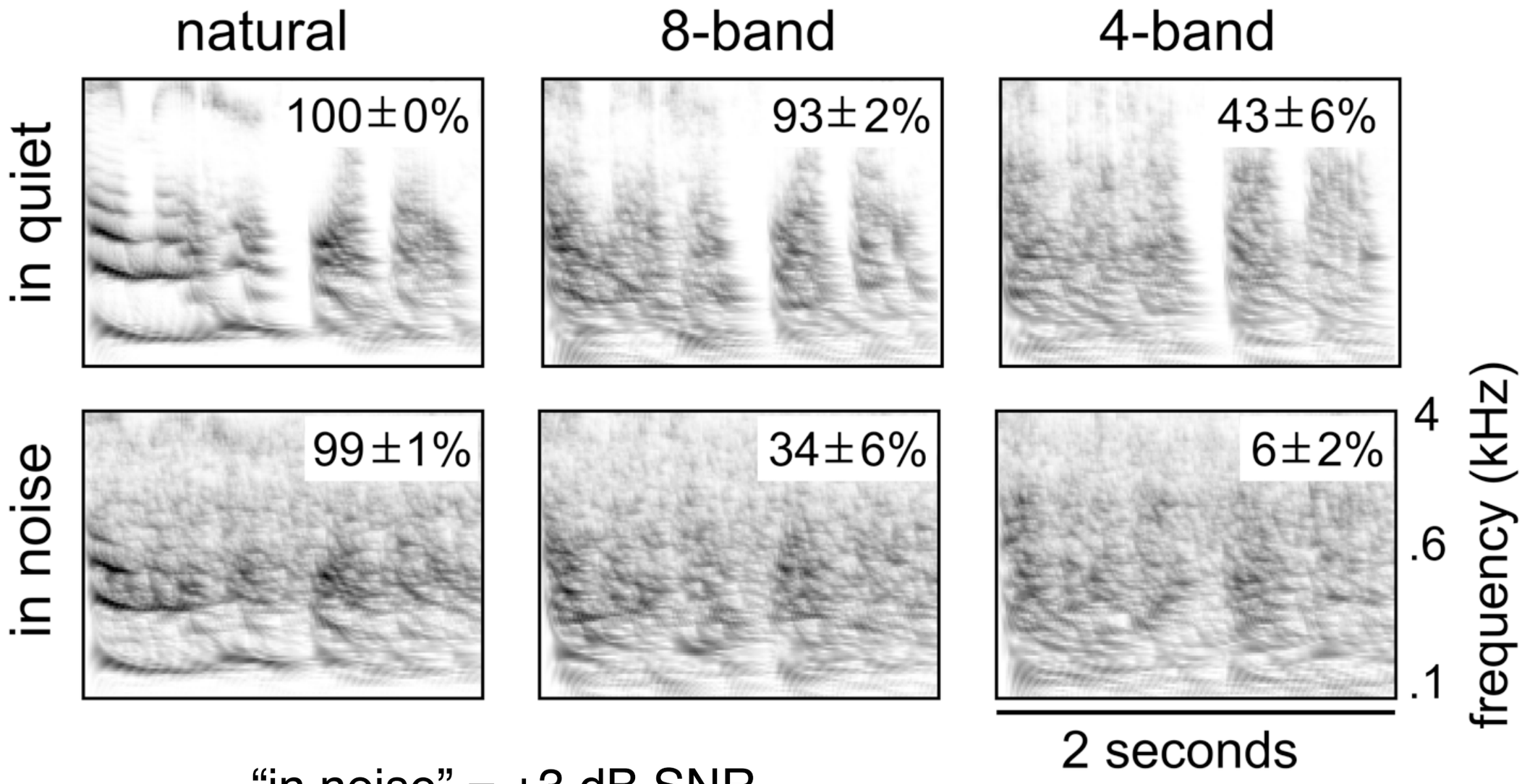




across Subjects

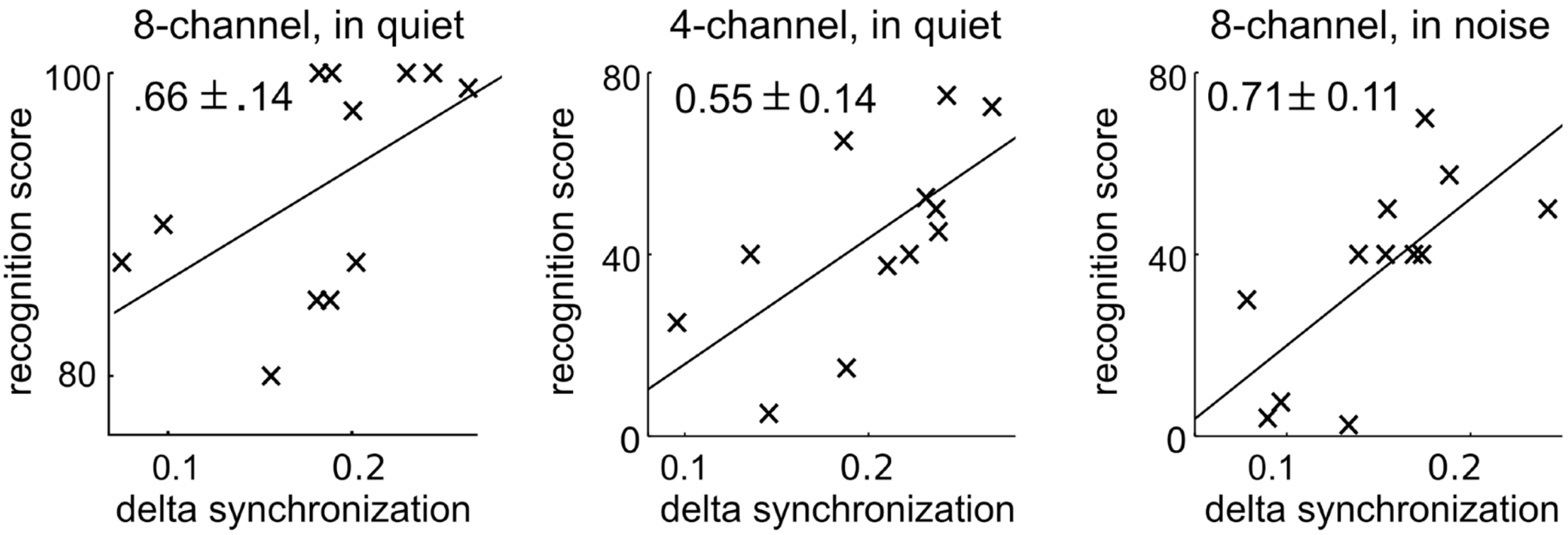
Ding & Simon, J Neuroscience (2013)

Noise-Vocoded Speech



Ding, Chatterjee & Simon, NeuroImage (2014)

Noise-Vocoded Speech: Results



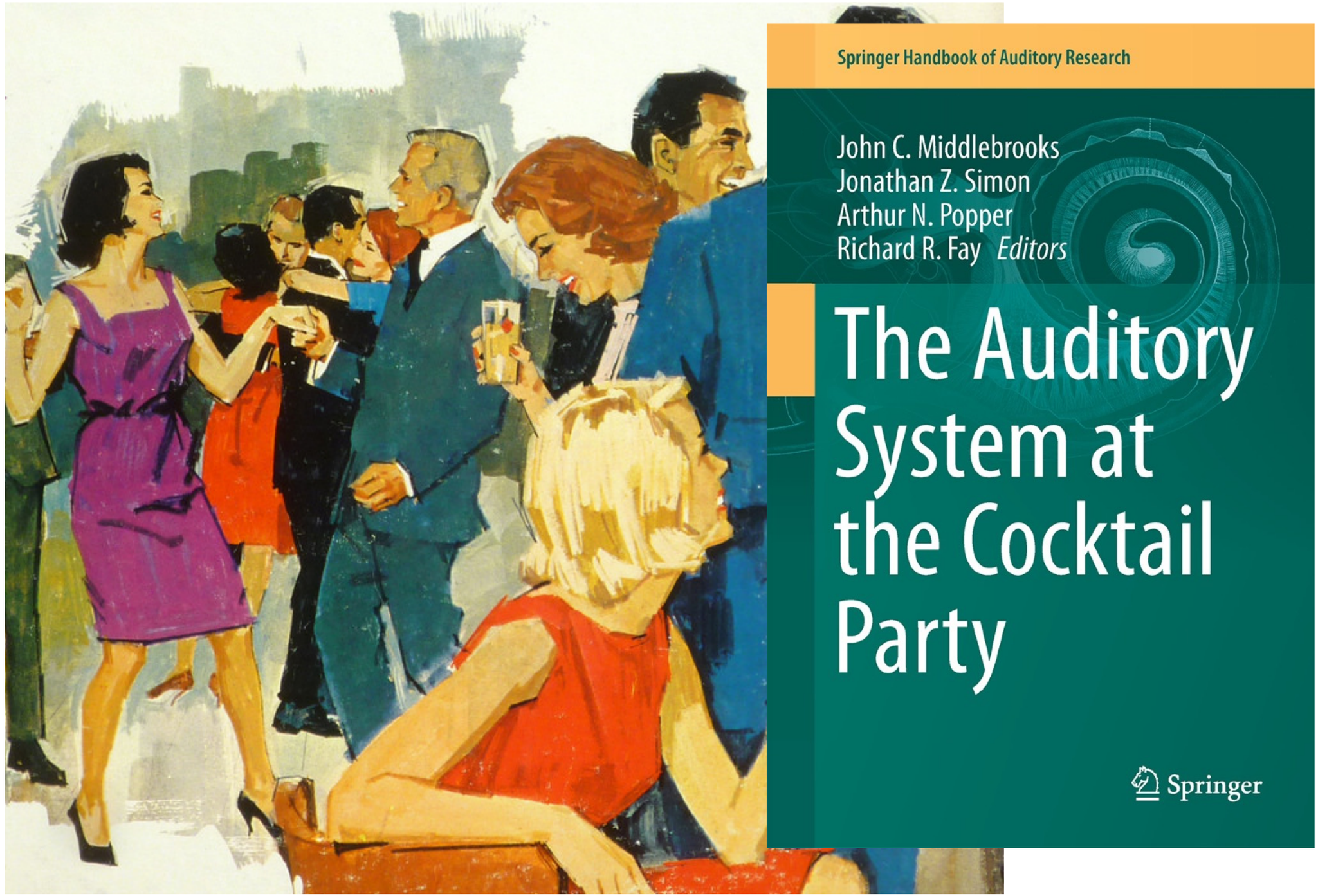
- Intelligibility linked to response in Delta band

Cortical Speech Representations

- Neural Representations: Encoding & Decoding
- Linear models: Useful & Robust
- Speech **Envelope** only
- Envelope Rates: ~ 1 - 10 Hz
- Intelligibility linked to lower range of frequencies (Delta)

Listening to Speech at the Cocktail Party

Listening to Speech at the Cocktail Party

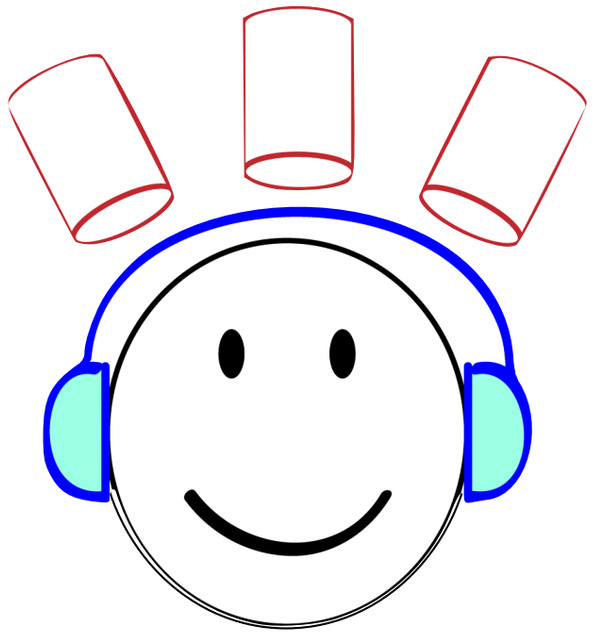


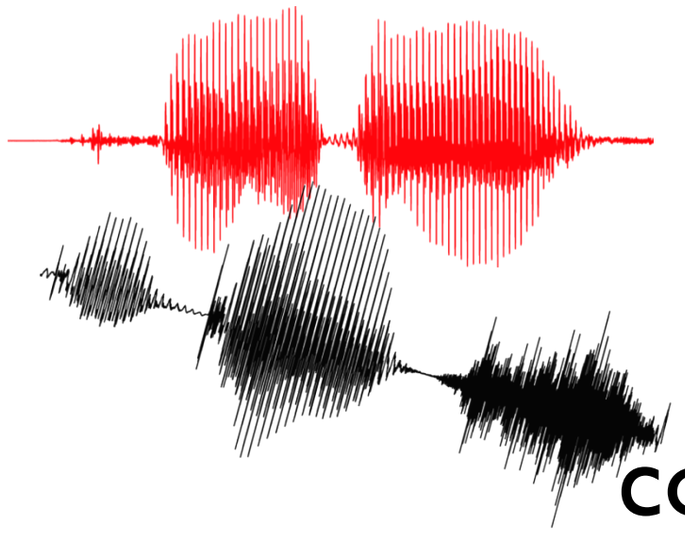
Listening to Speech at the Cocktail Party

Listening to Speech at the Cocktail Party

Listening to Speech at the Cocktail Party

Two Competing Speakers

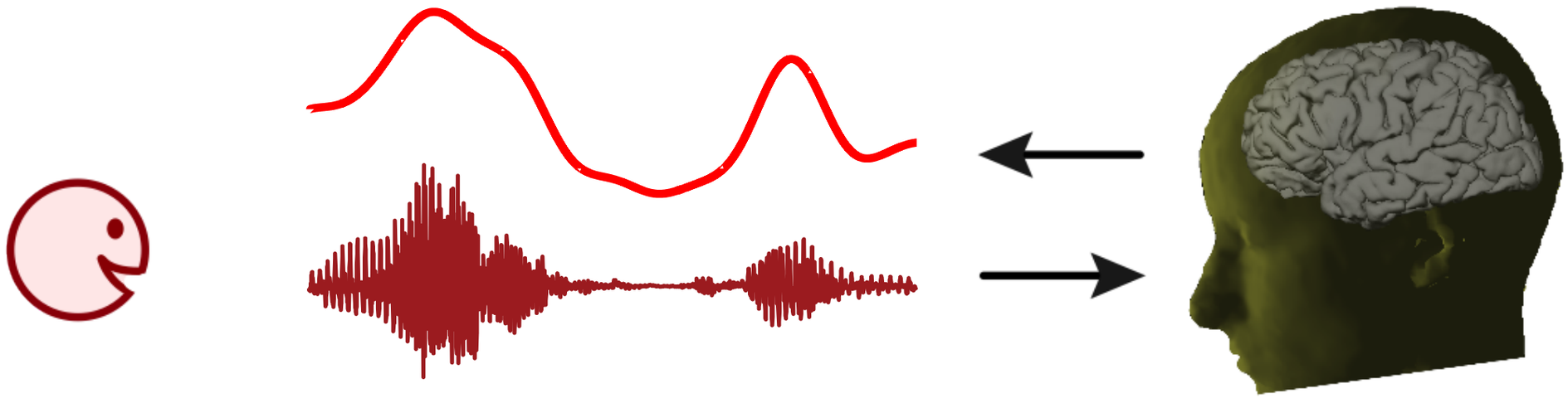




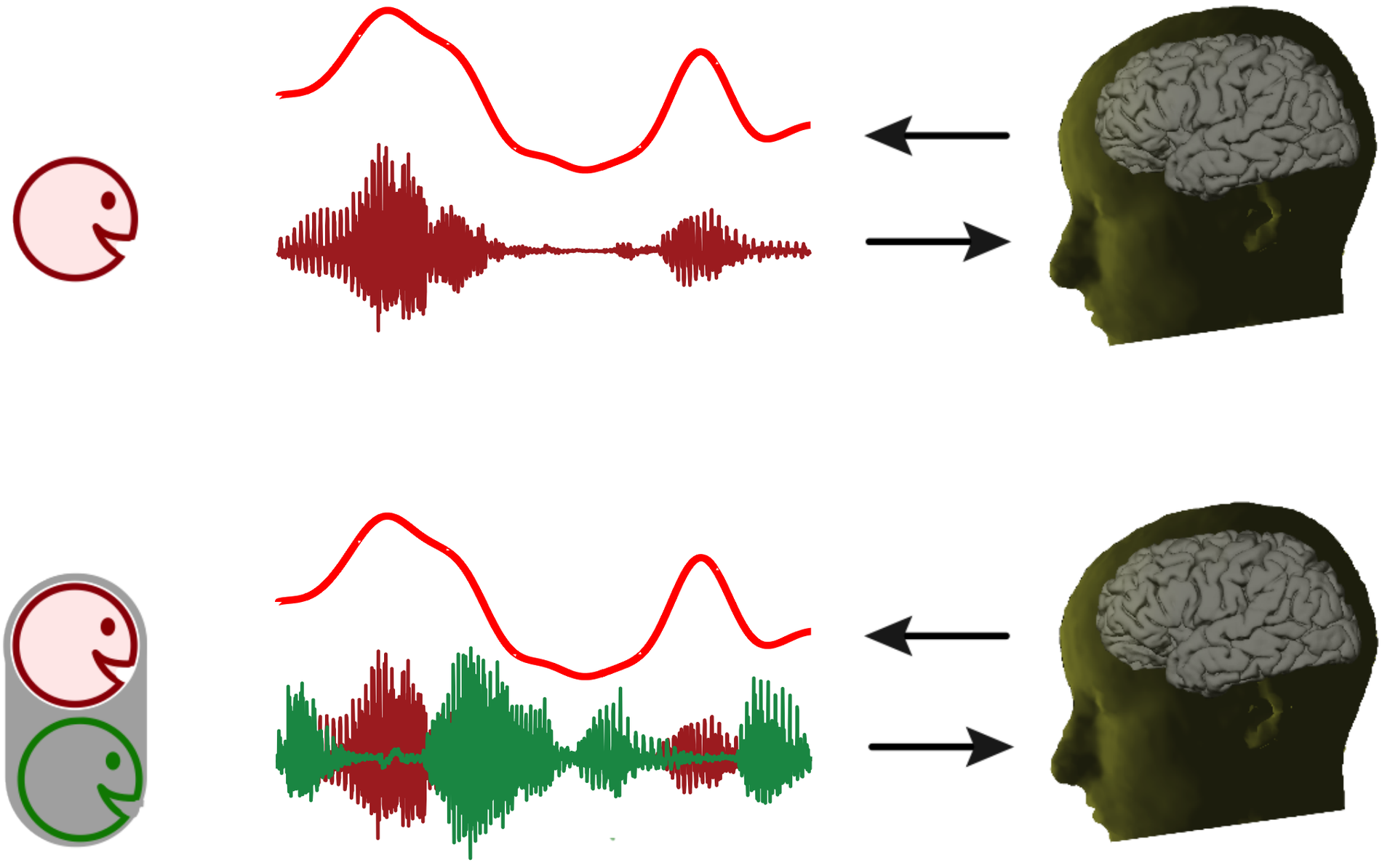
speech

competing speech

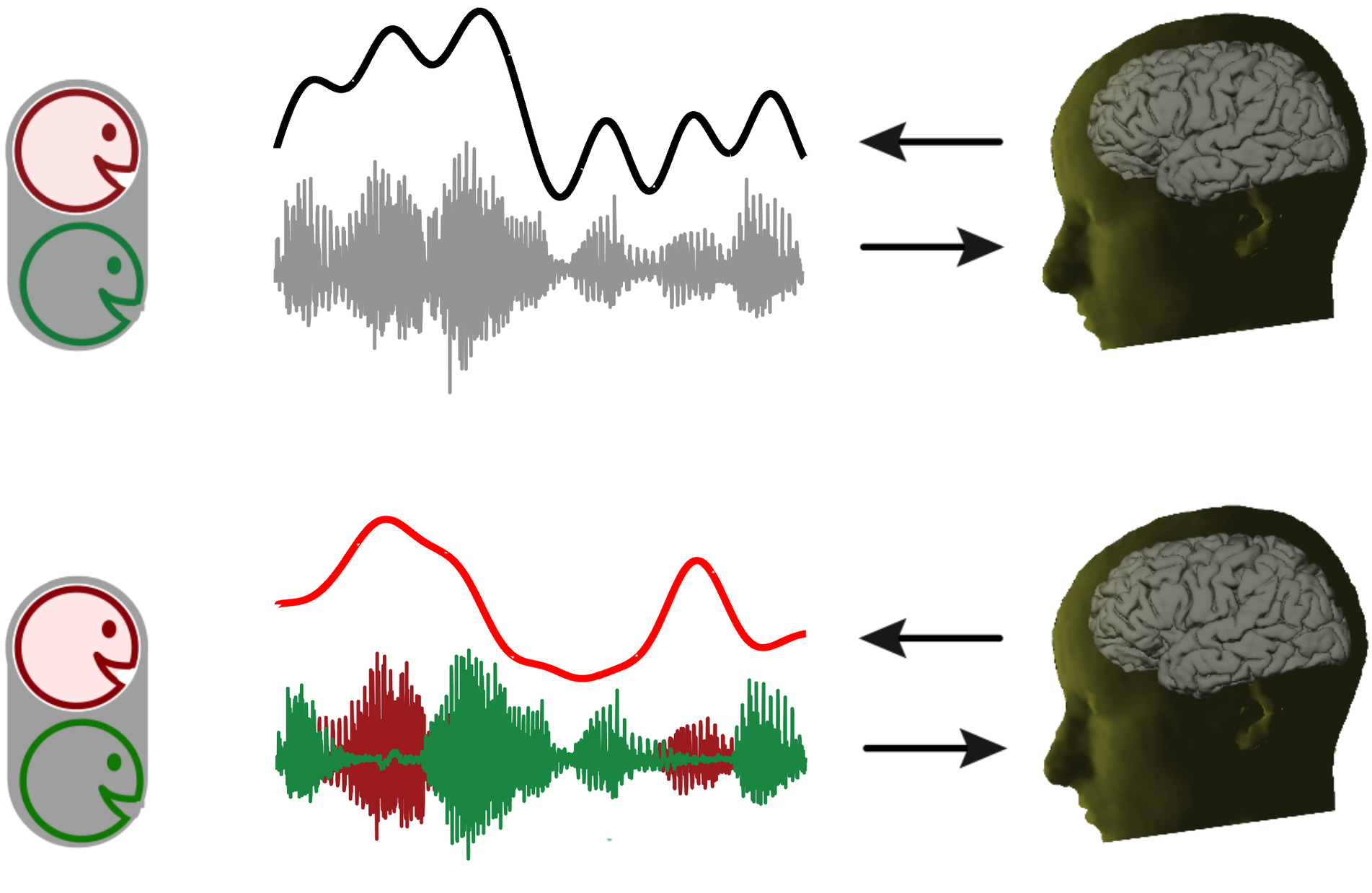
Selective Neural Encoding



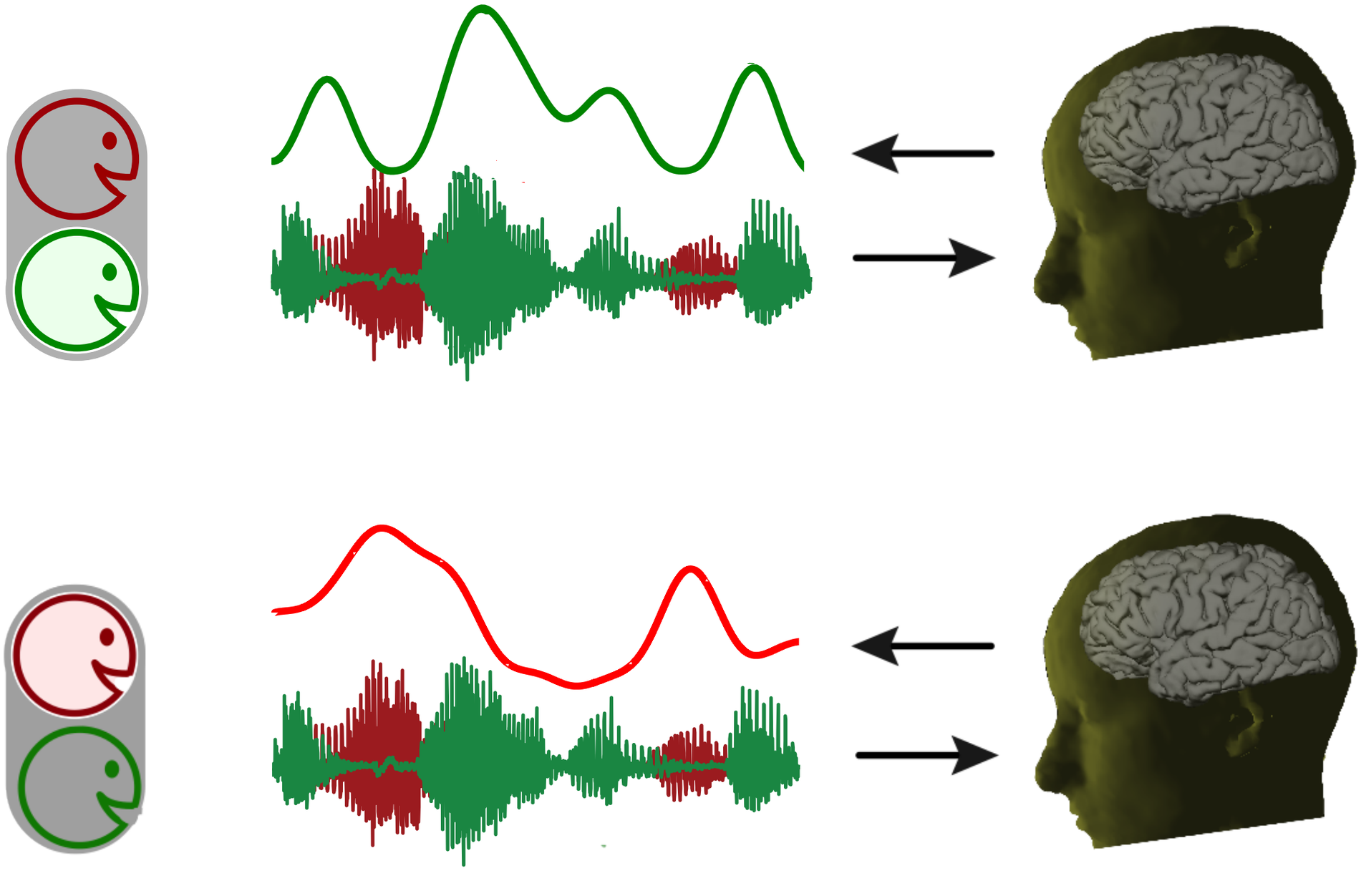
Selective Neural Encoding



Unselective vs. Selective Neural Encoding

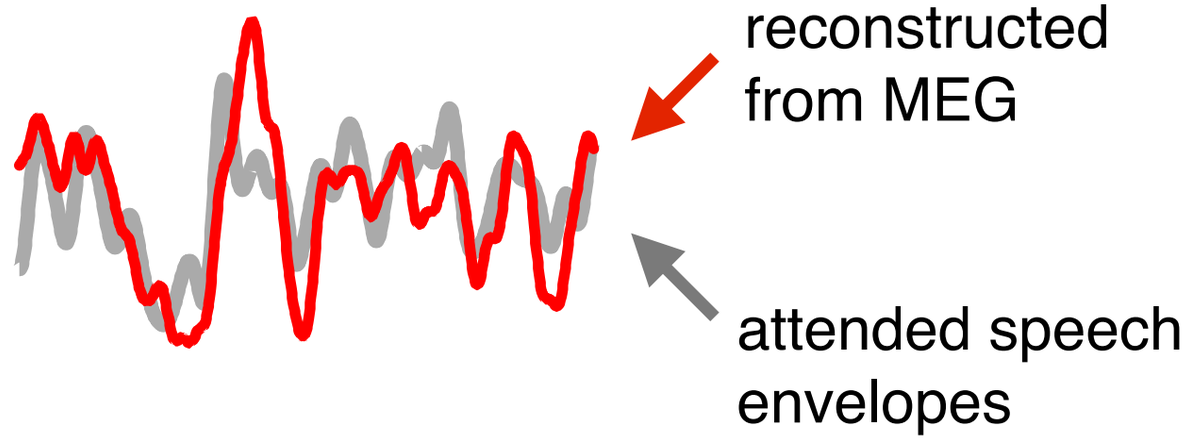


Selective Neural Encoding



Stream-Specific Representation

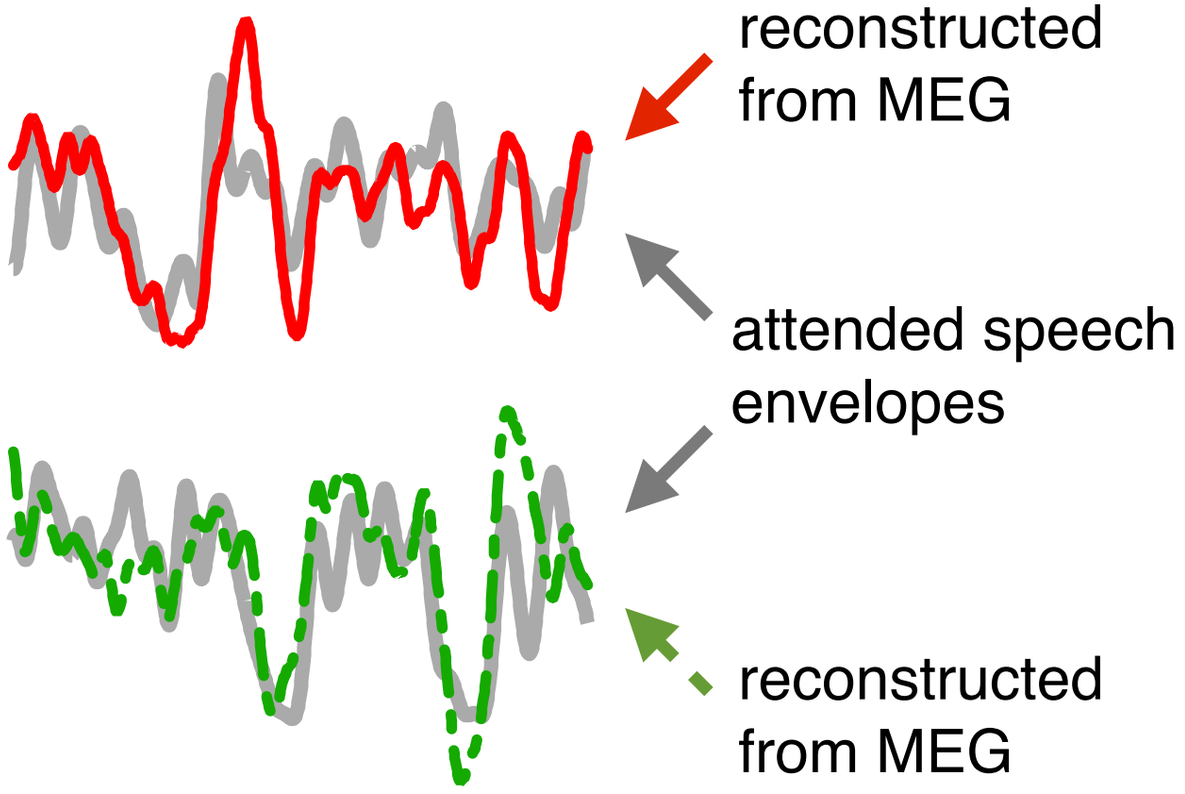
attending to speaker 1



Stream-Specific Representation

attending to speaker 1

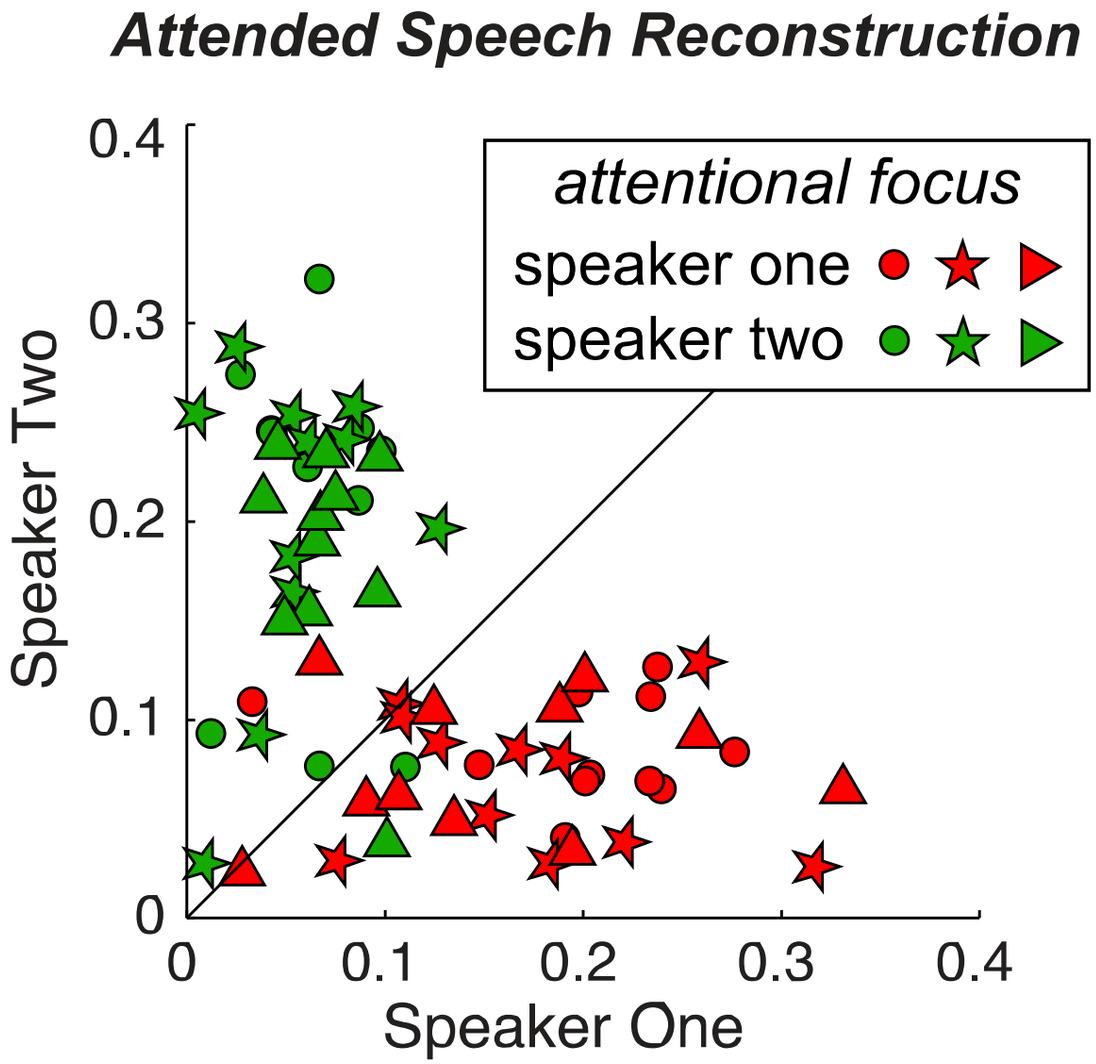
attending to speaker 2



Identical Stimuli!

Ding & Simon, PNAS (2012)

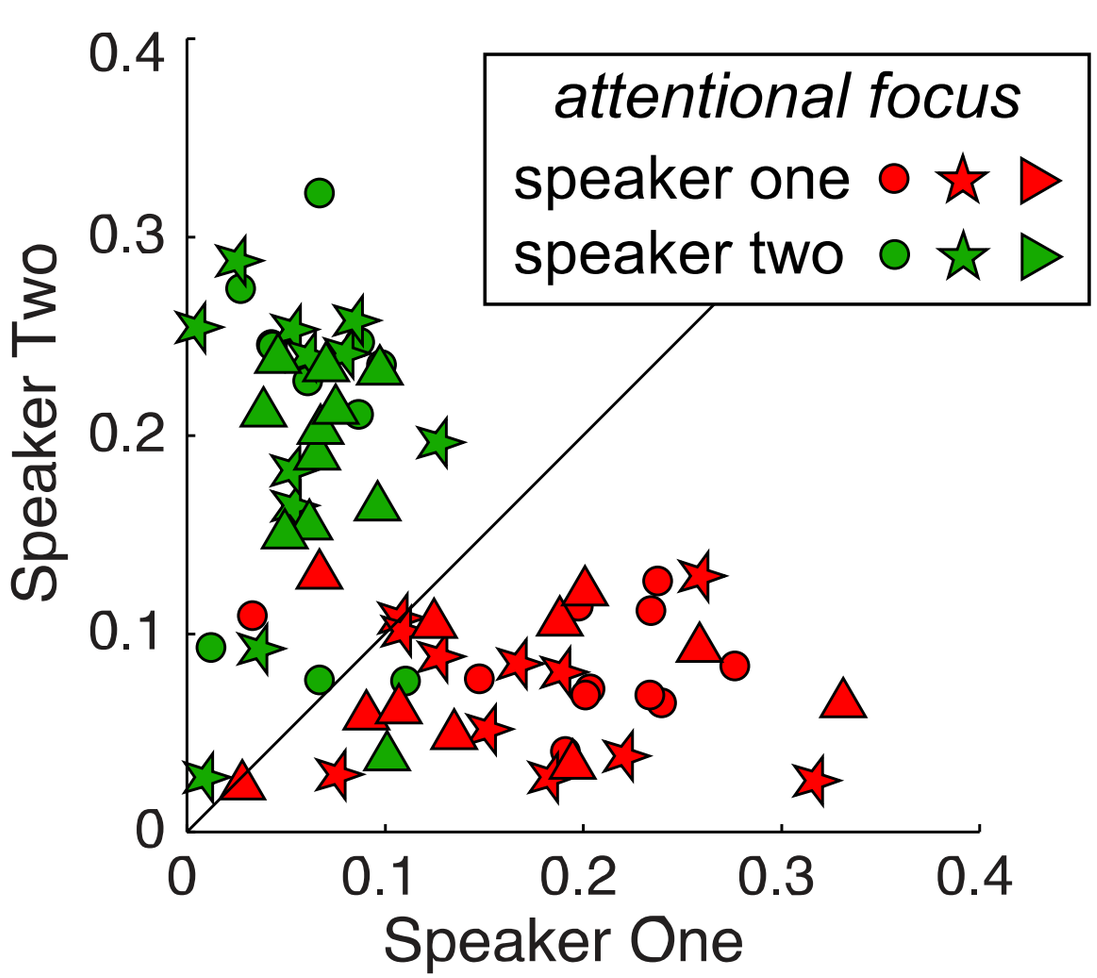
Single Trial Speech Reconstruction



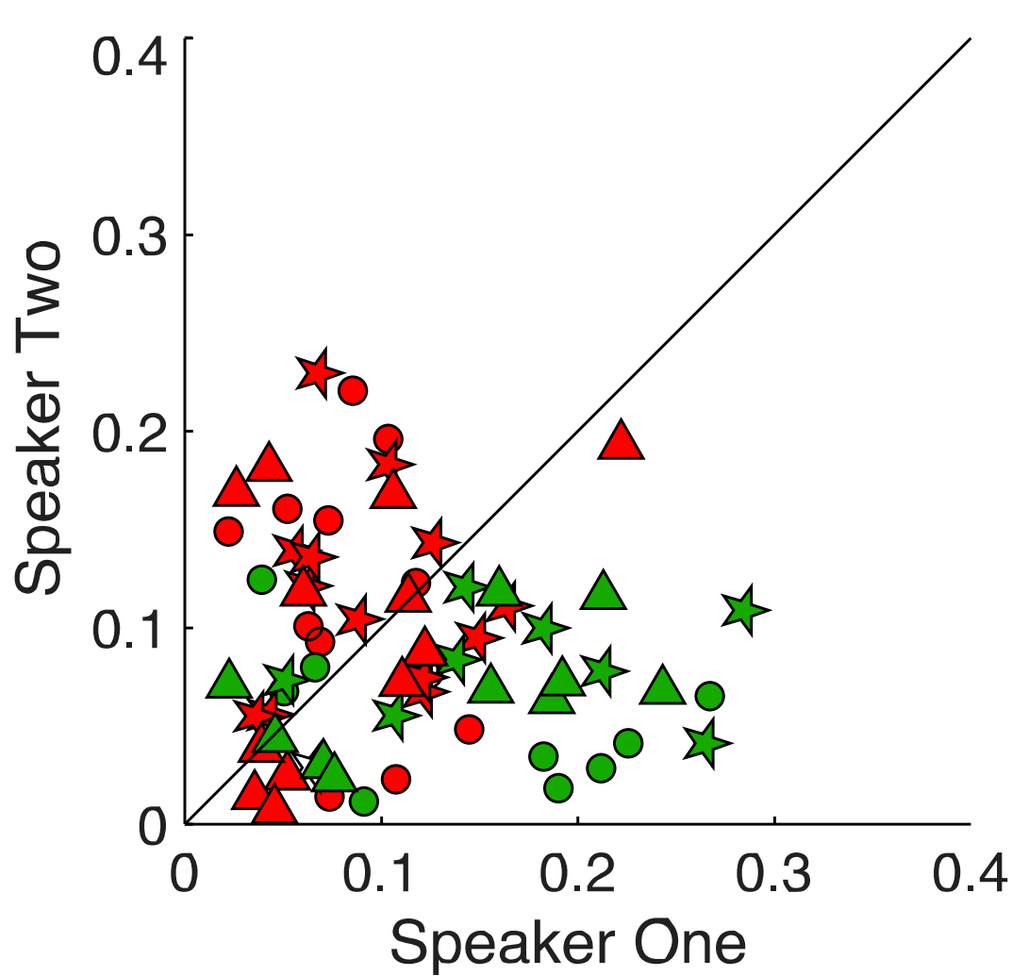
Ding & Simon, PNAS (2012)

Single Trial Speech Reconstruction

Attended Speech Reconstruction

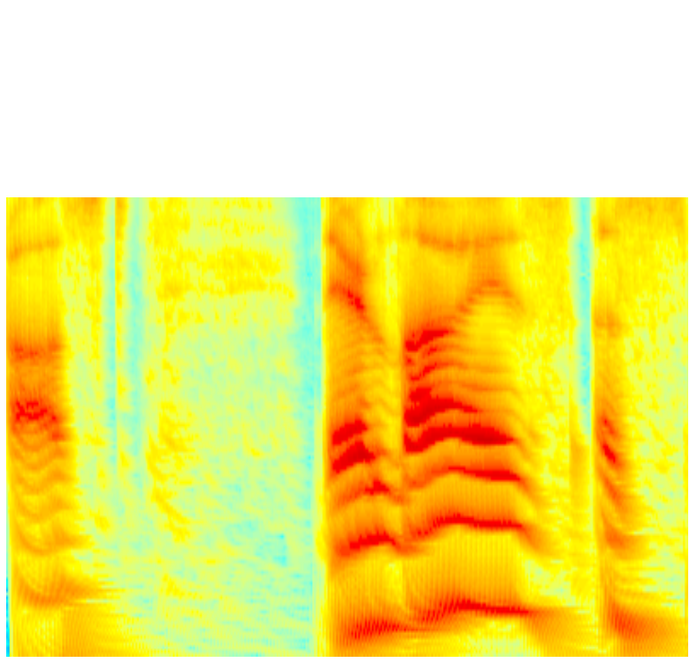


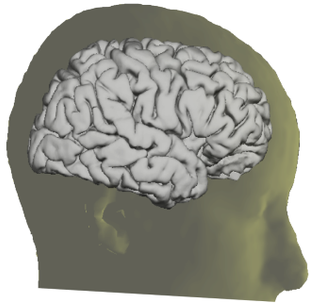
Background Speech Reconstruction

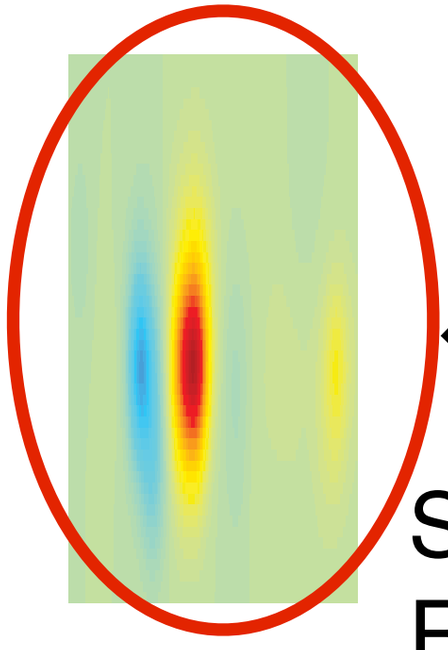


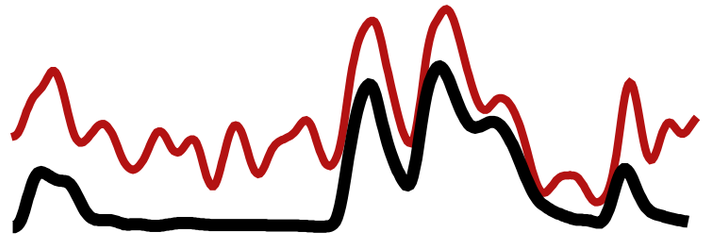
Ding & Simon, PNAS (2012)

Forward STRF Model



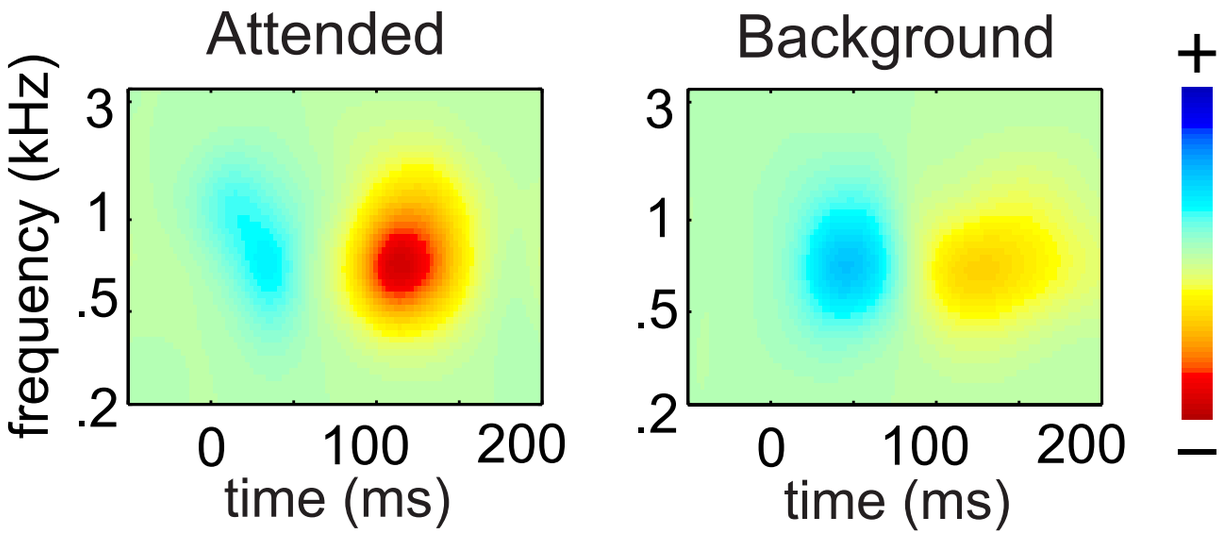






Spectro-Temporal
Response Function
(STRF)

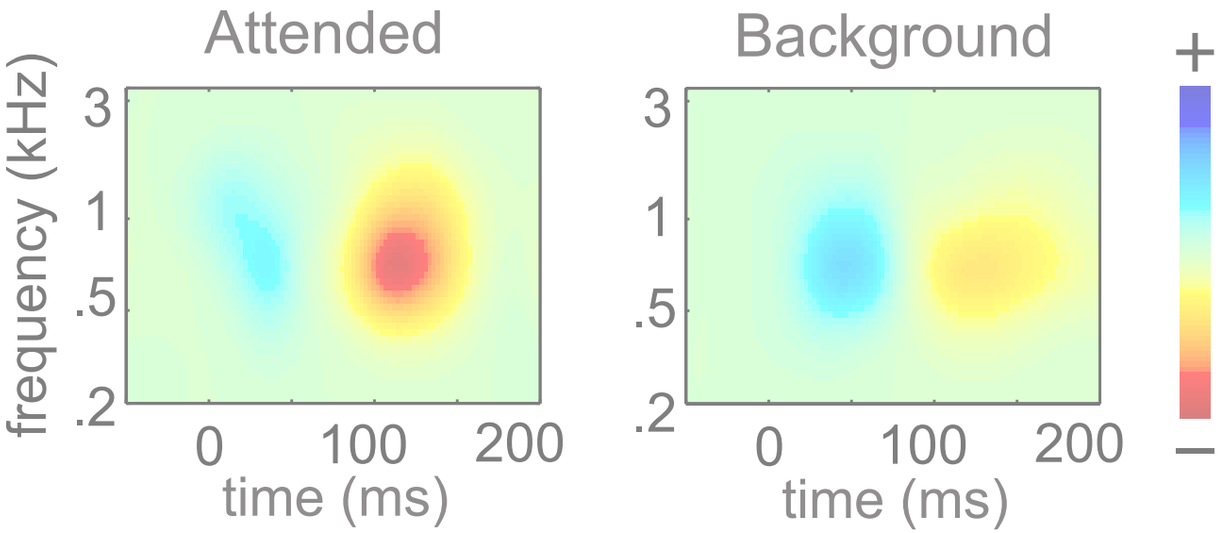
STRF Results

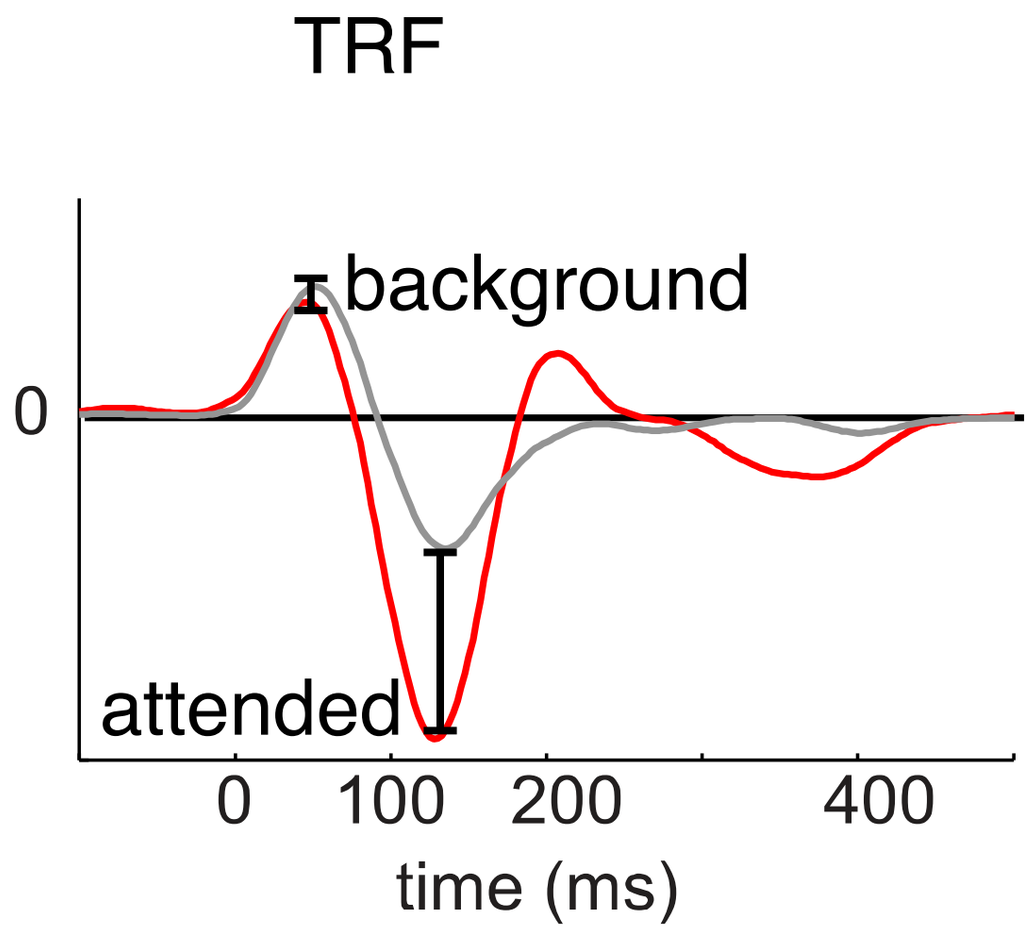


- STRF separable (time, frequency)
- 300 Hz - 2 kHz dominant carriers
- $M50_{STRF}$ positive peak
- $M100_{STRF}$ negative peak

Ding & Simon, PNAS (2012)

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 $M50_{STRF}$***

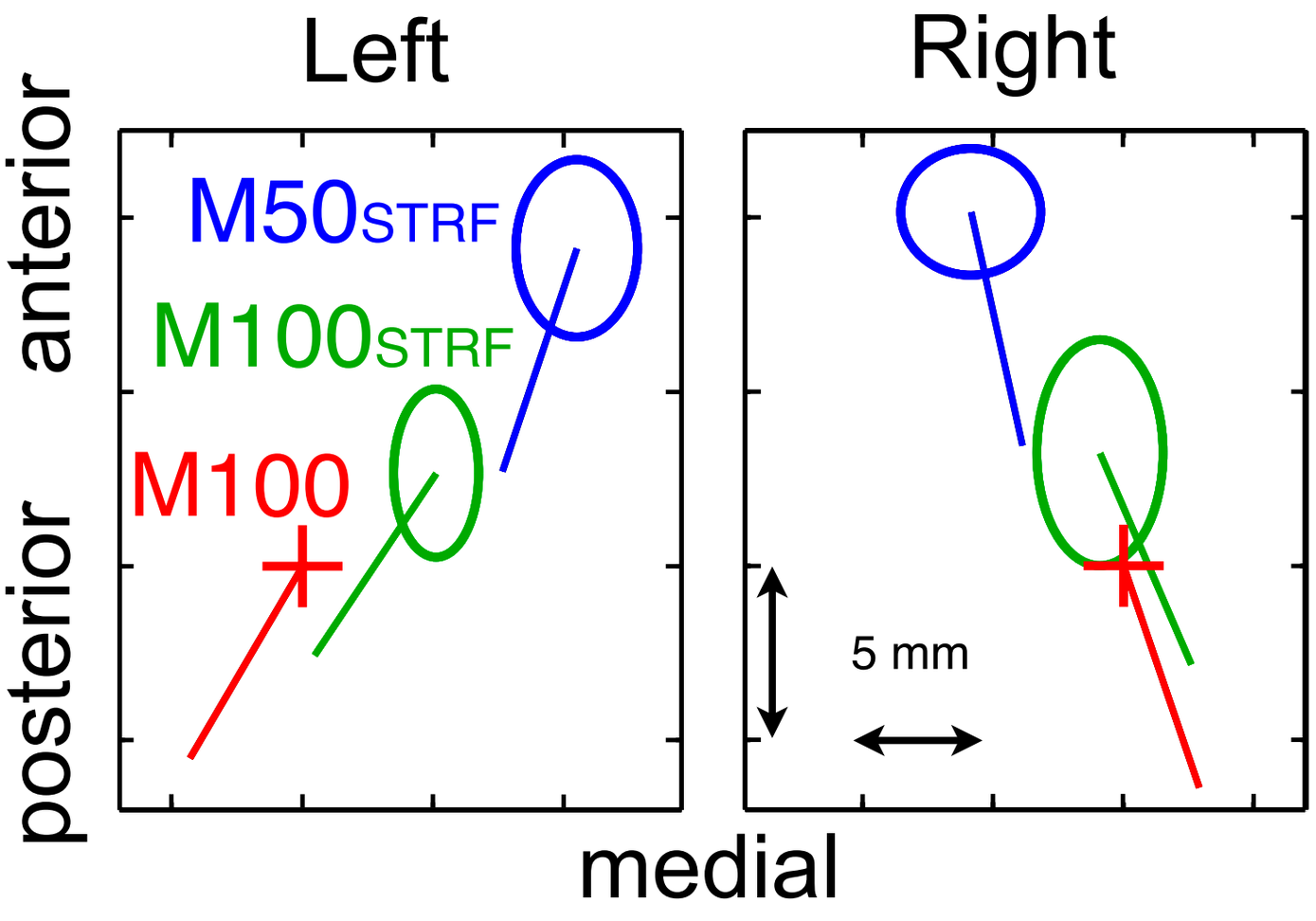
Ding & Simon, PNAS (2012)

Neural Sources

- **$M100_{STRF}$** source near (same as?) M100 source:
  Planum Temporale

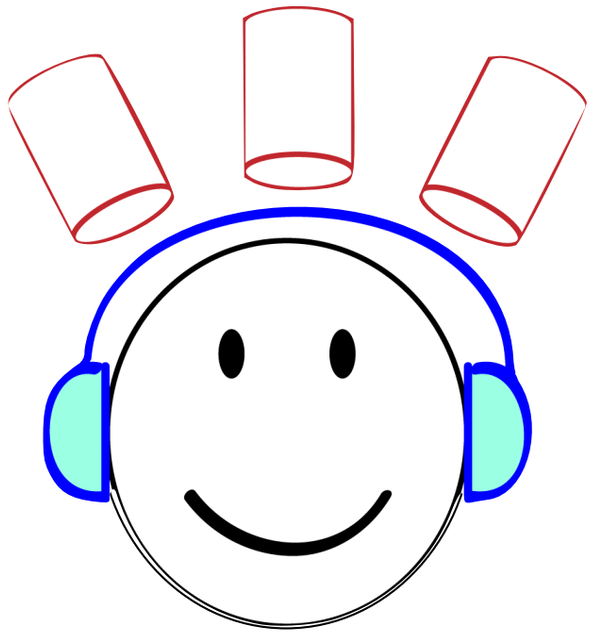
- **$M50_{STRF}$** source is anterior and medial to M100 (same as M50?):
  Heschl's Gyrus

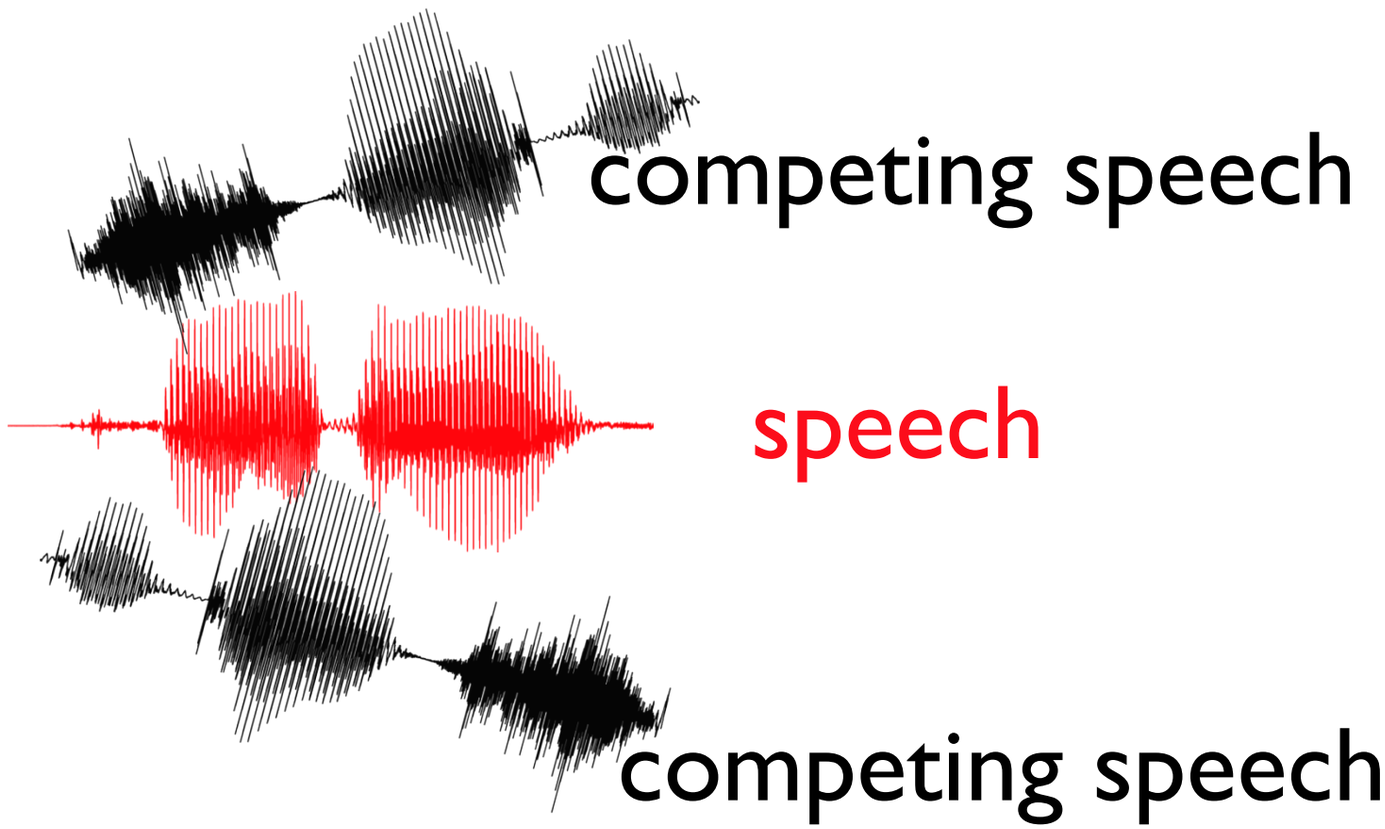
- **PT strongly affected by attention, *but not HG***



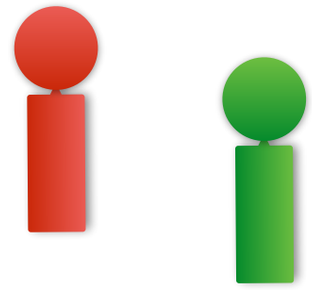
Ding & Simon, PNAS (2012)

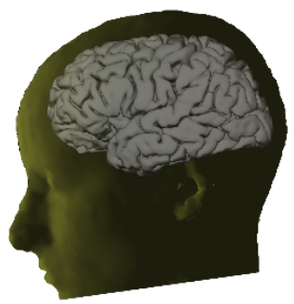
Three Competing Speakers





Foreground vs. Background





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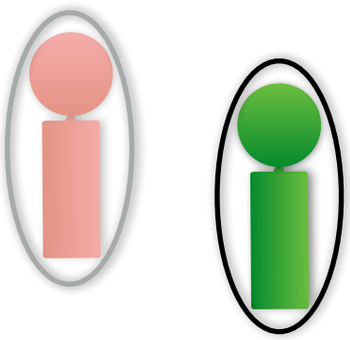

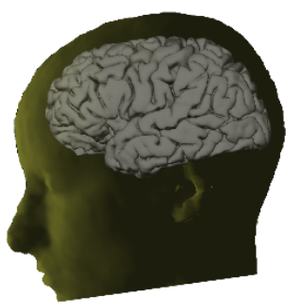

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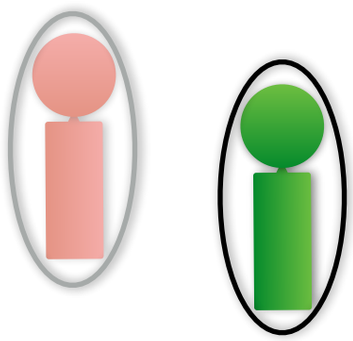

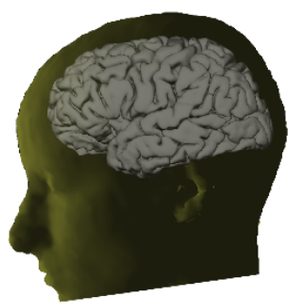

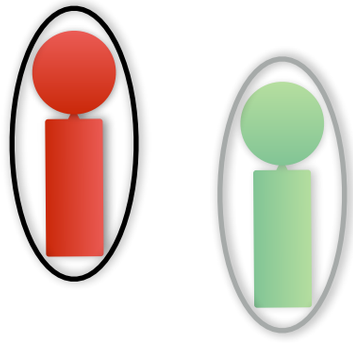

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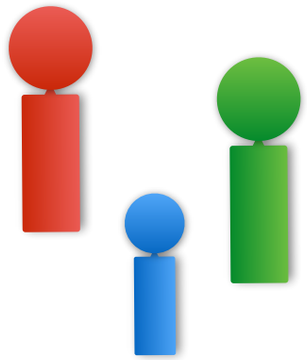

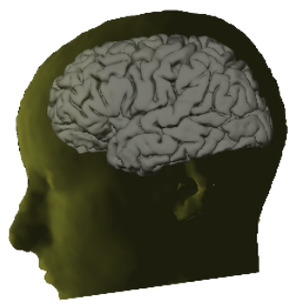

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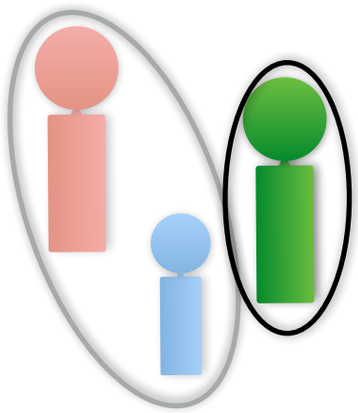

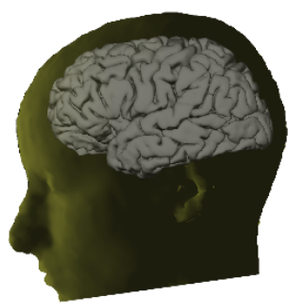

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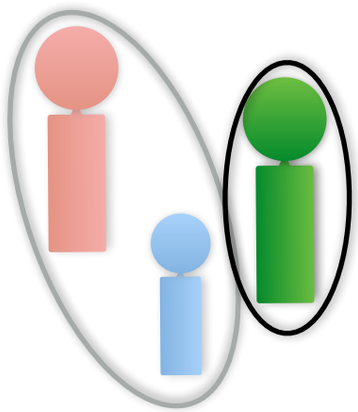
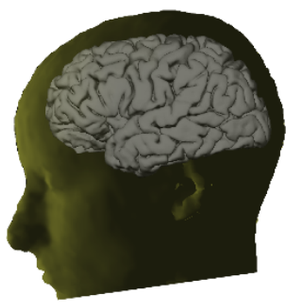
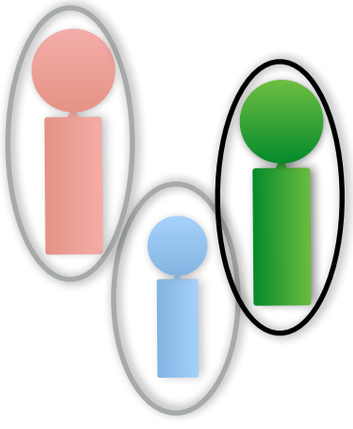
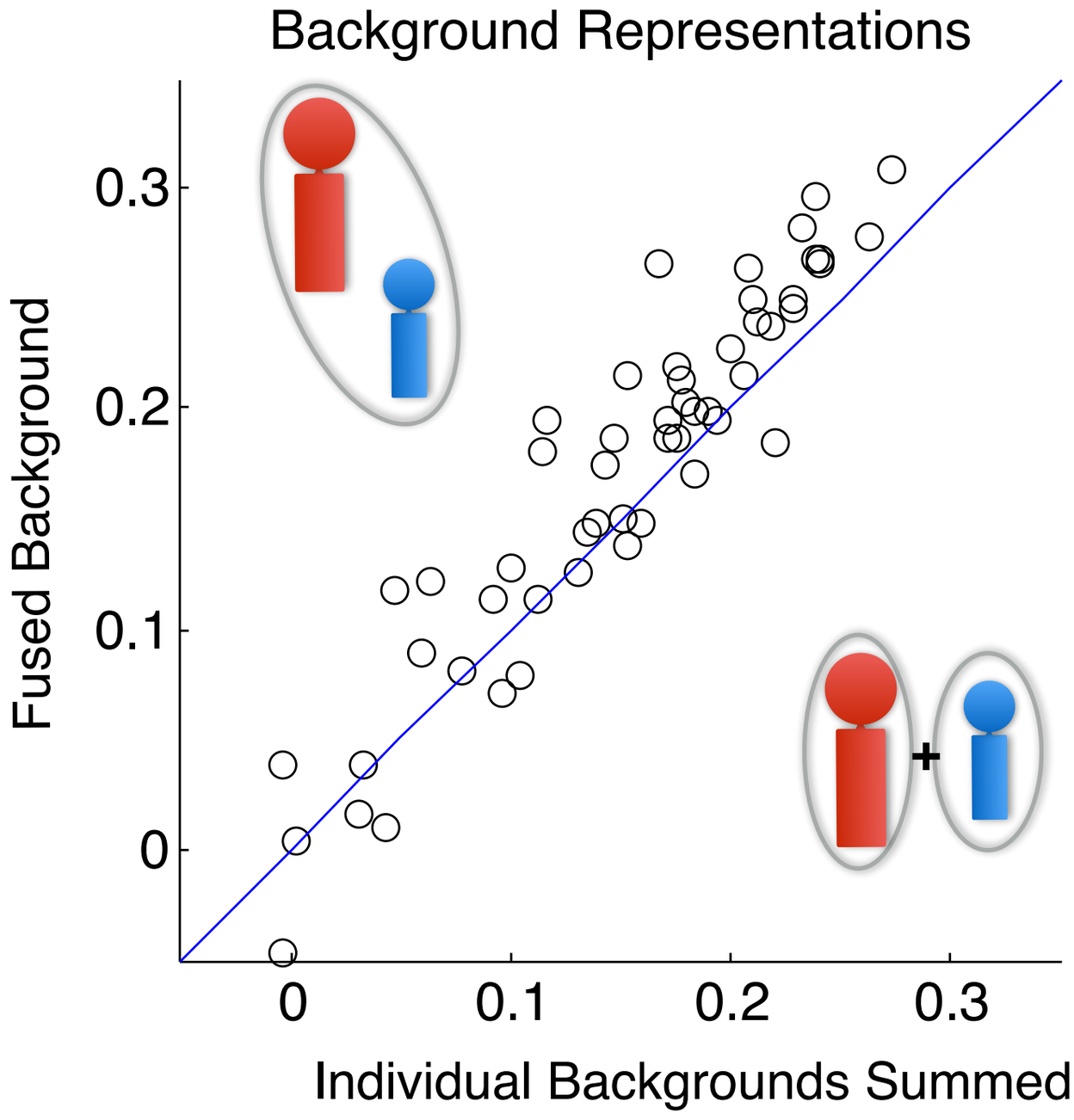






Backgrounds vs. Background

Integration Window
Late Times Only



Puvvada & Simon, J Neurosci (2017)

Backgrounds vs. Background

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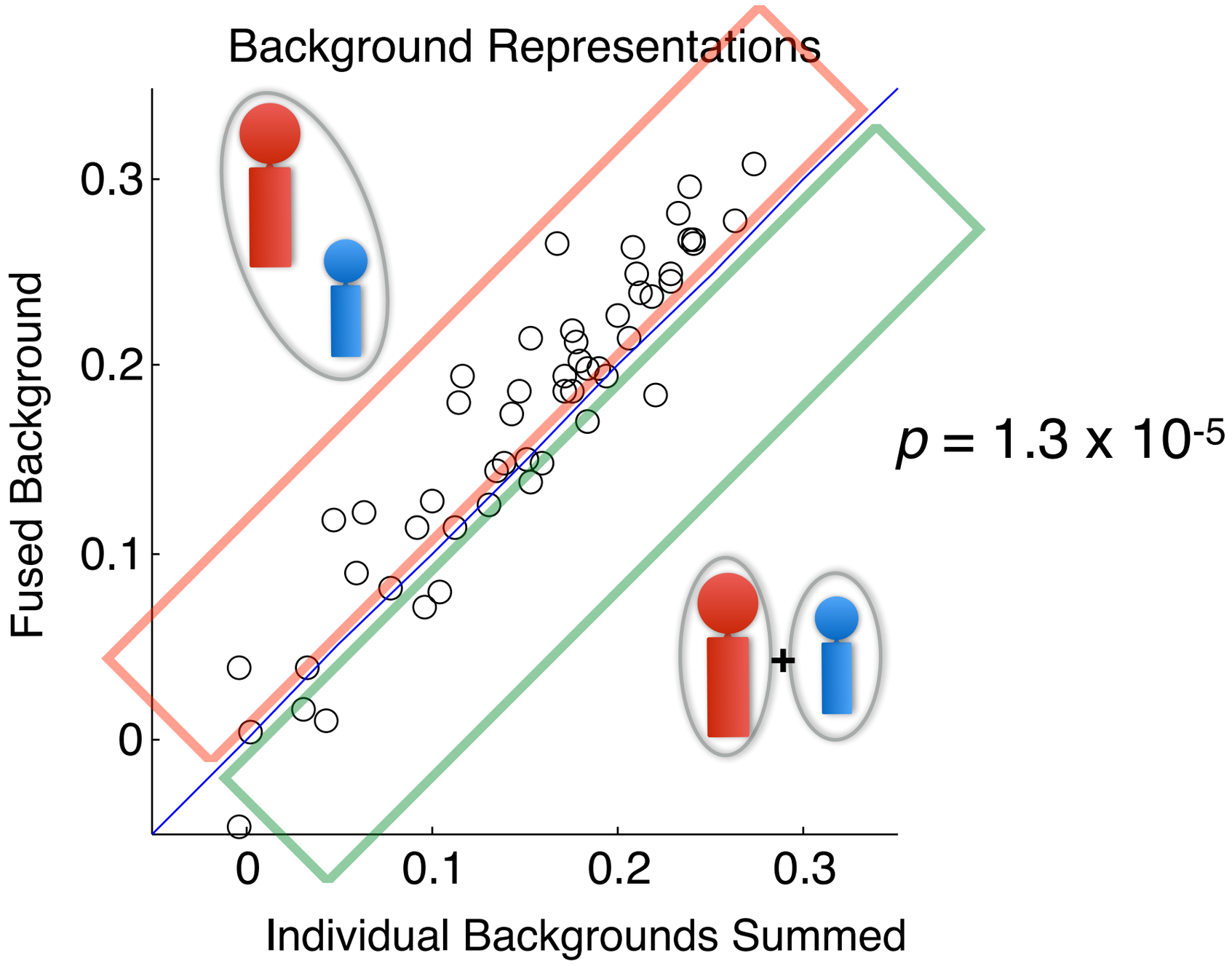
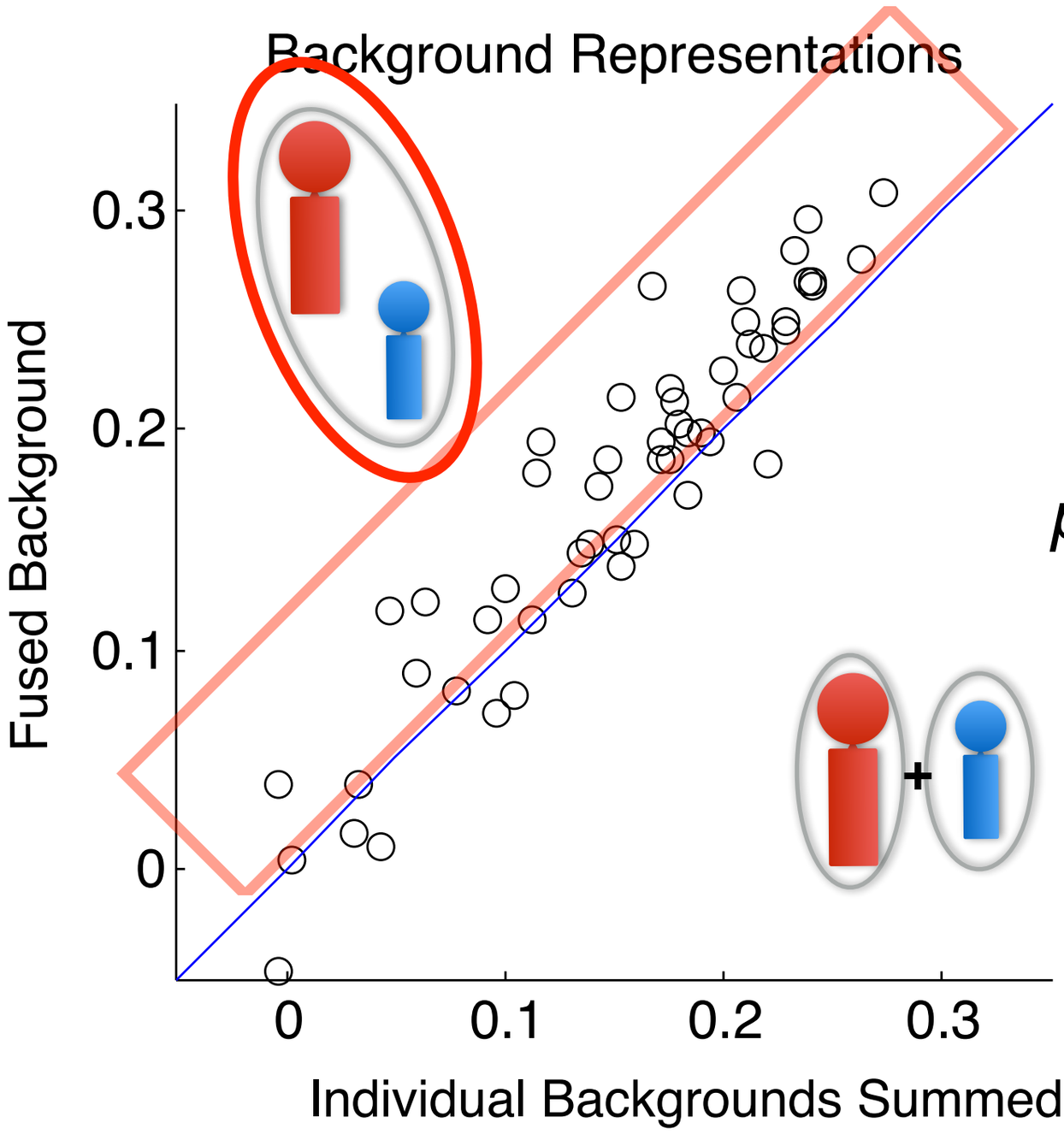


Puvvada & Simon, J Neurosci (2017)

Backgrounds vs. Background

Integration Window
Late Times Only

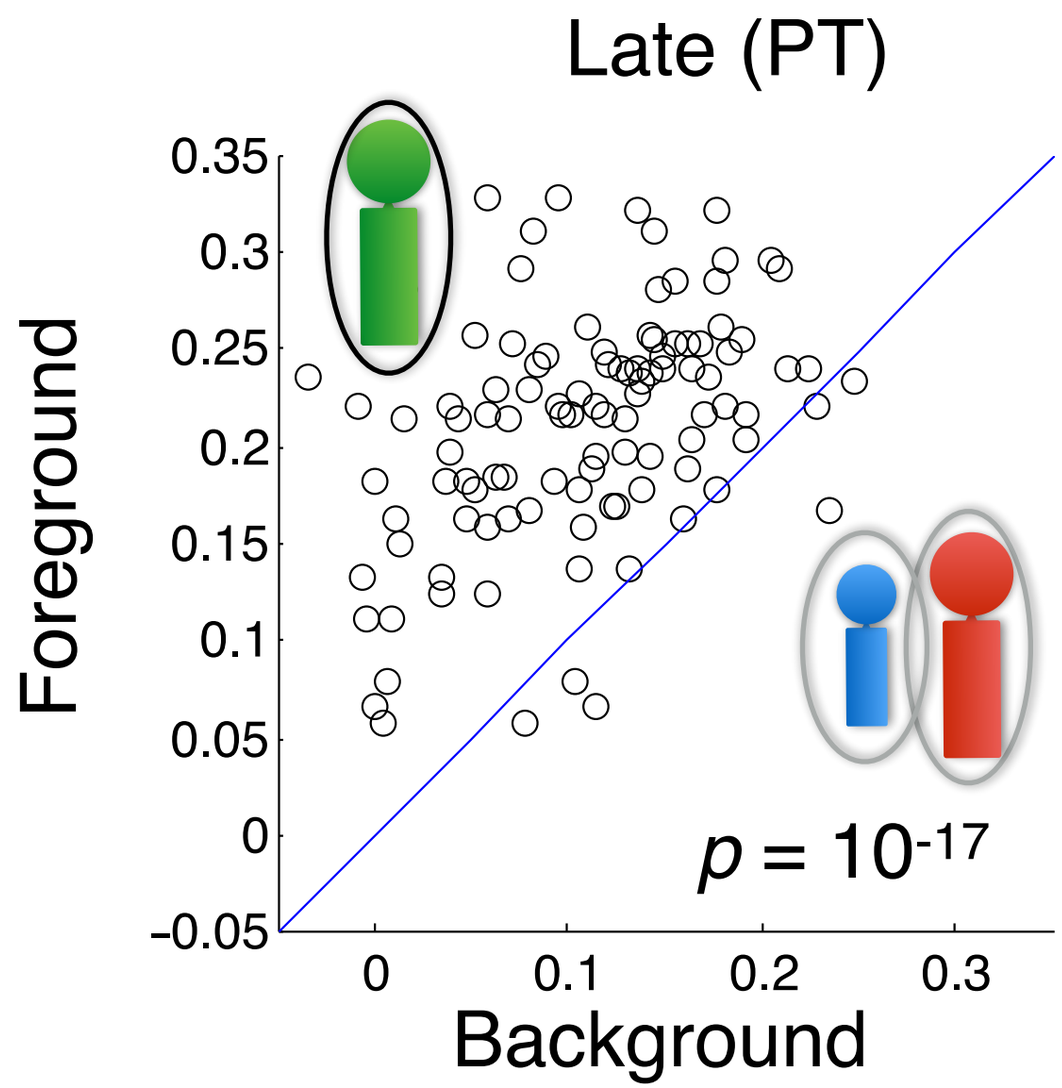
High latency areas (PT) represent ***fused*** background with better fidelity than ***individual*** backgrounds



$p = 1.3 \times 10^{-5}$

Puvvada & Simon, J Neurosci (2017)

Foreground vs. Background
Early vs. Late



Puvvada & Simon, J Neurosci (2017)

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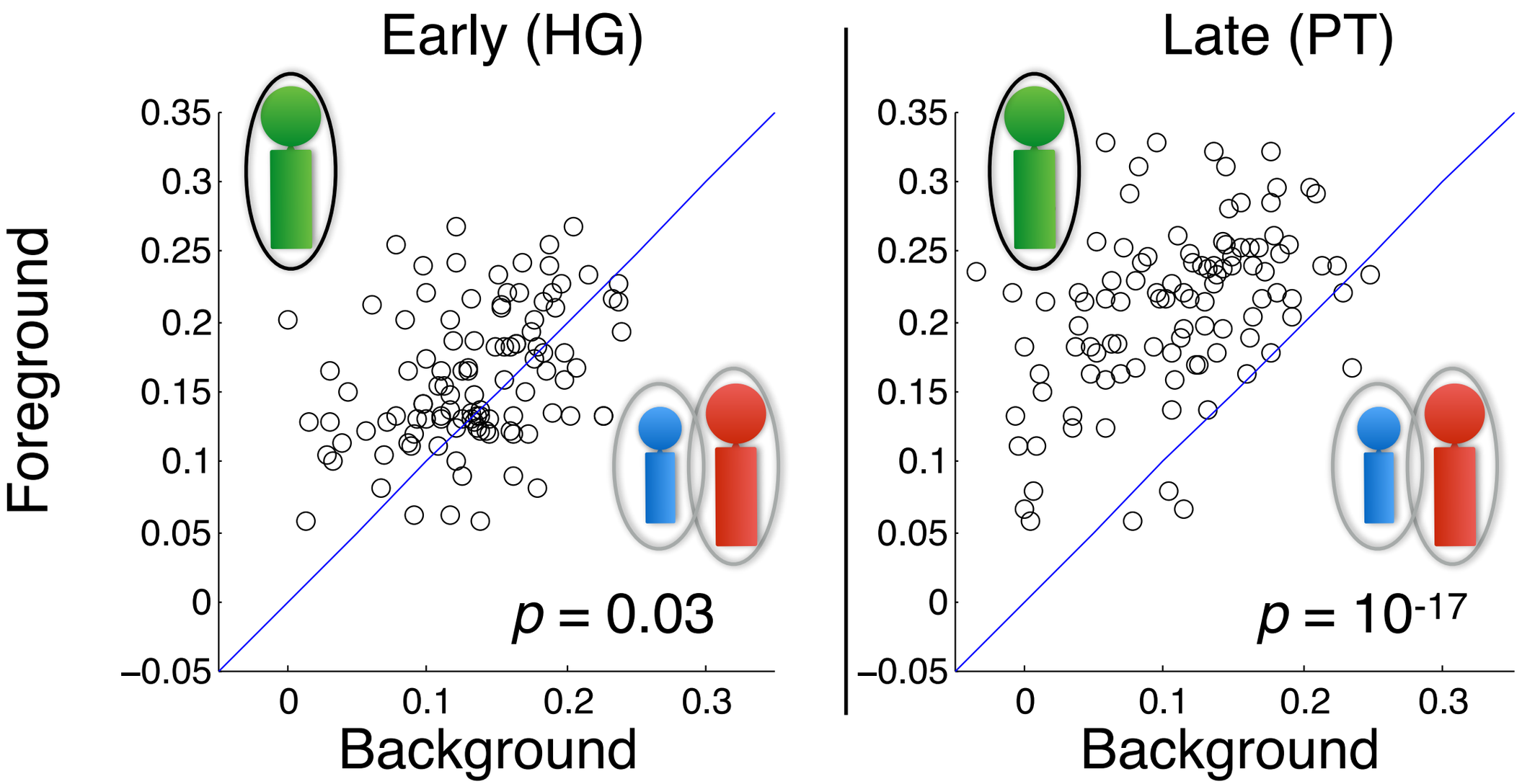
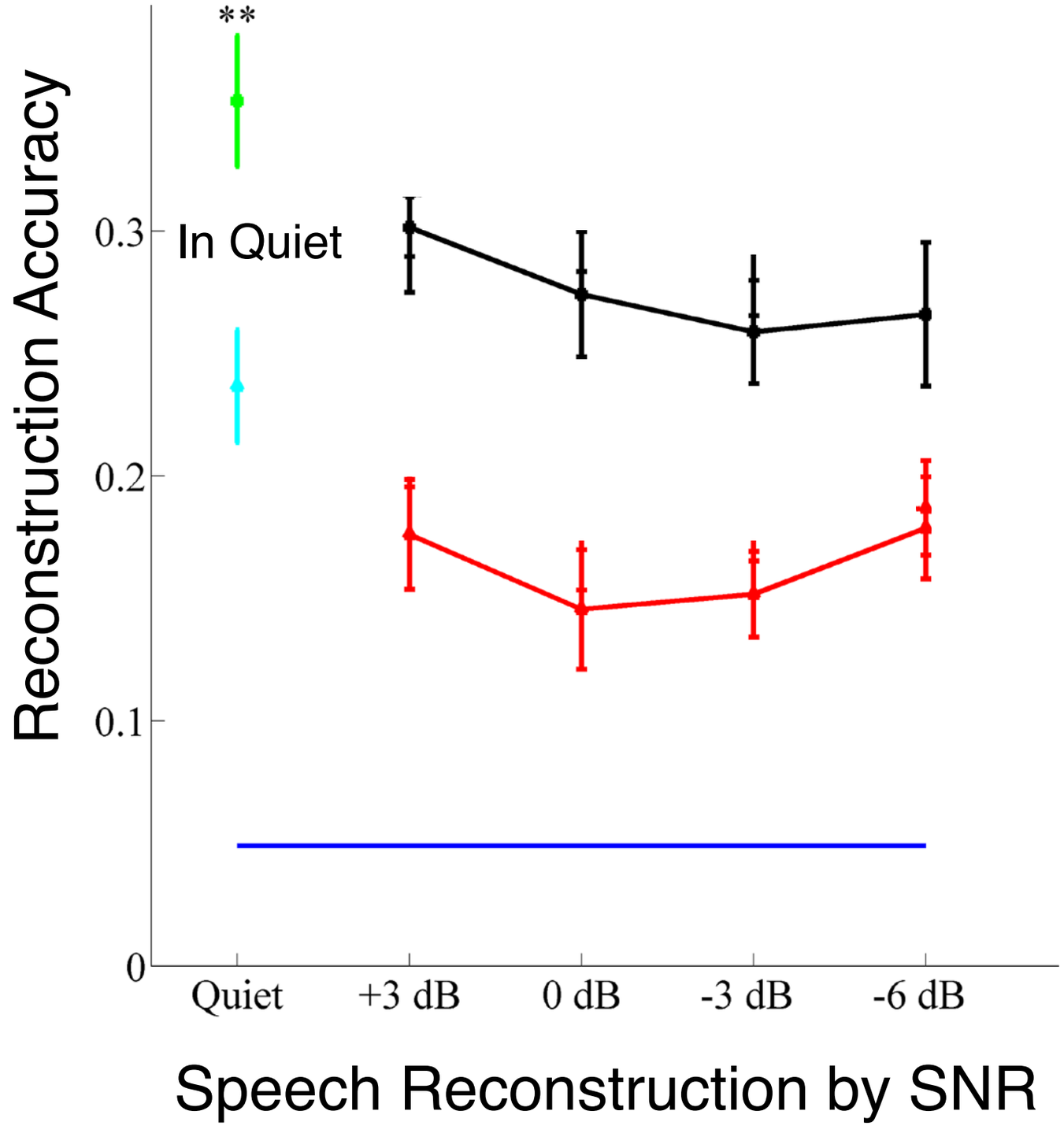
Early vs. Late



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

Puvvada & Simon, J Neurosci (2017)

Younger vs. Older Adults



Presacco et al., J Neurophysiol (2016a)

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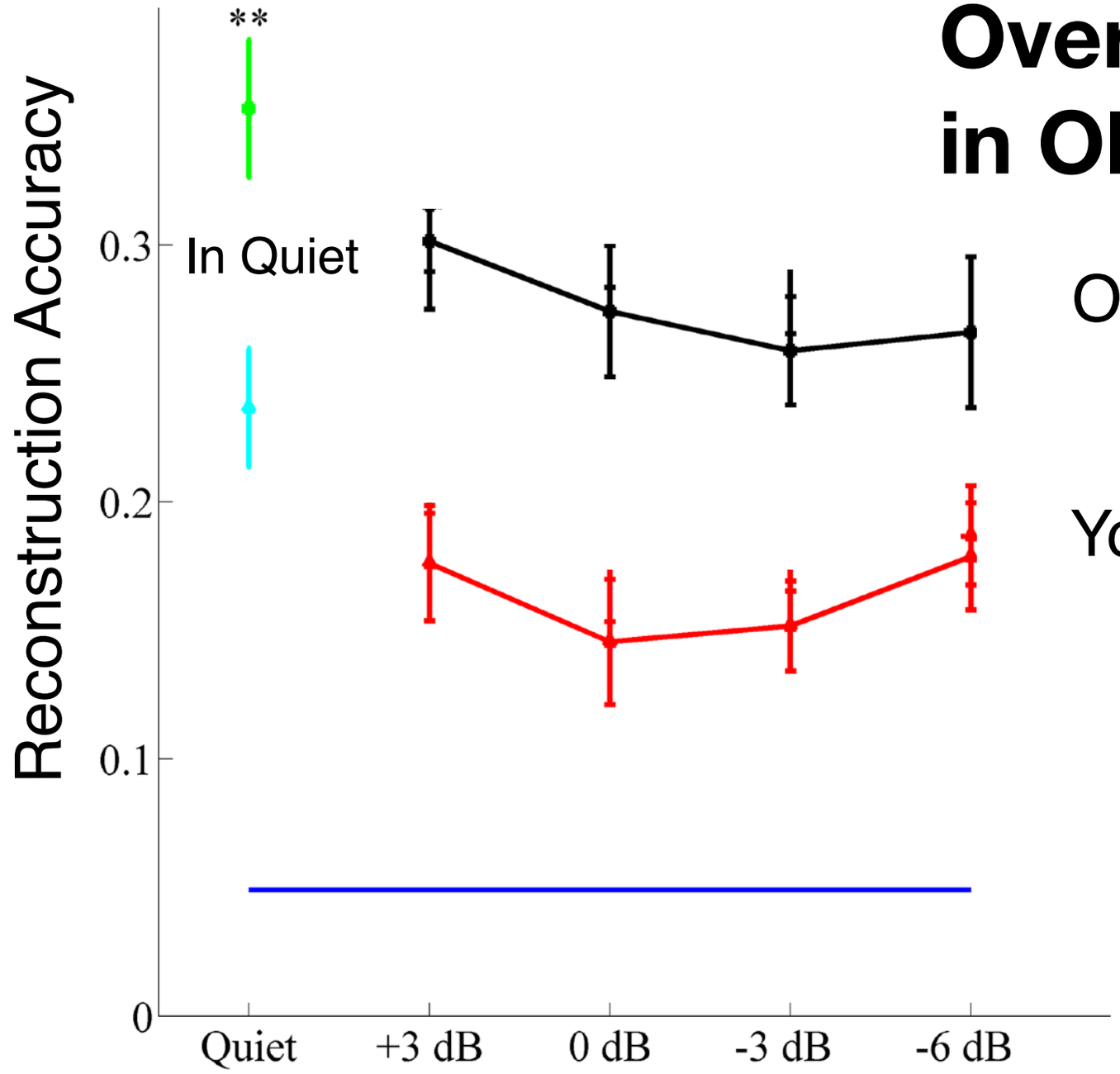


Over-Representation in Older Cortex

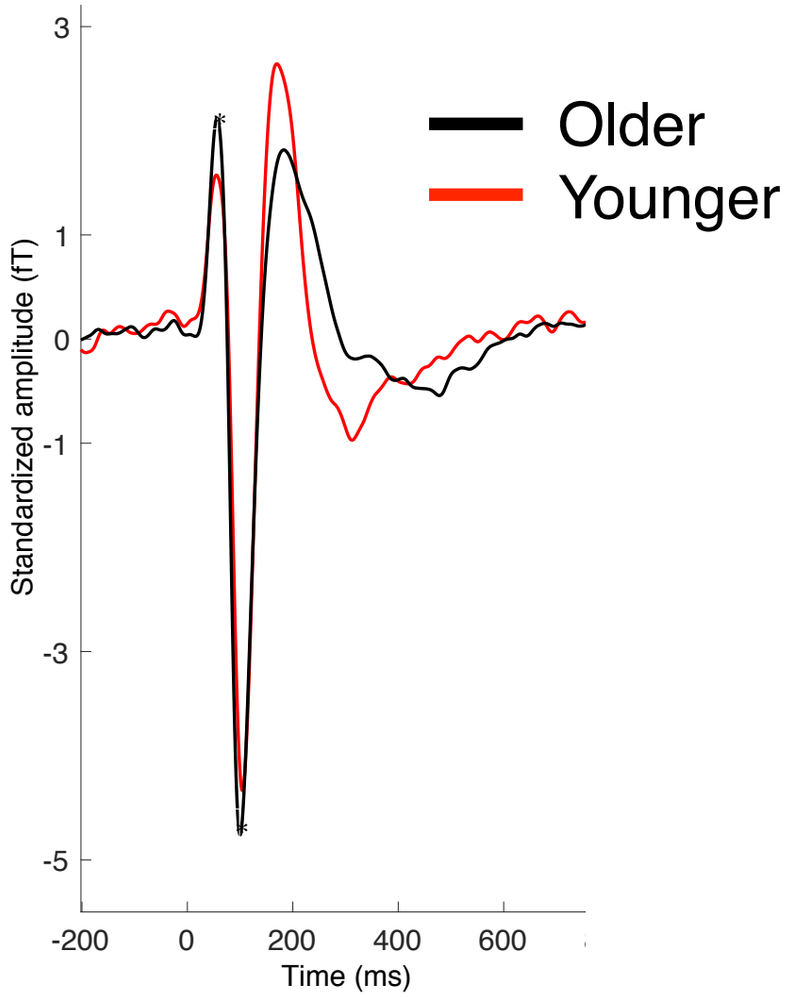
Older Adults

Younger Adults

Effect absent in Midbrain (FFR Response)

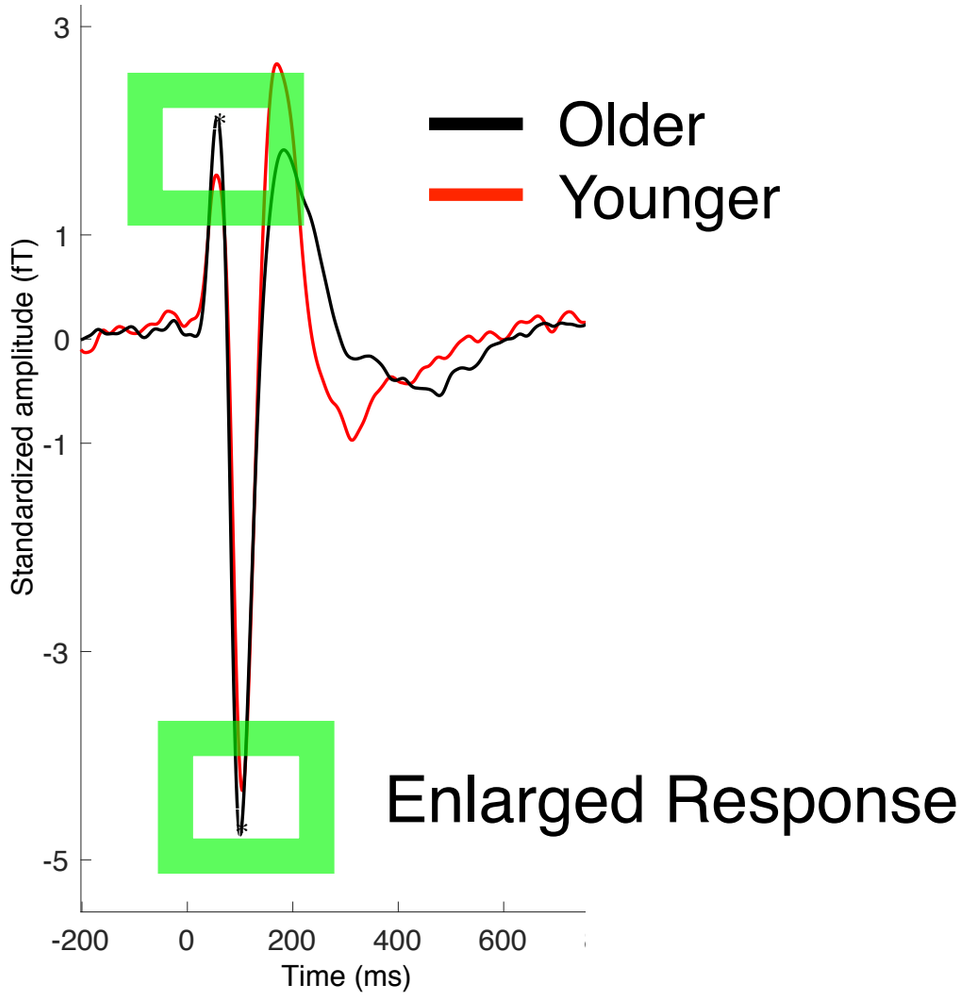
Presacco et al., J Neurophysiol (2016a)

Older Enlarged Response



Average Responses to Pure Tone

Older Enlarged Response



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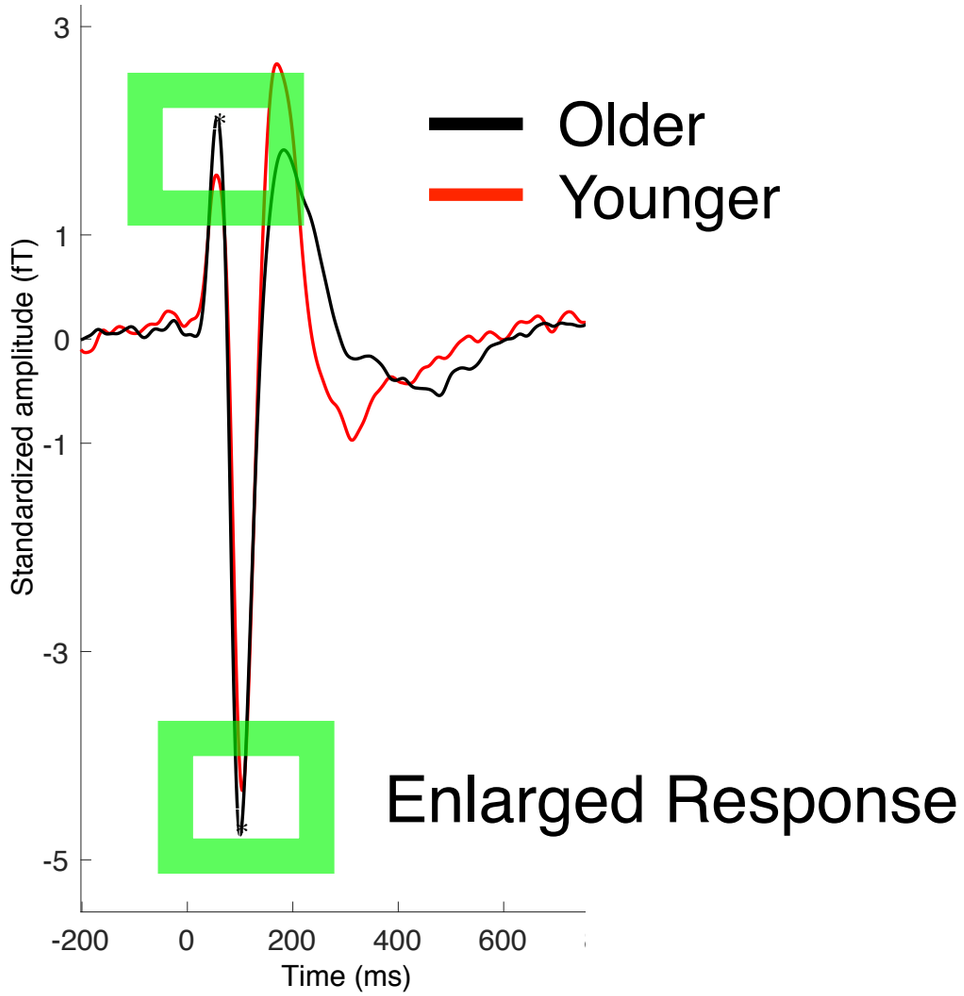
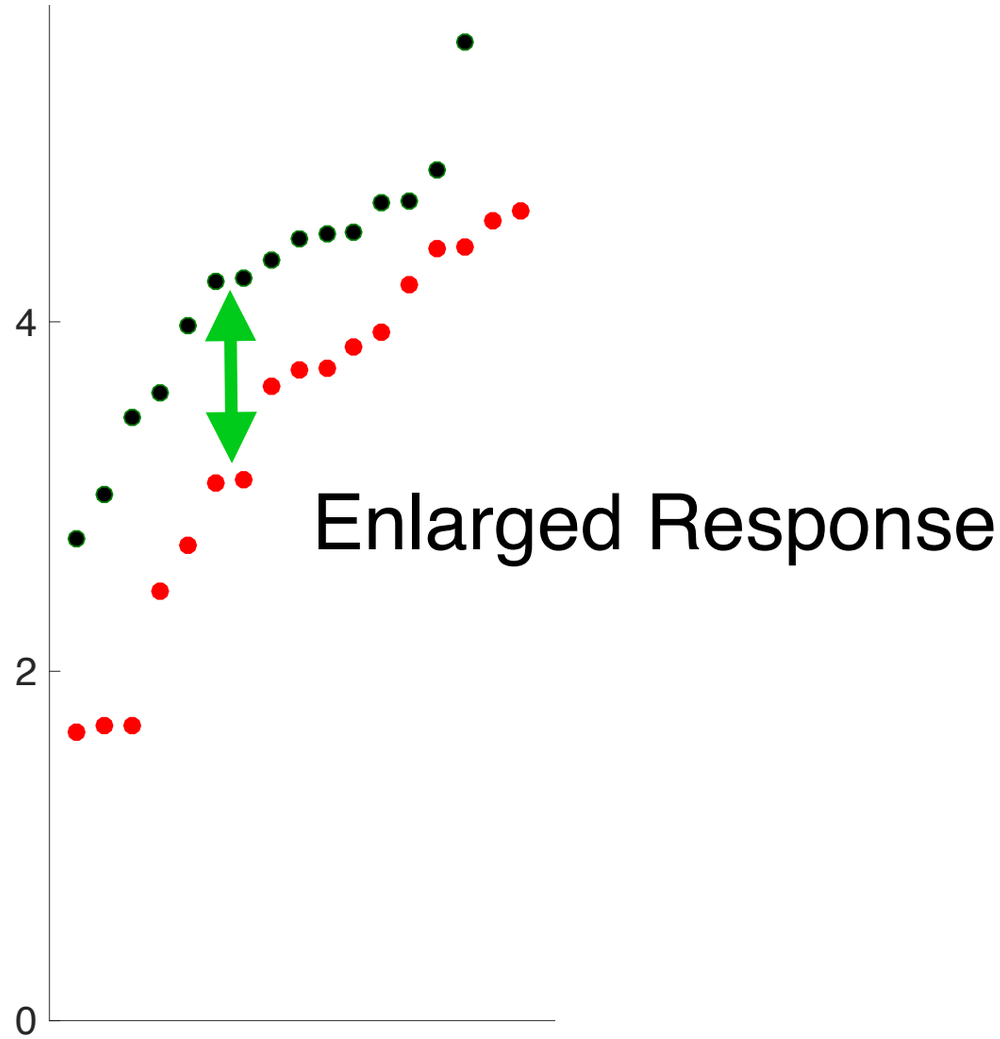


Average Responses to Pure Tone

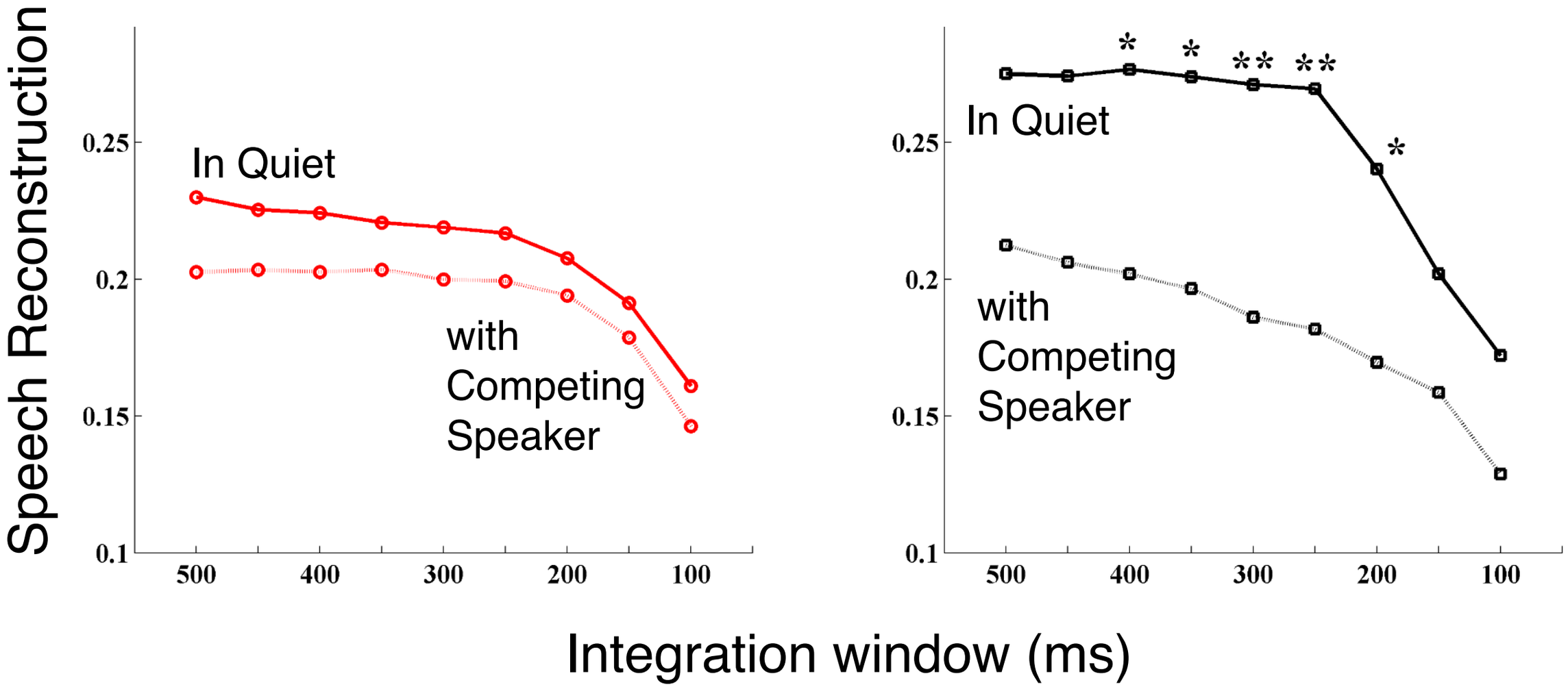


M100 Power by Subject

Also true for pure tones

Younger vs. Older Adults

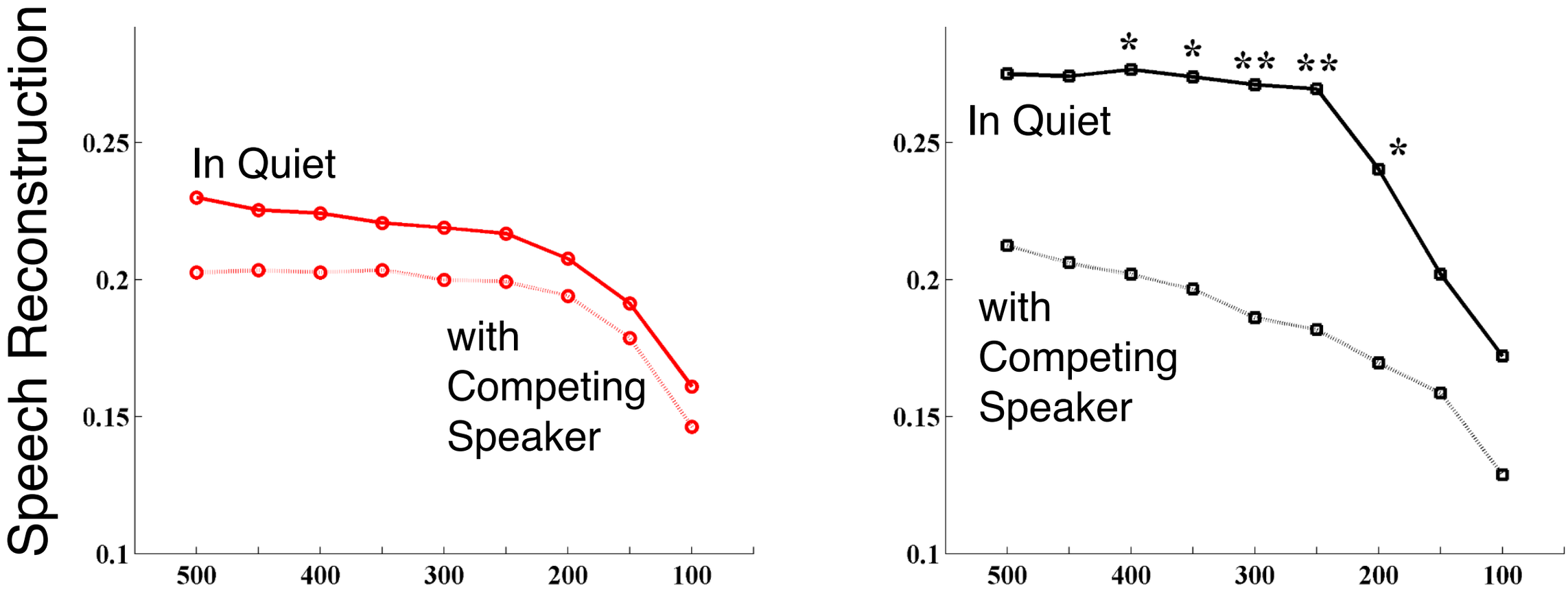
Temporal Integration



Presacco et al., J Neurophysiol (2016a)

Younger vs. Older Adults

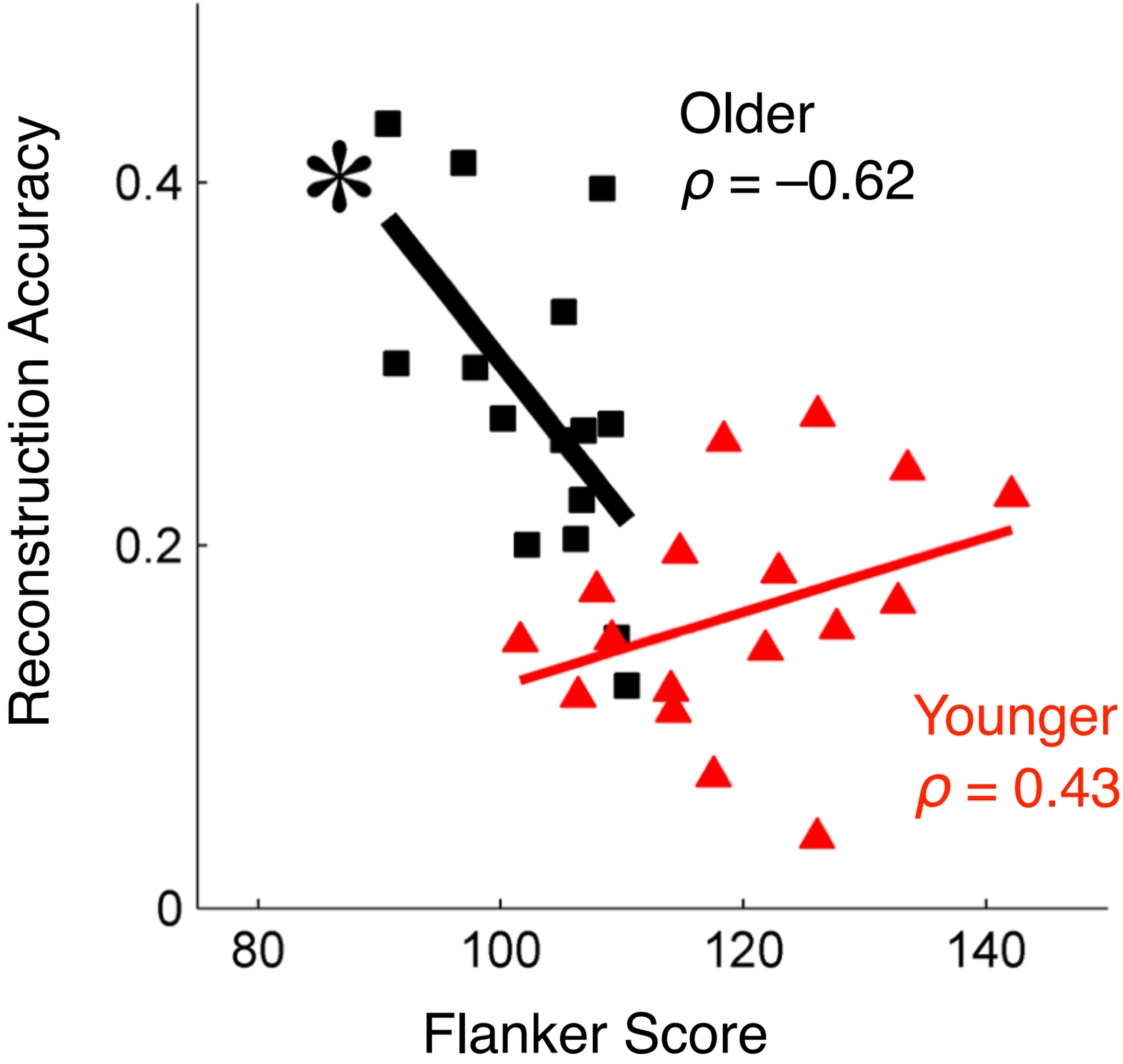
Temporal Integration



Presacco et al., J Neurophysiol (2016a)

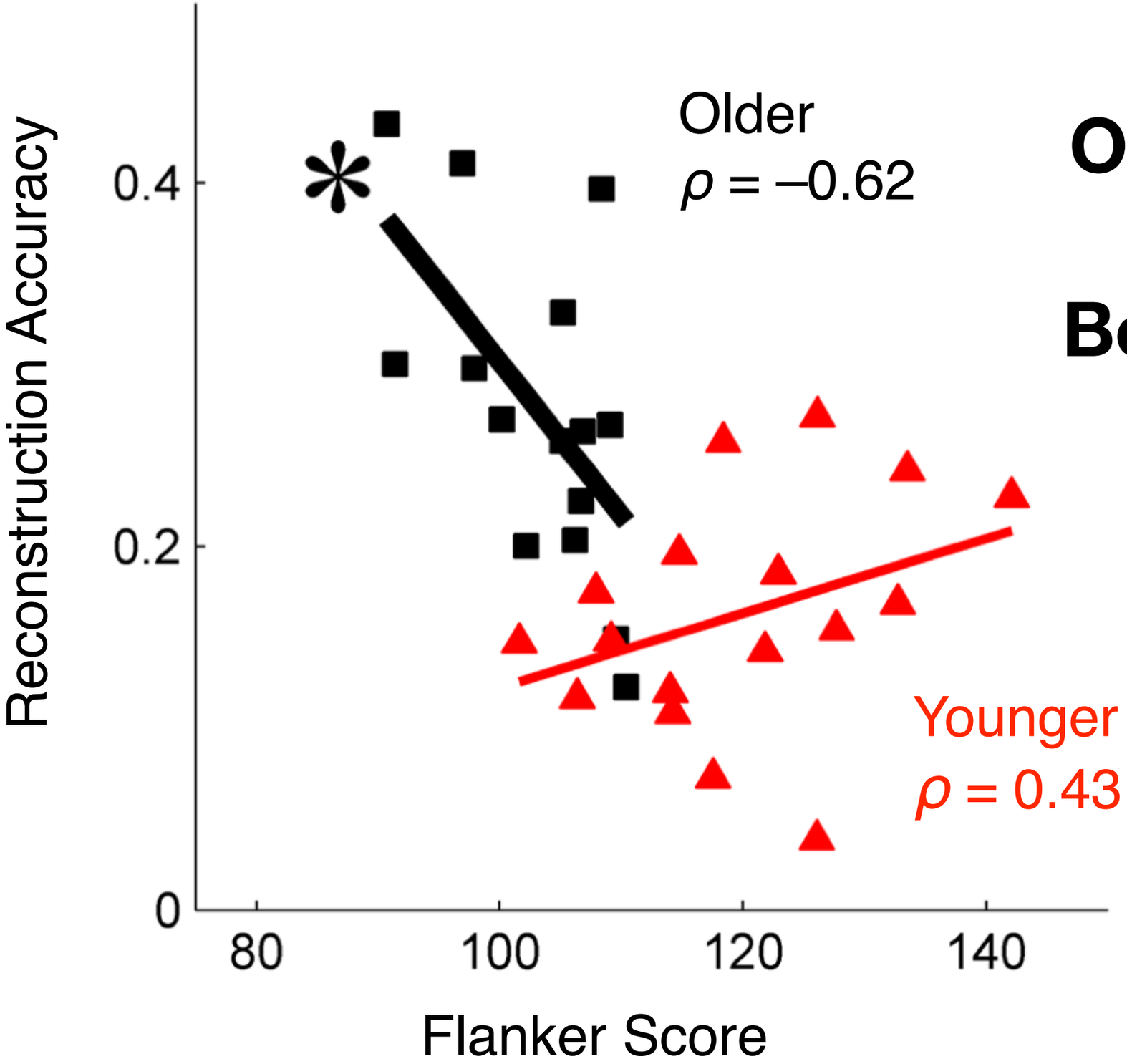
Losses in Temporal Integration

Neural vs Inhibitory Control



Presacco et al., J Neurophysiol (2016b)

Neural vs Inhibitory Control



Over-representation

↕

Behavioral inhibition reduction

Older Adults Only

Presacco et al., J Neurophysiol (2016b)

Missing Speech Restoration

- Can sustained, strongly non-stationary, speech be "restored"?
  - Might be aided by contextual knowledge/familiarity
  - Might be aided by strong rhythmicity

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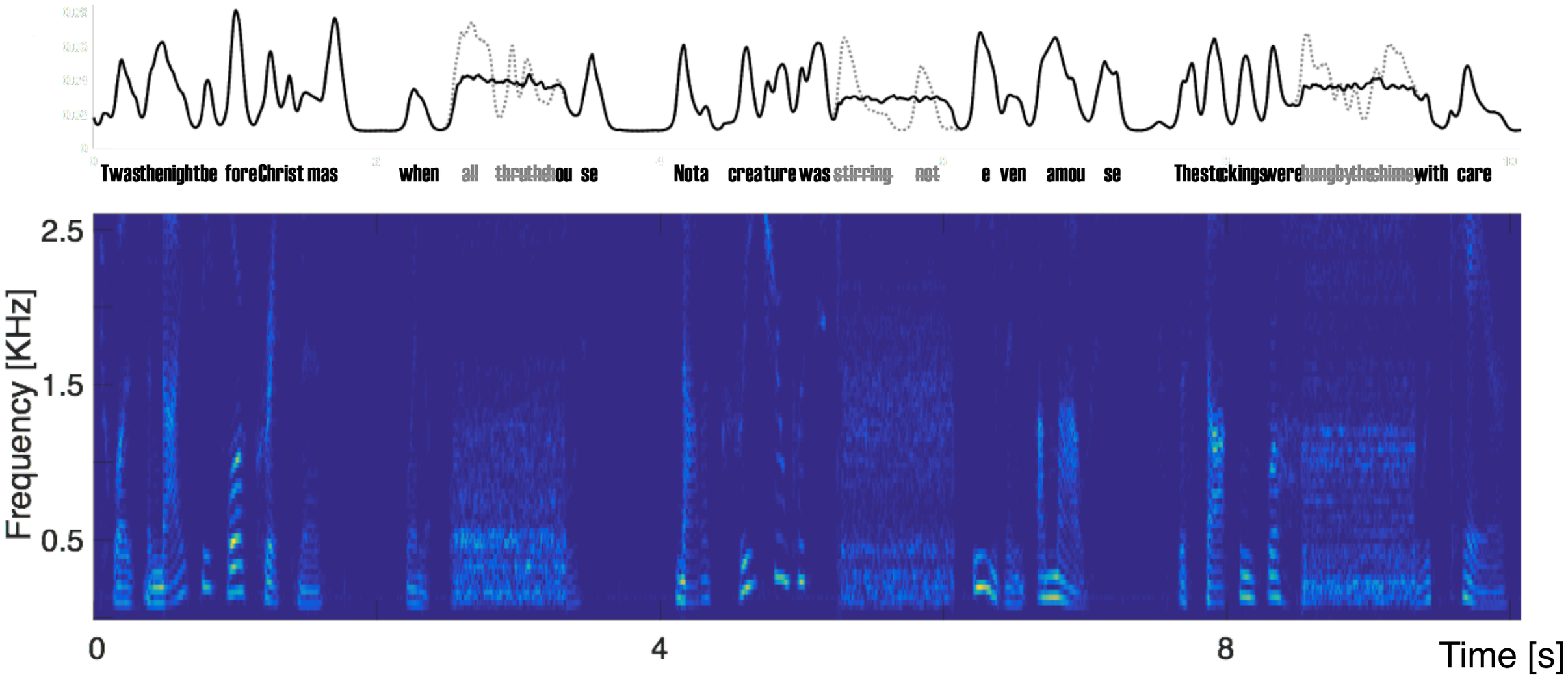


Cervantes Constantino & Simon, bioRxiv 251793

Missing Speech: Context

Twas the night before Christmas, when all through the house
not a creature was stirring, not even a mouse.
The stockings were hung by the chimney with care,
in hopes that St. Nicholas soon would be there.

The children were nestled all snug in their beds,
while visions of sugar plums danced in their heads.
And Mama in her 'kerchief, and I in my cap,
had just settled our brains for a long winter's nap.

When out on the lawn there arose such a clatter,
I sprang from my bed to see what was the matter.
Away to the window I flew like a flash,
tore open the shutter, and threw up the sash.

The moon on the breast of the new-fallen snow
gave the lustre of midday to objects below,
when, what to my wondering eyes should appear,
but a miniature sleigh and eight tiny reindeer.

With a little old driver, so lively and quick,
I knew in a moment it must be St. Nick.
More rapid than eagles, his coursers they came,
and he whistled and shouted and called them by name.

"Now Dasher! Now Dancer! Now, Prancer and Vixen!
On, Comet! On, Cupid! On, Donner and Blitzen!
To the top of the porch! To the top of the wall!
Now dash away! Dash away! Dash away all!"

As dry leaves that before the wild hurricane fly,
when they meet with an obstacle, mount to the sky
so up to the house-top the coursers they flew,
with the sleigh full of toys, and St. Nicholas too.

And then, in a twinkling, I heard on the roof
the prancing and pawing of each little hoof.
As I drew in my head and was turning around,
down the chimney St. Nicholas came with a bound.

He was dressed all in fur, from his head to his foot,
and his clothes were all tarnished with ashes and soot.
A bundle of toys he had flung on his back,
and he looked like a peddler just opening his pack.

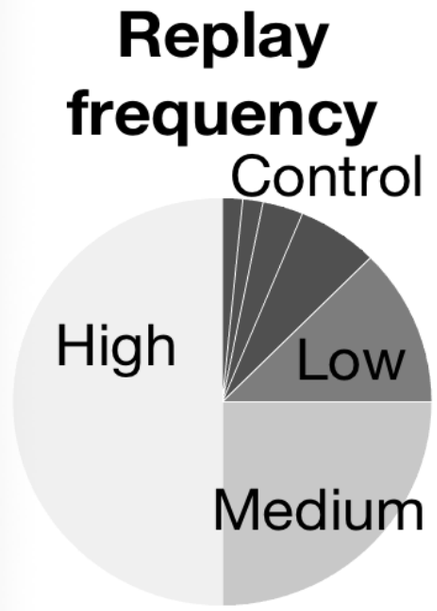
His eyes--how they twinkled! His dimples, how merry!
His cheeks were like roses, his nose like a cherry!
His droll little mouth was drawn up like a bow,
and the beard on his chin was as white as the snow.

The stump of a pipe he held tight in his teeth,
and the smoke it encircled his head like a wreath.
He had a broad face and a little round belly,
that shook when he laughed, like a bowl full of jelly.

He was chubby and plump, a right jolly old elf,
and I laughed when I saw him, in spite of myself.
A wink of his eye and a twist of his head
soon gave me to know I had nothing to dread.

He spoke not a word, but went straight to his work,
and filled all the stockings, then turned with a jerk.
And laying his finger aside of his nose,
and giving a nod, up the chimney he rose.

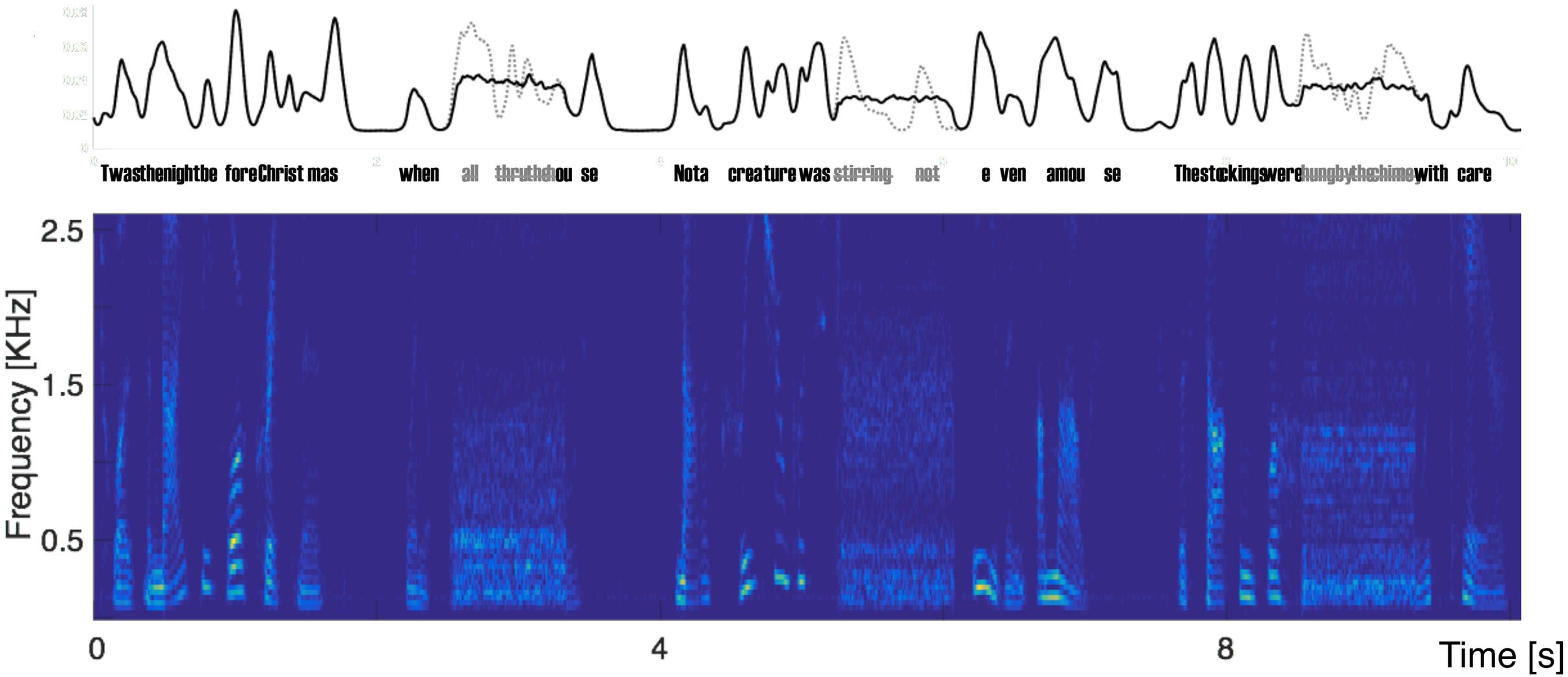
He sprang to his sleigh, to his team gave a whistle,
And away they all flew like the down of a thistle.
But I heard him exclaim, 'ere he drove out of sight,
"Happy Christmas to all, and to all a good night!"



- Hypothesis: contextual knowledge of missing speech can be controlled by exposure to the speech

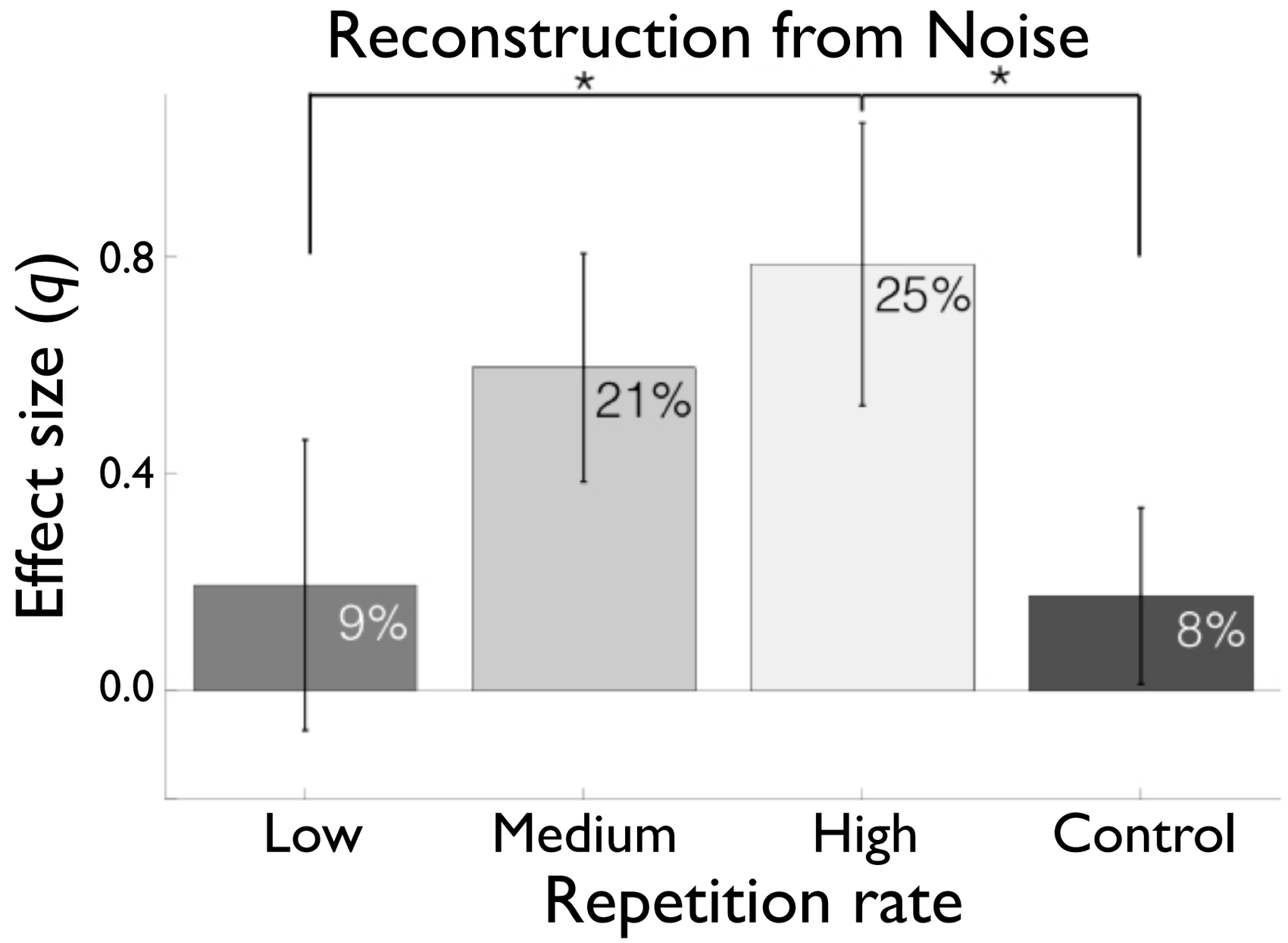
Missing Speech Restoration

- Can sustained, strongly non-stationary, speech be "restored"?
  - Might be aided by contextual knowledge/familiarity
  - Might be aided by strong rhythmicity



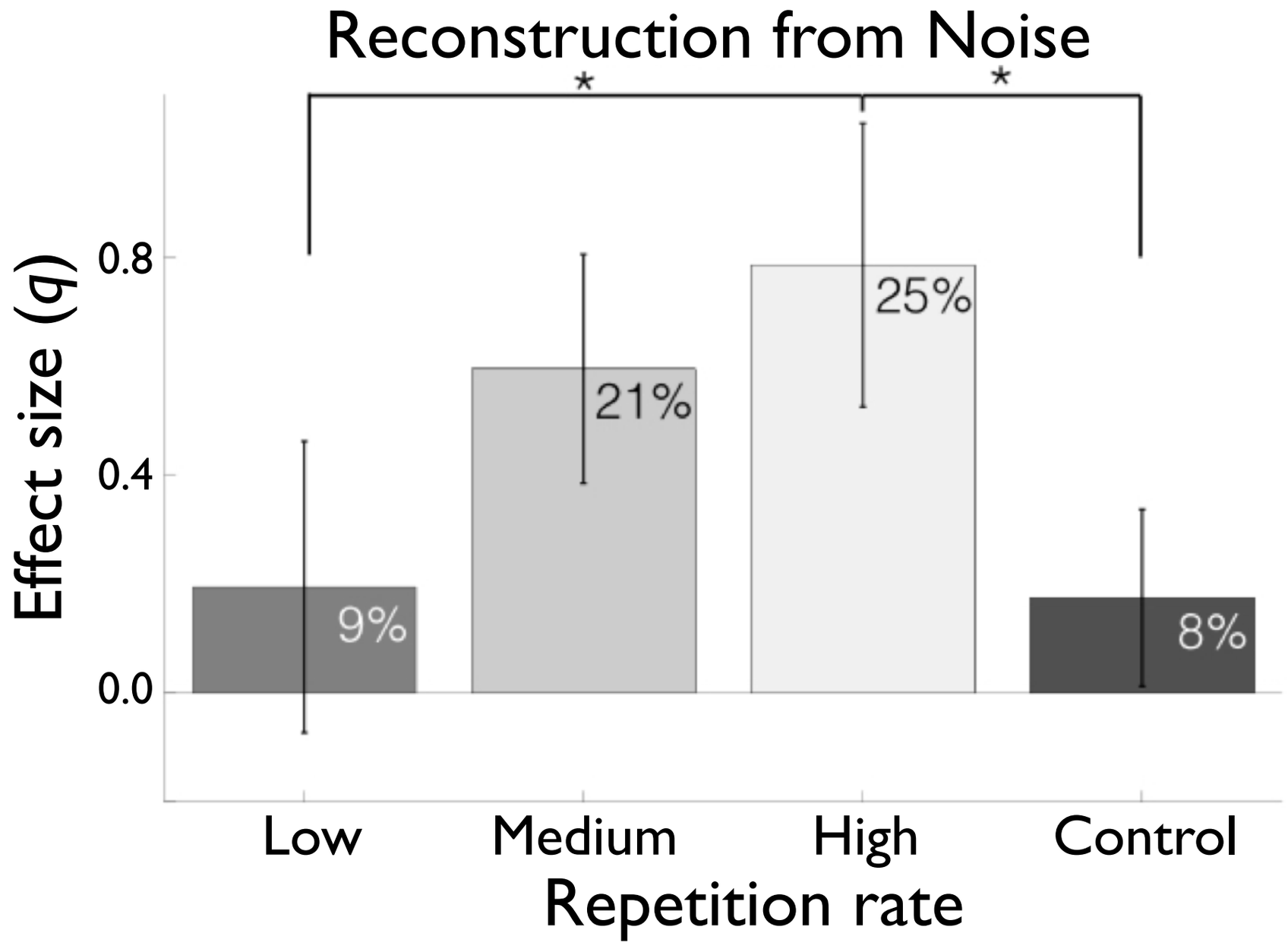
Cervantes Constantino & Simon, bioRxiv 251793

Missing Speech “Reconstruction”



Cervantes Constantino & Simon, bioRxiv 251793

Missing Speech "Reconstruction"



- Decoding of the ***missing*** speech improves with prior experience
- Performance is a considerable fraction of that for clean speech

Cervantes Constantino & Simon, bioRxiv 251793

Summary

- Cortical representations of speech
  - representation of envelope (up to ~10 Hz)
  - robust against a variety of noise types
  - robust against competing speech!
- Object-based representation at 100 ms latency (PT), but not by 50 ms (HG)
- Aging shows over-representation (and time integration deficits)
- Applies to acoustically missing internal speech

Thank You

Acknowledgements

Current Lab Members & Affiliates

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