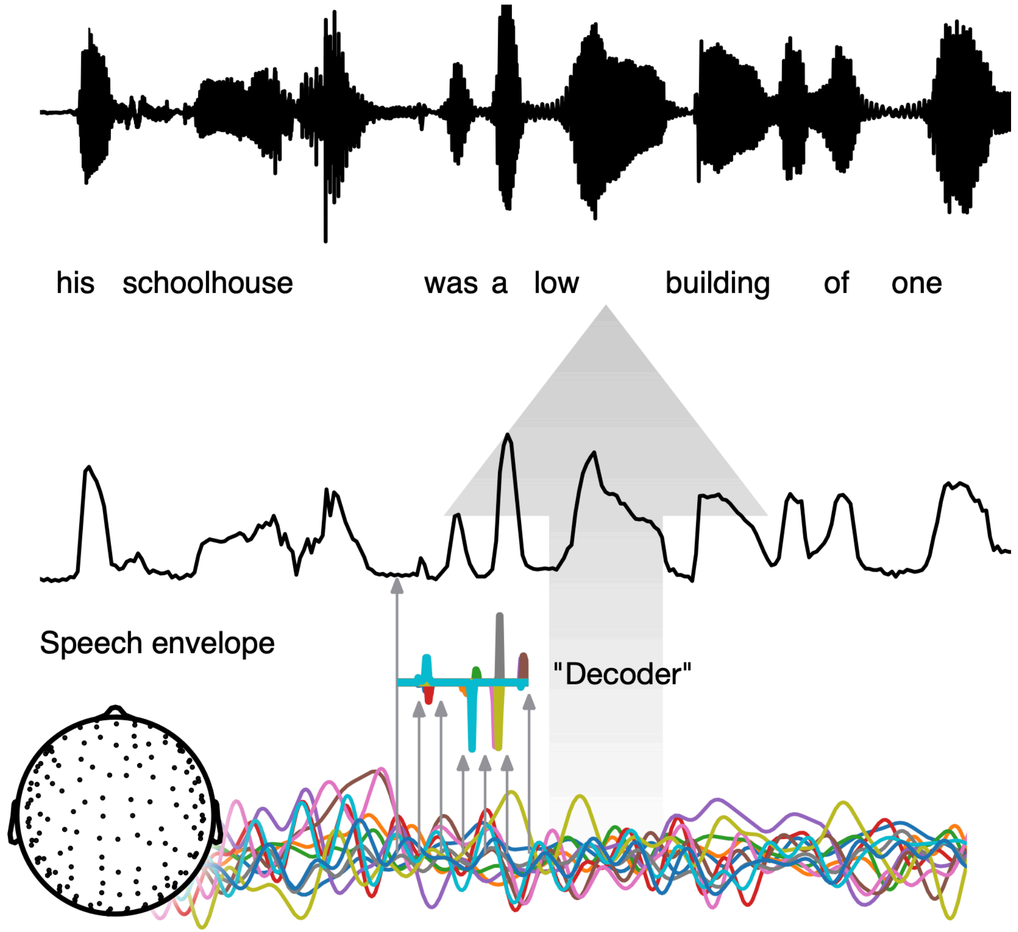
What Can We Decode?

Jonathan Z. Simon

University of Maryland, College Park

What is Decoding?

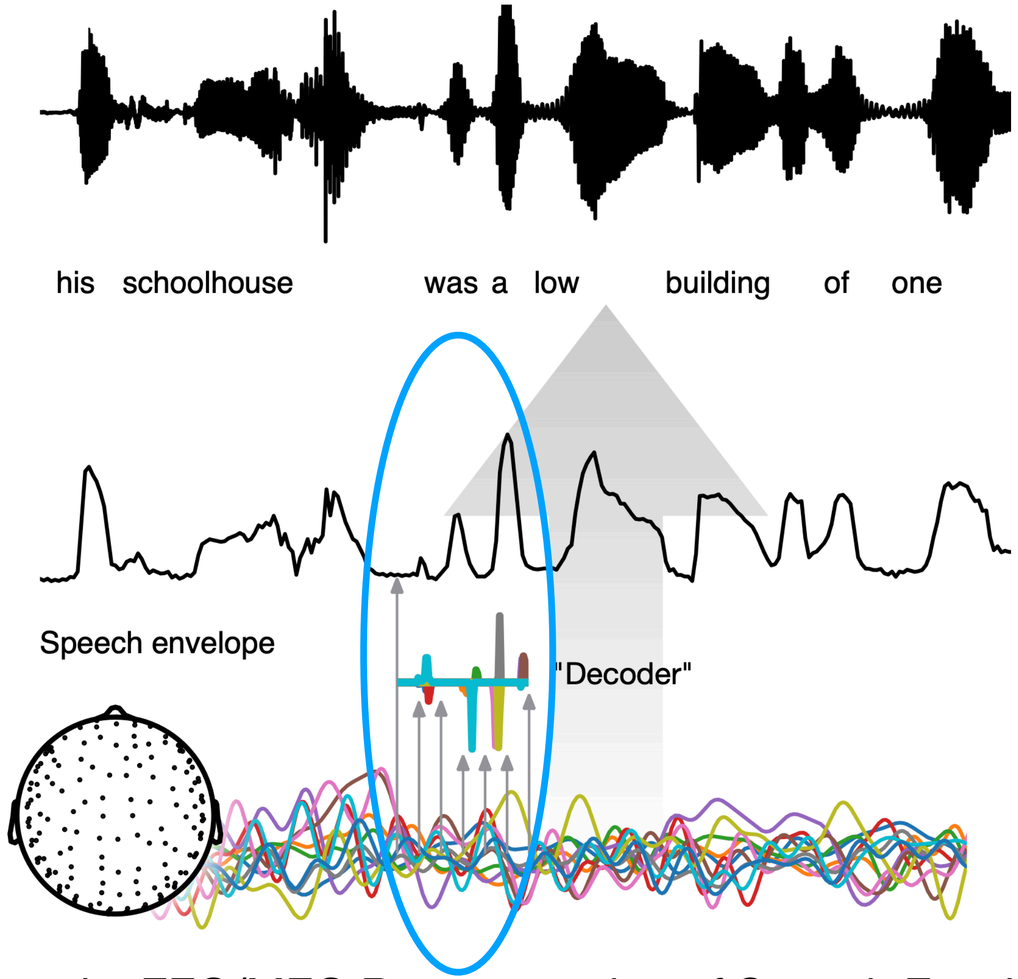
- Stimulus Reconstruction (from neural responses)
  - Subset of decoding
  - I will use “decoding” and “reconstruction” interchangeably (until it gets me into trouble)
  - I will use “stimulus” reconstruction and “other kinds” of reconstruction interchangeably (until it gets me into trouble)
- Linear decoding/reconstruction emphasized here



Example: EEG/MEG Reconstruction of Speech Envelope

What is Decoding?

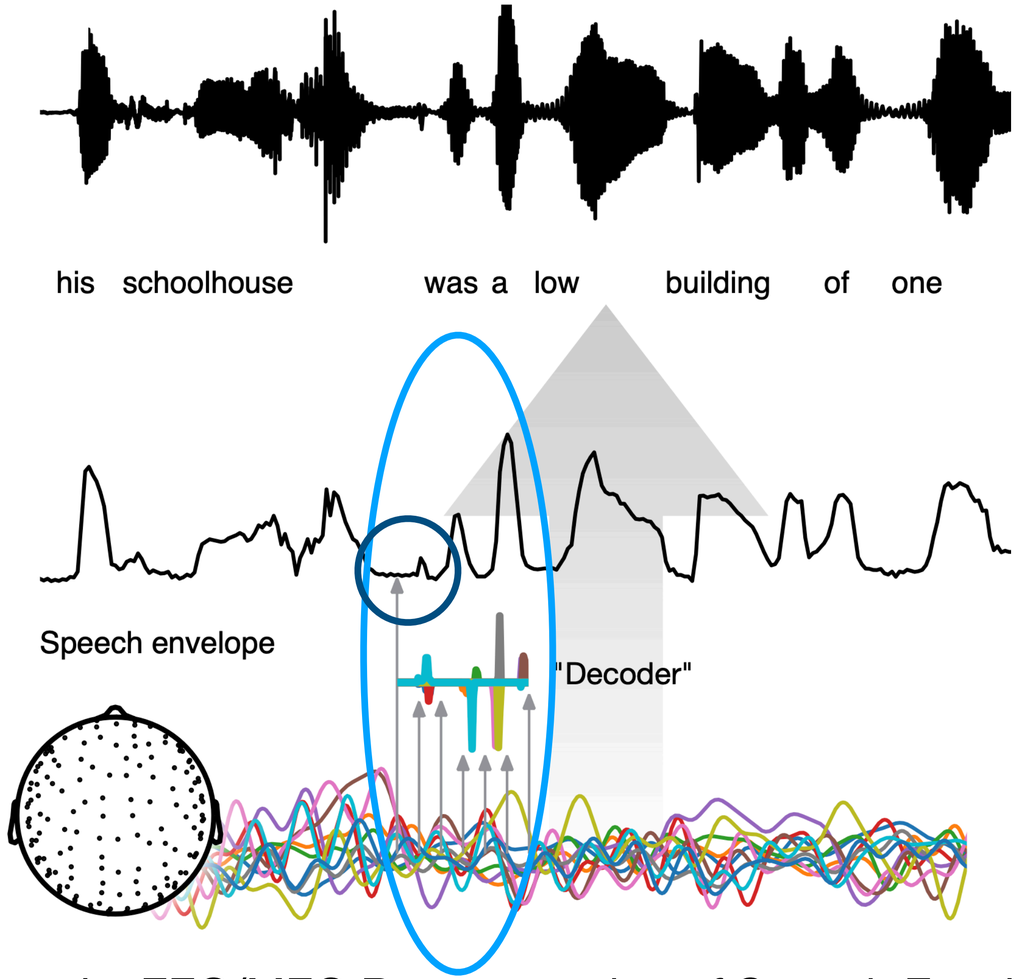
- Stimulus Reconstruction (from neural responses)
  - Subset of decoding
  - I will use “decoding” and “reconstruction” interchangeably (until it gets me into trouble)
  - I will use “stimulus” reconstruction and “other kinds” of reconstruction interchangeably (until it gets me into trouble)
- Linear decoding/reconstruction emphasized here



Example: EEG/MEG Reconstruction of Speech Envelope

What is Decoding?

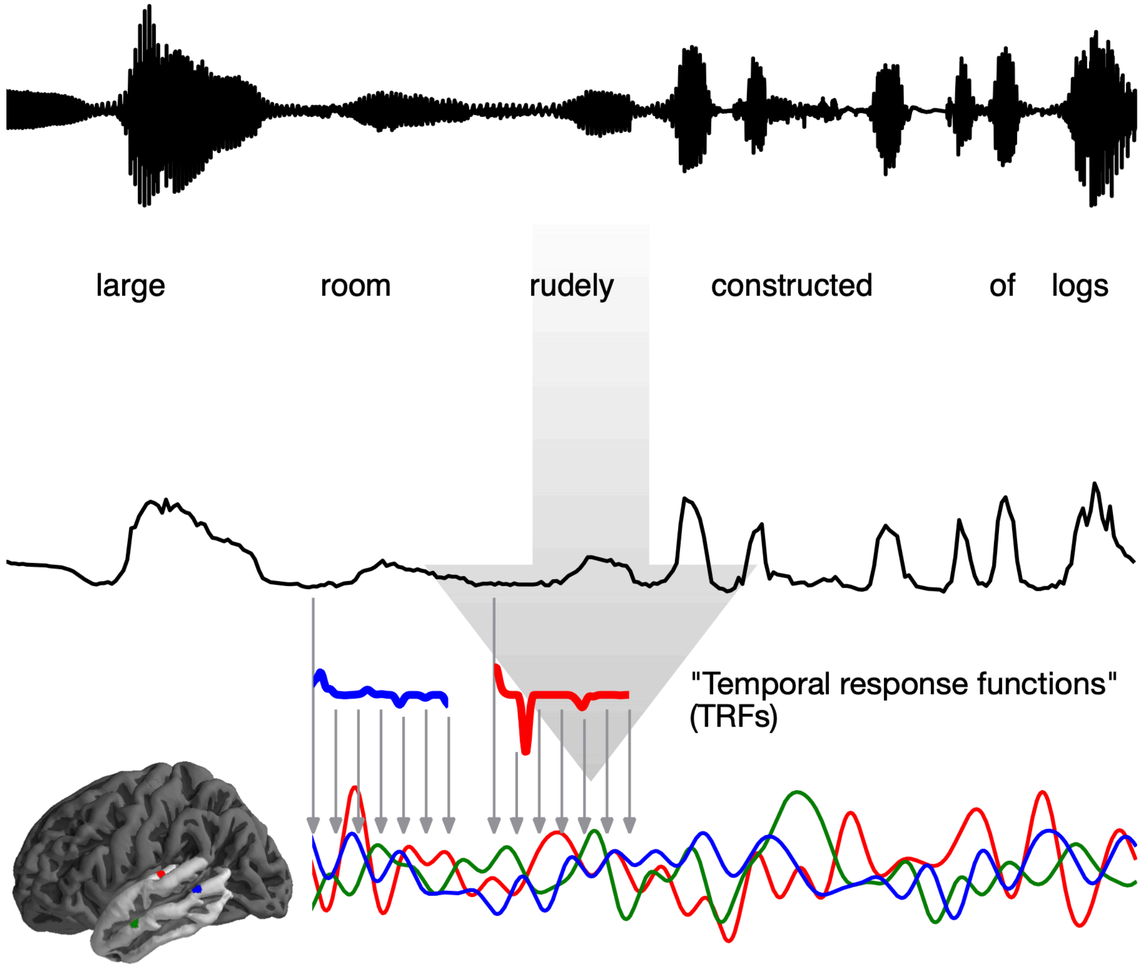
- Stimulus Reconstruction (from neural responses)
  - Subset of decoding
  - I will use “decoding” and “reconstruction” interchangeably (until it gets me into trouble)
  - I will use “stimulus” reconstruction and “other kinds” of reconstruction interchangeably (until it gets me into trouble)
- Linear decoding/reconstruction emphasized here



Example: EEG/MEG Reconstruction of Speech Envelope

Decoding ≠ Encoding

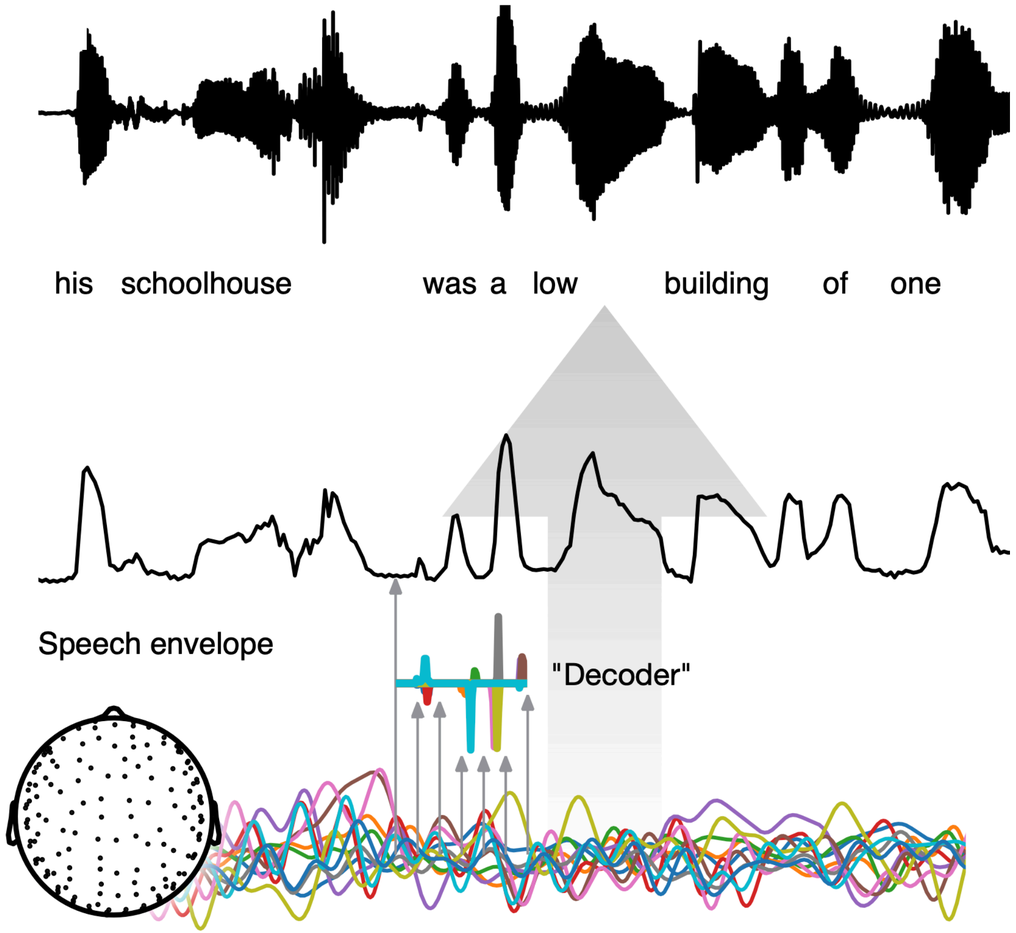
- Encoding = predicting neural responses from stimulus features, e.g., via TRF
  - “Stimulus features”? the sky's the limit
- *Typically* harder than reconstruction, since stimulus dimension ≪ response dimension
  - For this reason: stimulus features that can be seen to be encoded = excellent candidates for decoding
- Why bother looking at encoding? It *often* tells us more about the brain



Example: MEG Prediction of Voxel Responses

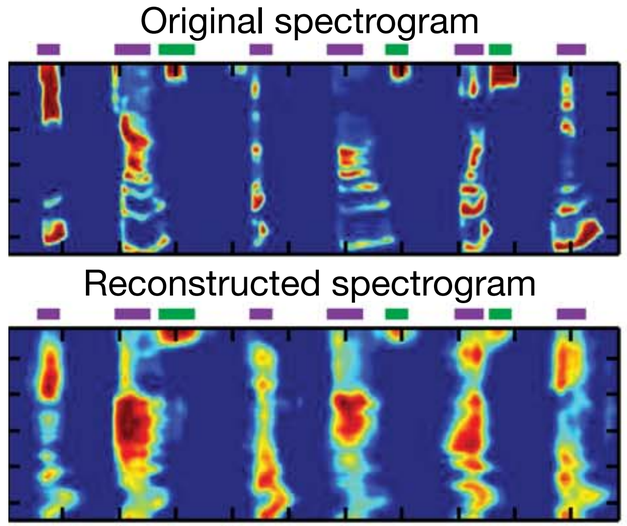
Decoding: easier vs. harder

easier



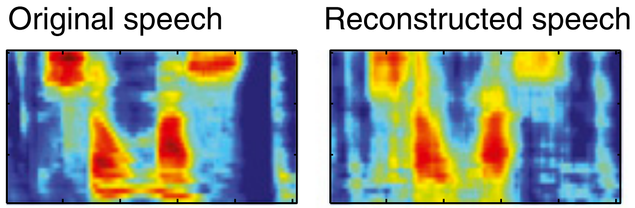
Example: EEG/MEG Reconstruction of Speech Envelope

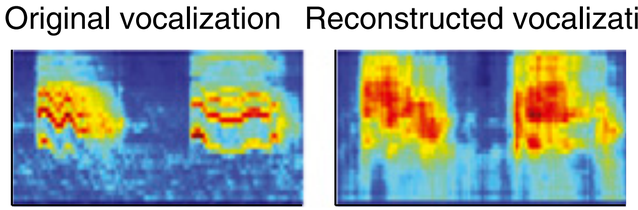
harder



Human STG

Pasley et al., PLoS Biol. 2012





Ferret A1

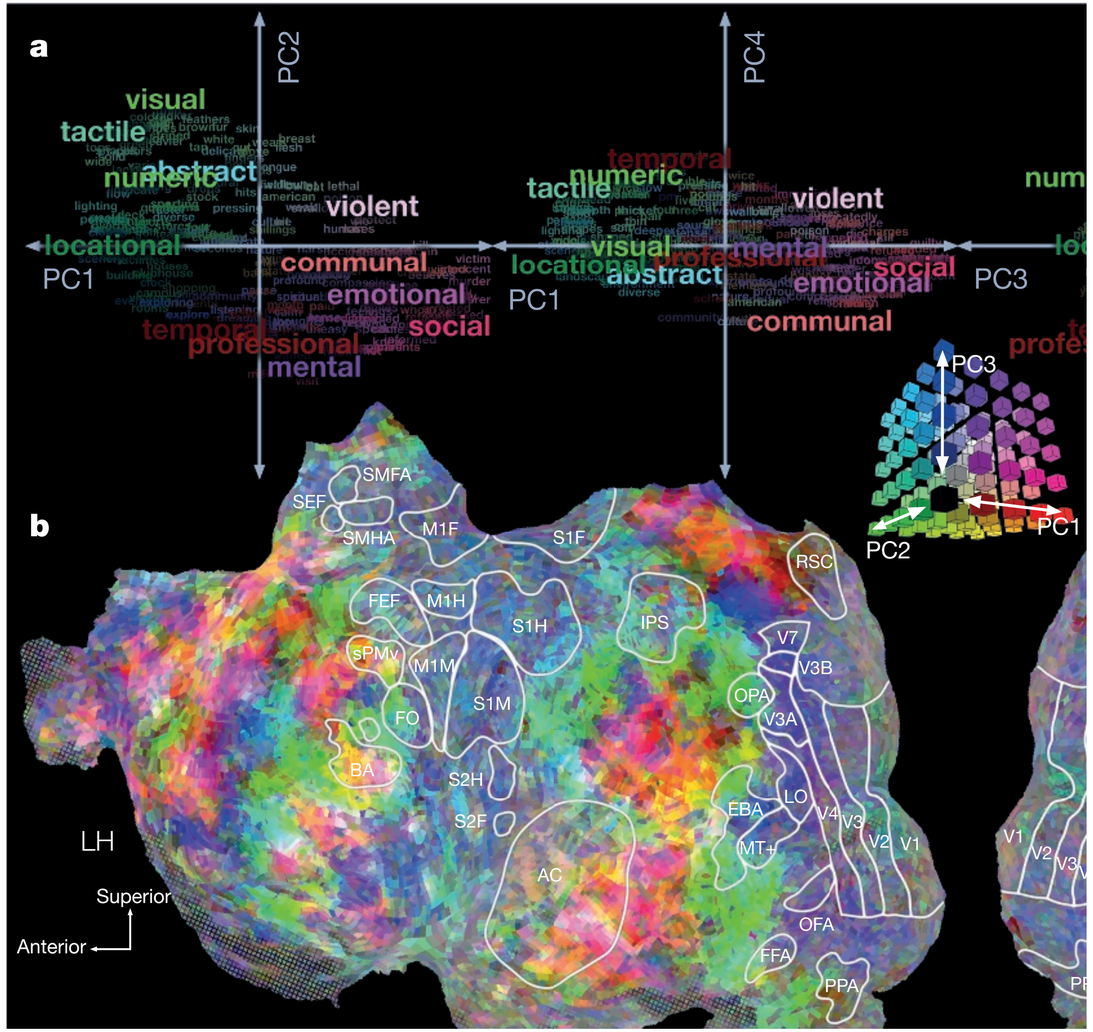
Mesgarani et al., PNAS 2014

Decoding: Brain Machine Interface

- Decoding of “motor intent”
- Shamefully ignored here ☹

Static vs. Continuous Decoding

- Decoding of static stimulus not emphasized today
  (but please interject if interested!)
- Examples: image / visual object, semantic object
- Strongly related to temporal decoding
- Emphasis here on decoding of continuous/natural speech
  - Applications + Data Richness

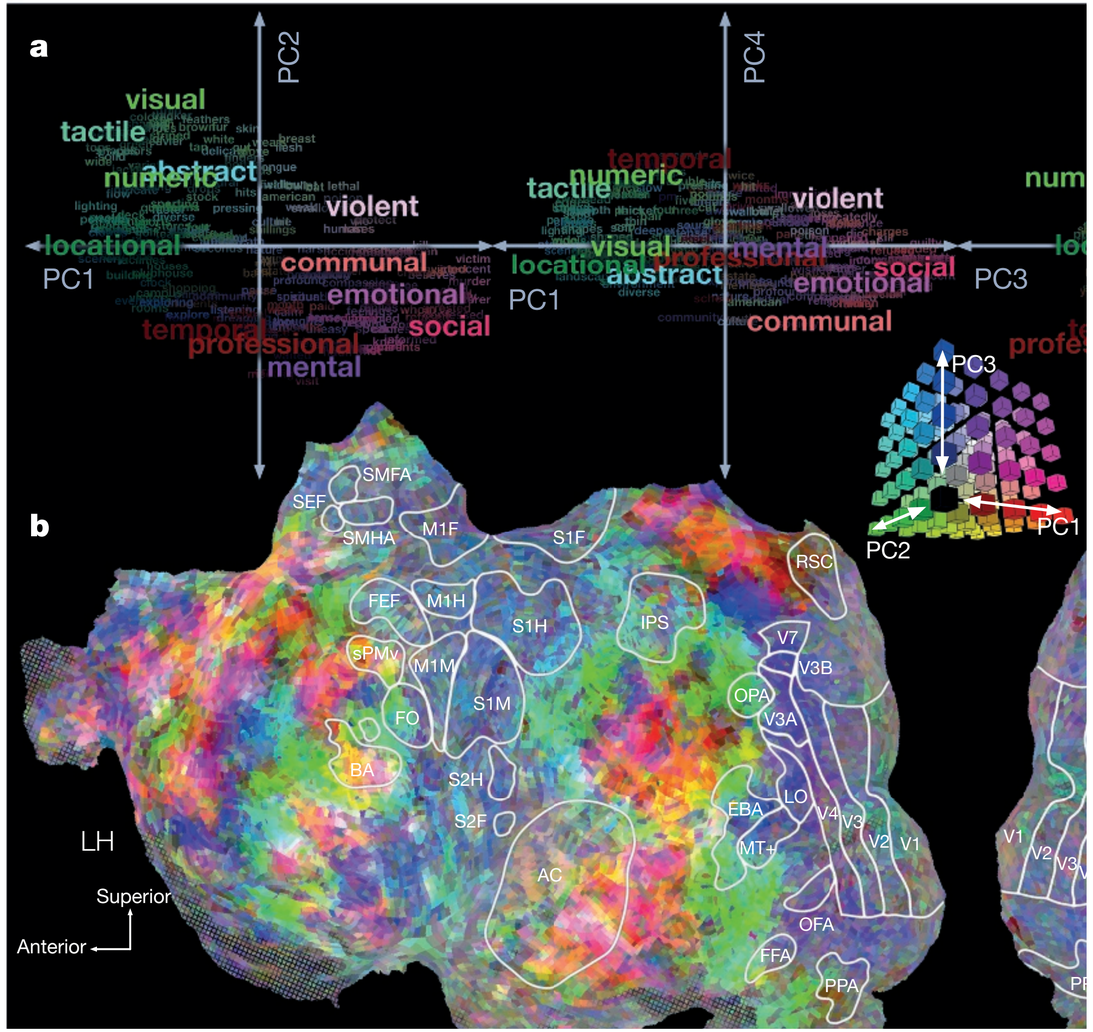


fMRI

Huth et al. Nature 2019

Static vs. Continuous Decoding

- Decoding of static stimulus not emphasized today
  (but please interject if interested!)
- Examples: image / visual object, semantic object
- Strongly related to temporal decoding
- Emphasis here on decoding of continuous/natural speech
  - Applications + Data Richness



fMRI

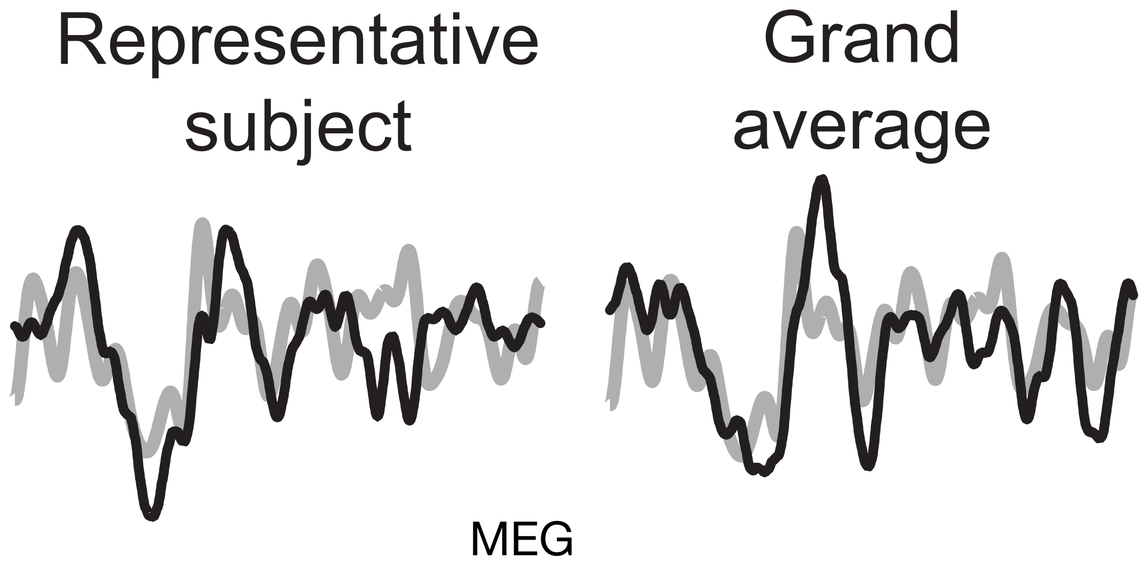
Huth et al. Nature 2019

The revolution will not be controlled: natural stimuli in speech neuroscience

Liberty S. Hamilton[a,b] and Alexander G. Huth[c,d]

Reconstruction Examples

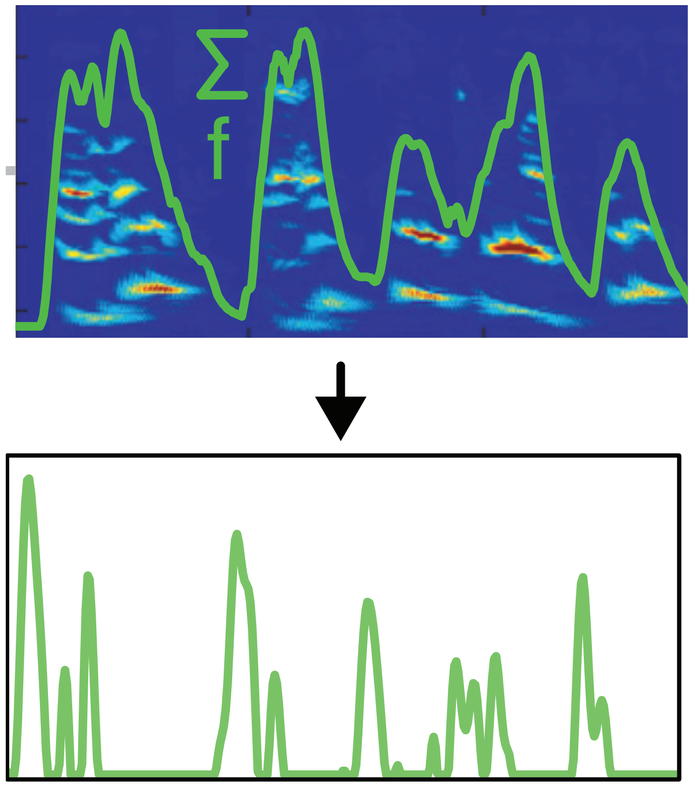
- Speech envelope



Ding & Simon, PNAS 2012

Reconstruction Examples

- Speech envelope
- Speech envelope-onsets



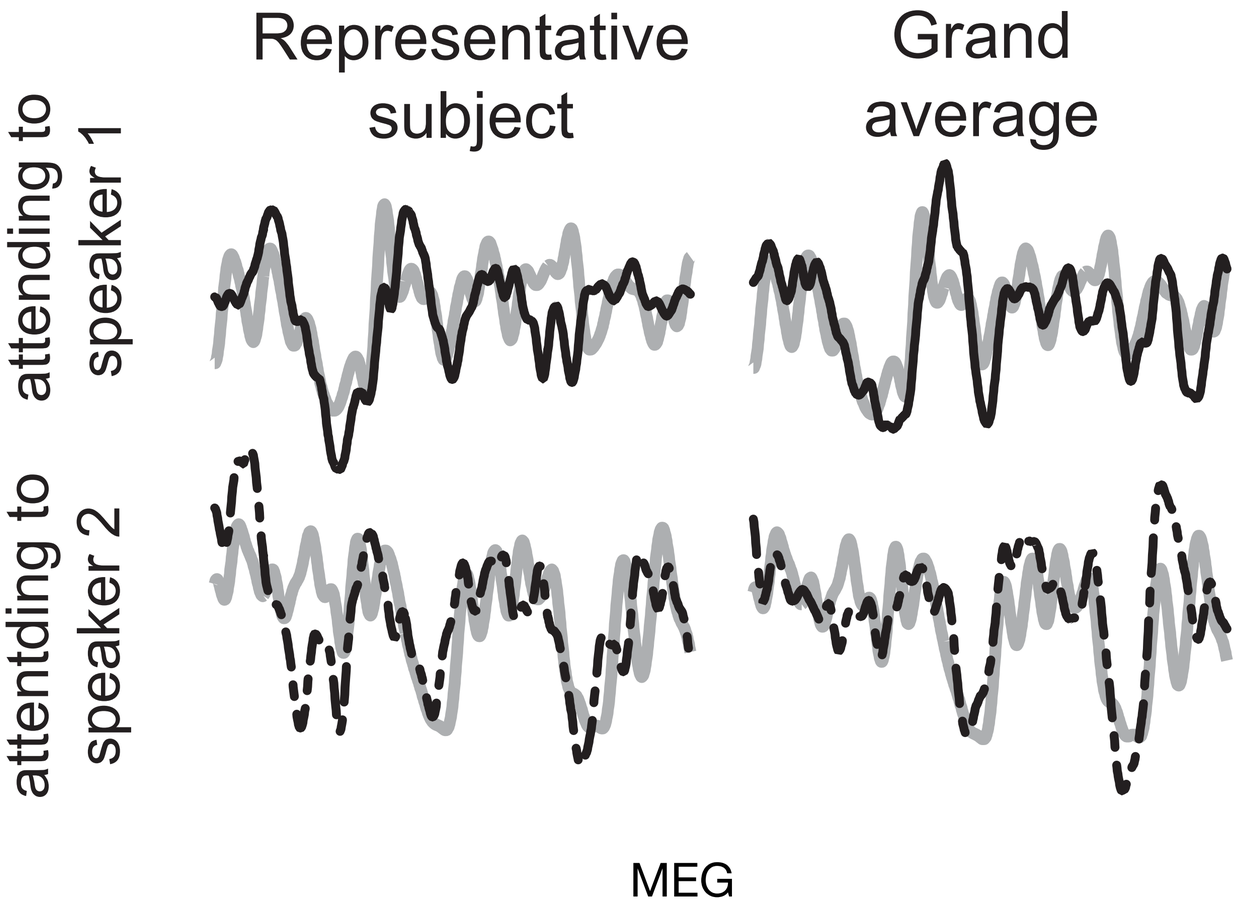
broadband temporal envelope

onset envelope

Fiedler et al., J Neural Engineering 2017

Reconstruction Examples

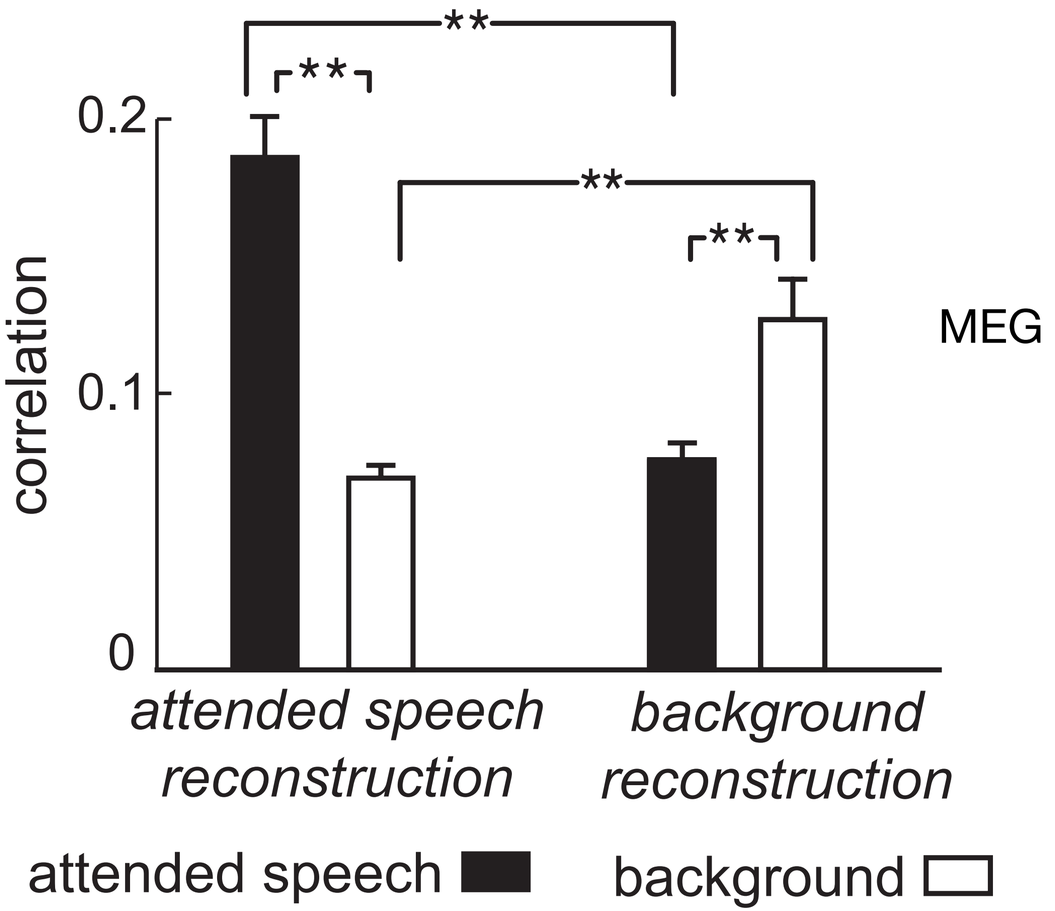
- Speech envelope
- Speech envelope-onsets
- Multiple speech envelopes from individual speakers in mixture



Ding & Simon, PNAS 2012

Reconstruction Examples

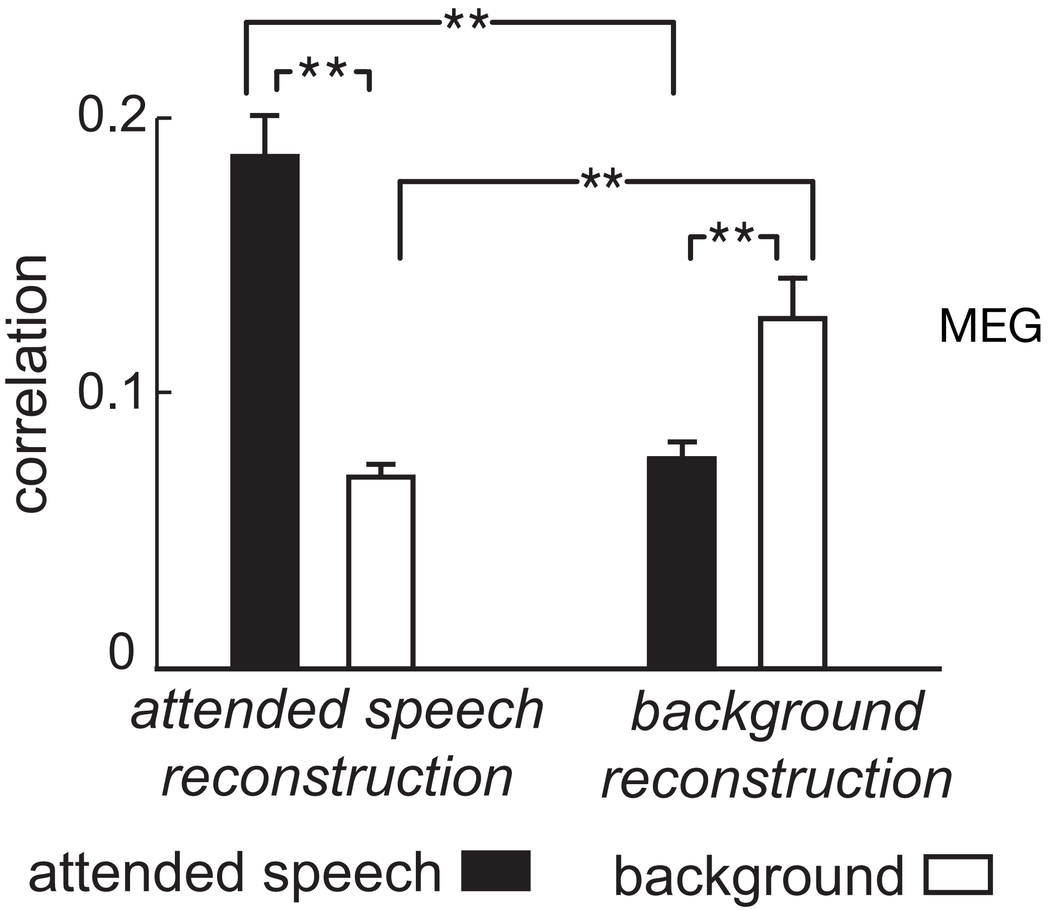
- Speech envelope
- Speech envelope-onsets
- Multiple speech envelopes from individual speakers in mixture



Ding & Simon, PNAS 2012

Reconstruction Examples

- Speech envelope
- Speech envelope-onsets
- Multiple speech envelopes from individual speakers in mixture
- Acoustic envelope of mixture of multiple speakers



Ding & Simon, PNAS 2012

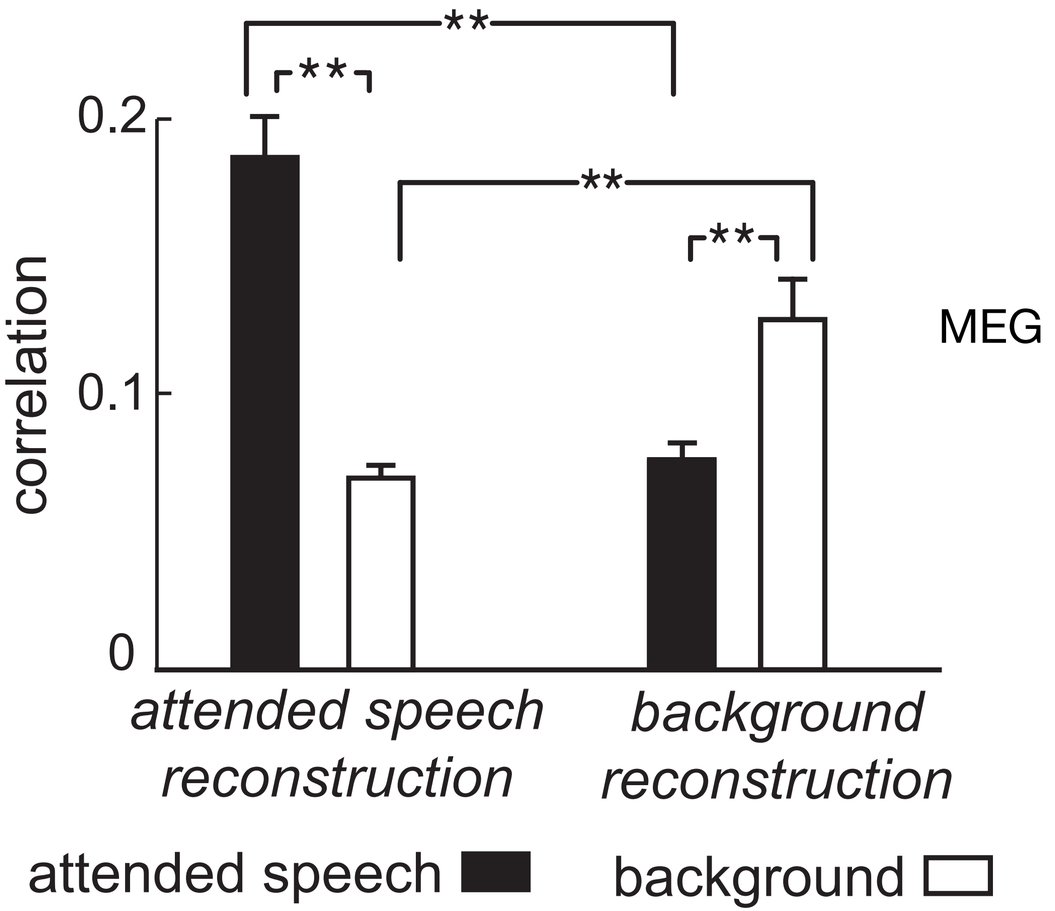
Reconstruction Examples

- Speech envelope
- Speech envelope-onsets
- Multiple speech envelopes from individual speakers in mixture
- Acoustic envelope of mixture of multiple speakers

Not actually reconstructing anything

Not a stimulus, so can't reconstruct, but can decode

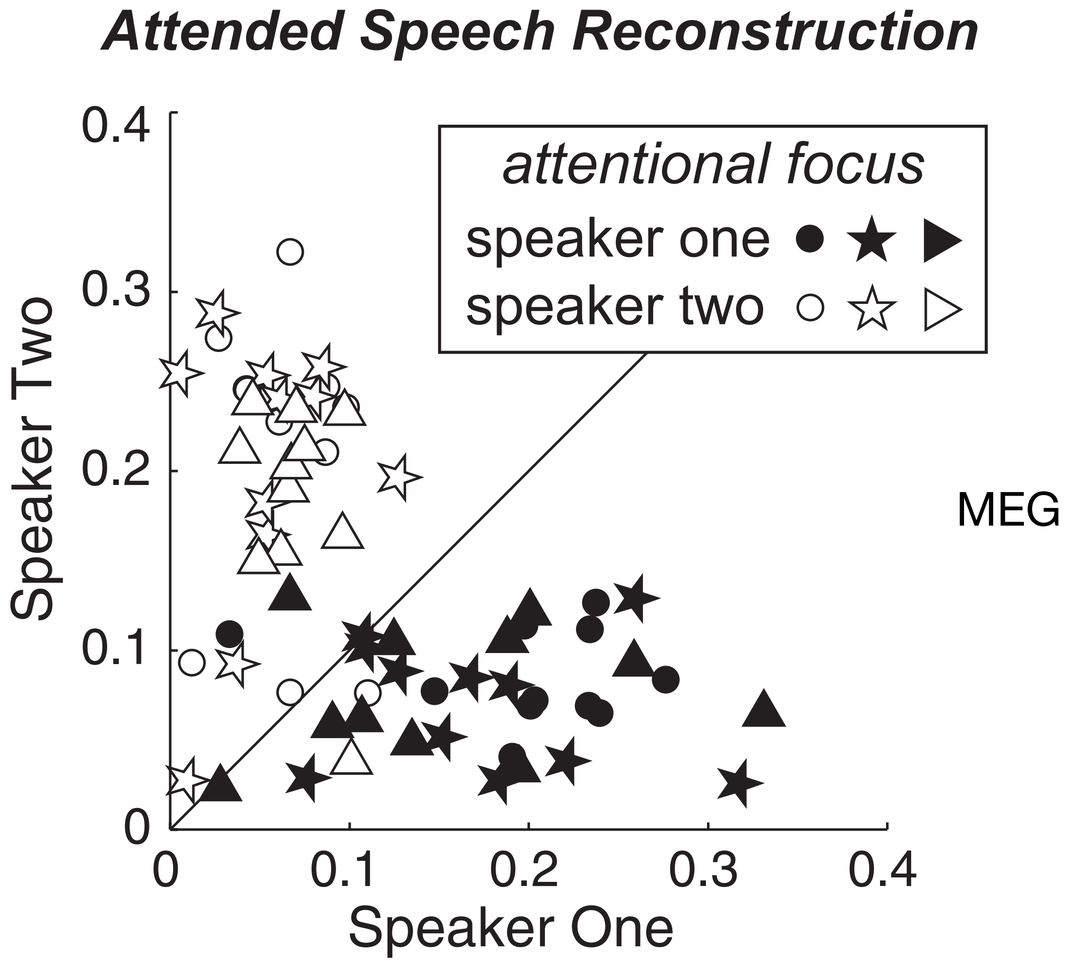
Decoding the envelope of a perceived auditory stream



Ding & Simon, PNAS 2012

Reconstruction Examples

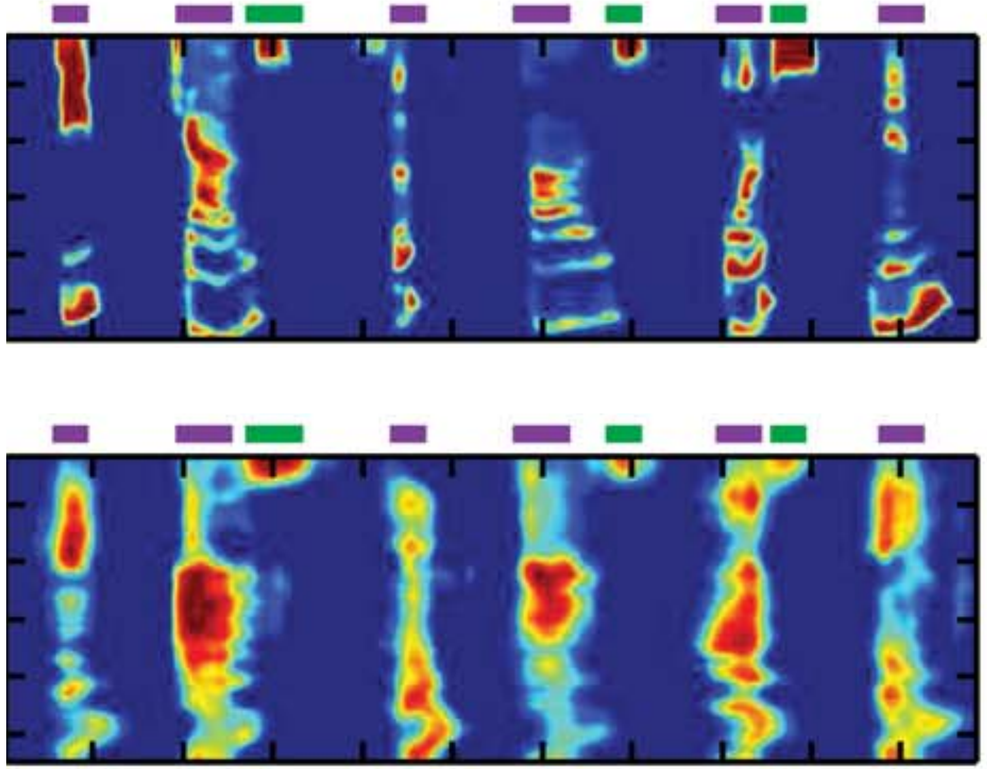
- Speech envelope
- Speech envelope-onsets
- Multiple speech envelopes from individual speakers in mixture
- Acoustic envelope of mixture of multiple speakers
- Focus of selective attention



Ding & Simon, PNAS 2012

Reconstruction Examples

- Speech envelope
- Speech envelope-onsets
- Multiple speech envelopes from individual speakers in mixture
- Acoustic envelope of mixture of multiple speakers
- Focus of selective attention
- Spectrogram(s)

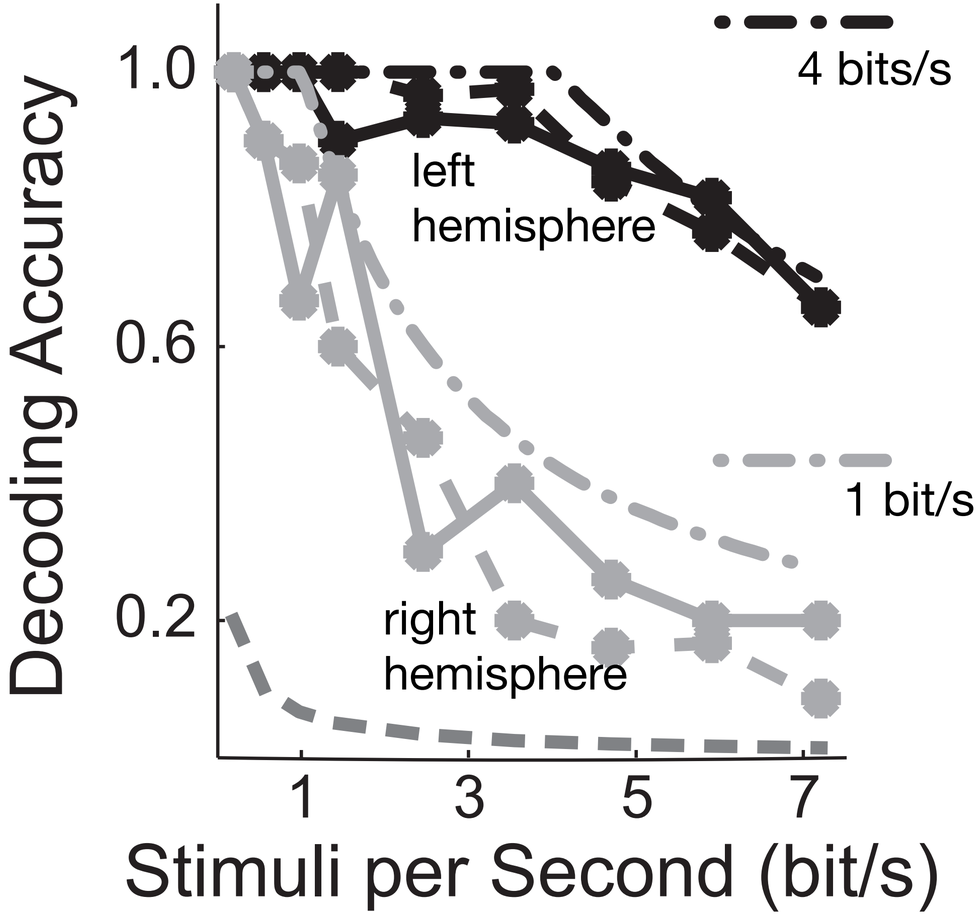


ECoG (Human STG)

Pasley et al., PLoS Biol. 2012

Practical Limitations

- Typically only single trial decoding performance matters
- More difficult with shorter durations (or shorter integration windows)
- Decoding performance depends strongly on neural SNR

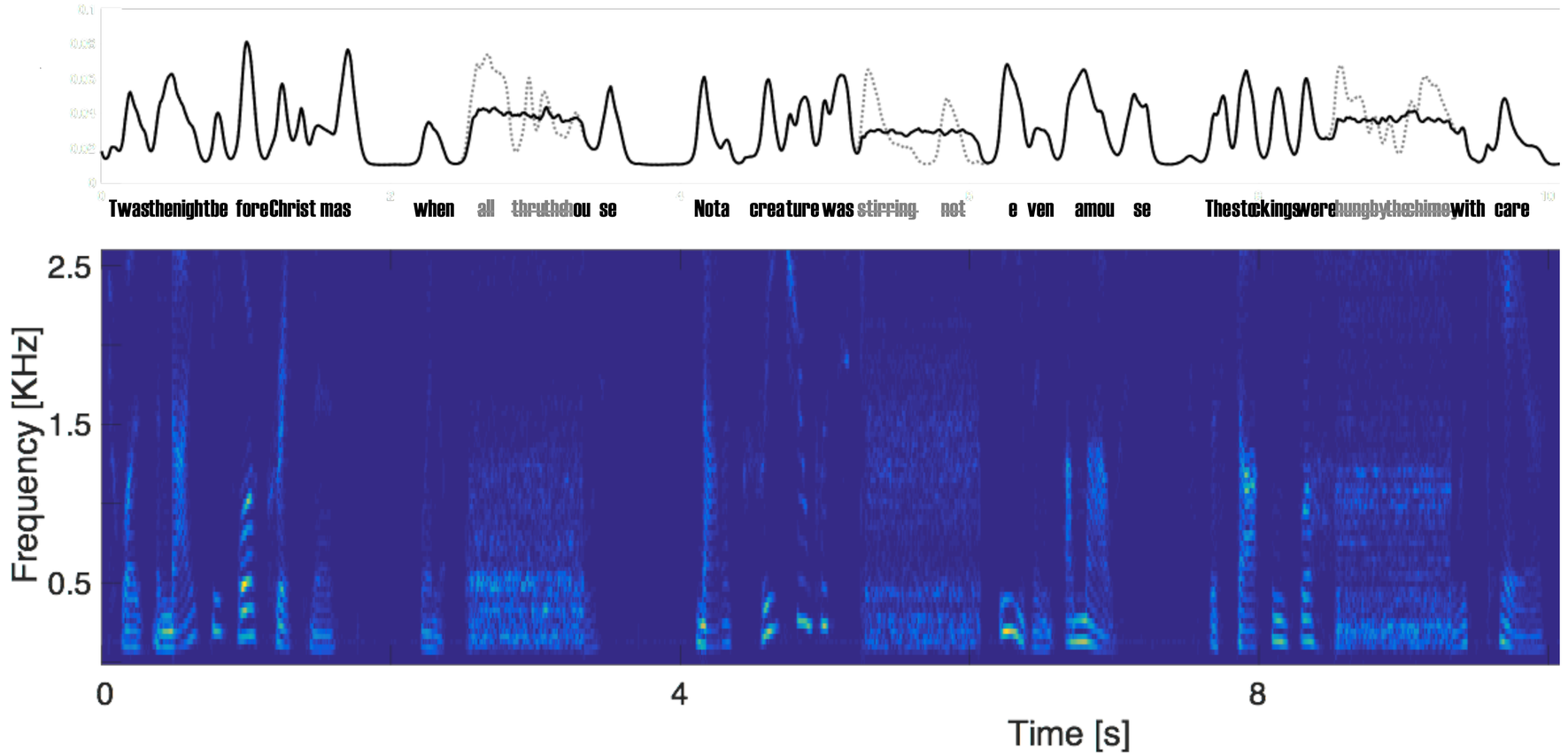


Ding & Simon, J Neurophysiol 2012

Decoding the Attended Speech Stream: Issues

- Still critical engineering issues in practice
  - What are the actual neural marker(s) of selective attention?
  - Don’t know the actual speech streams (not present in the acoustic stimulus!)
  - more…

Reconstructing Imagined Speech



Can non-stationary, imagined speech be decoded?

- might be aided by contextual knowledge/familiarity
- might be aided by strong rhythmicity

Cervantes Constantino & Simon
Front Syst Neurosci 2018

Neural “Reconstruction” & Familiarity

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.

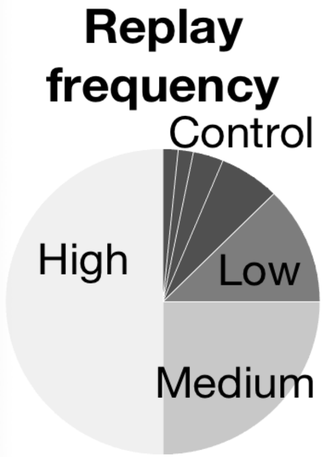
His eyes--how they twinkled! His dimples, how merry!
His cheeks were like roses, his nose like a cherry!
His droll little mouth was drawn up like a bow,
and the beard on his chin was as white as the snow.

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.

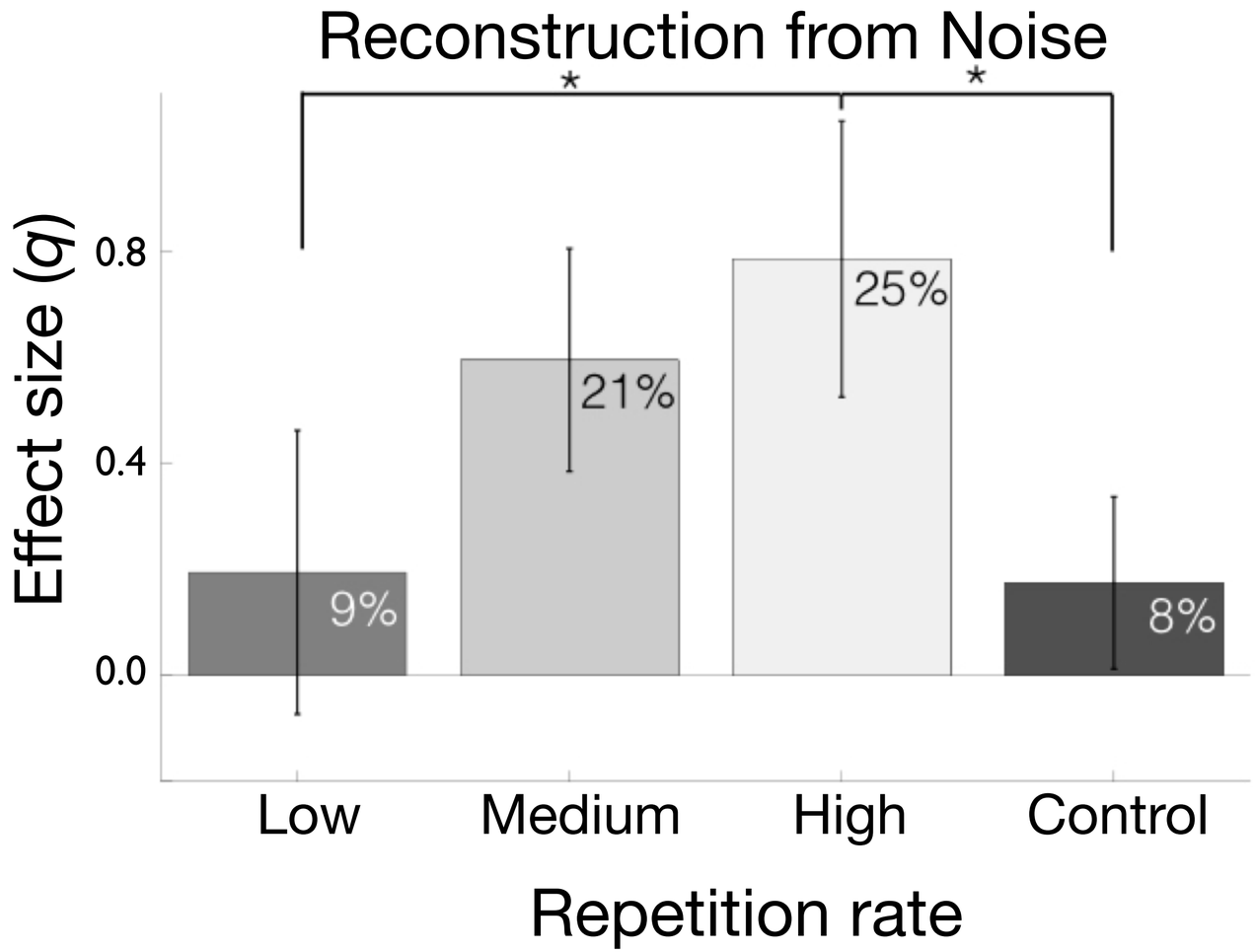
He sprang to his sleigh, to his team gave a whistle,
And away they all flew like the down of a thistle.
But I heard him exclaim, 'ere he drove out of sight,
"Happy Christmas to all, and to all a good night!"



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

Imagined Speech “Reconstruction”

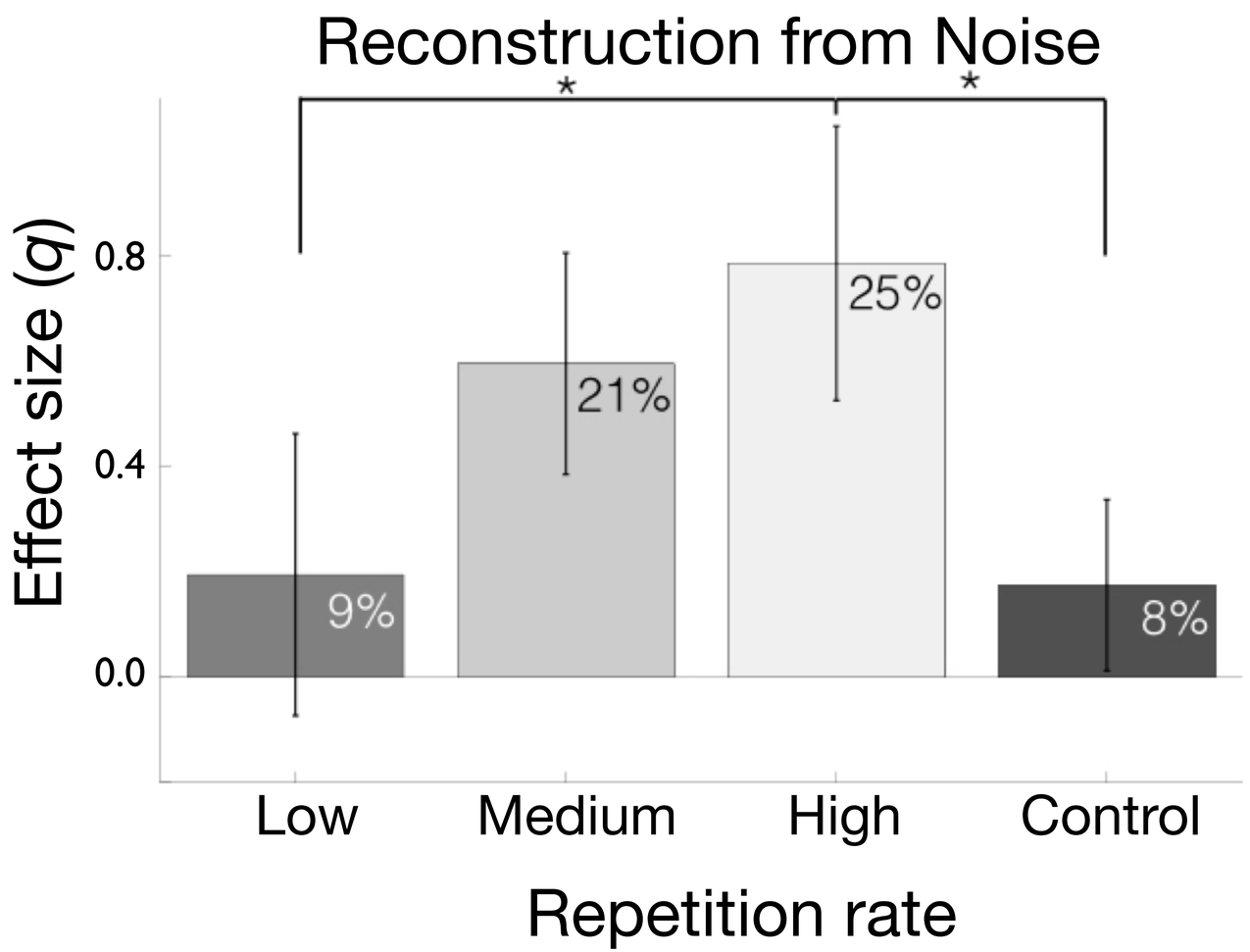
MEG



Cervantes Constantino & Simon, Front Syst Neurosci 2018

Imagined Speech “Reconstruction”

MEG



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

Cervantes Constantino & Simon, Front Syst Neurosci 2018

Speech Features as Language

- Many non-acoustic speech features are perceptually highly salient
  - phonemes
  - words & word boundaries
  - semantic features
  - phrasal features

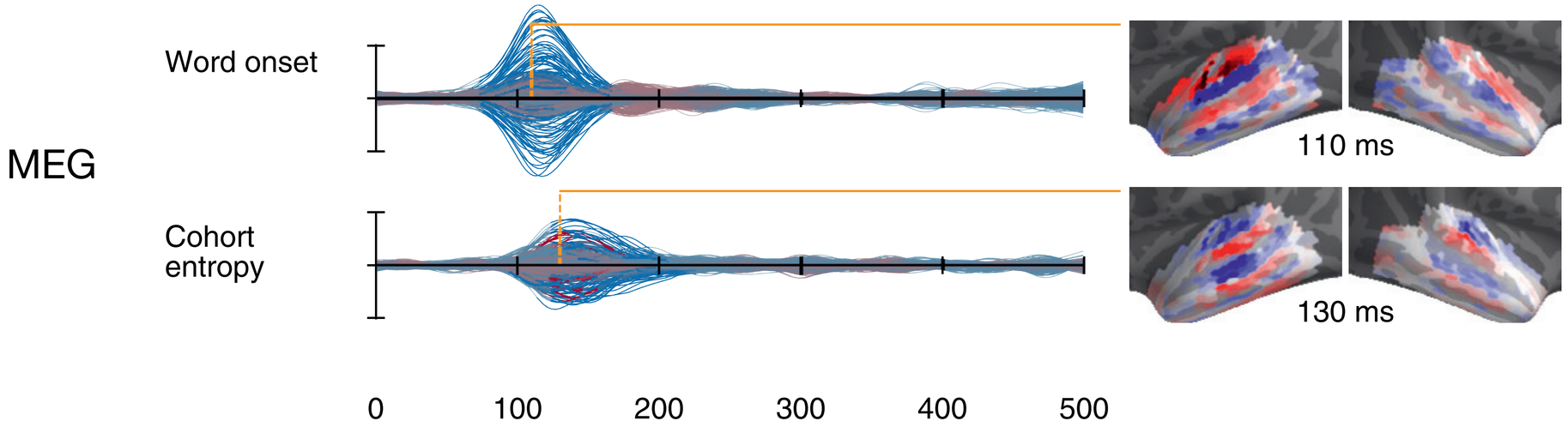
Decoding Language-based Features?

- Most investigations, so far, predictive of responses: via TRF
  - phonemes
  - words & word boundaries

Di Liberto et al., Curr Biol 2015

Teoh & Lalor, bioRxiv 2020

Brodbeck et al., Curr Biol 2018



Decoding Language-based Features?

- Most investigations, so far, predictive of responses: via TRF
  - phonemes
  - words & word boundaries
  - semantic features

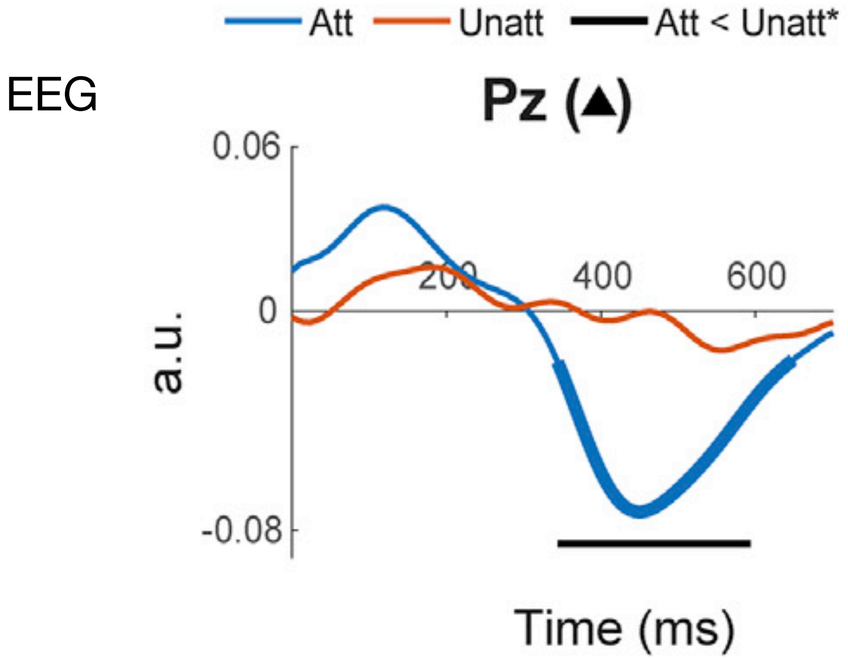
Di Liberto et al., Curr Biol 2015

Teoh & Lalor, bioRxiv 2020

Brodbeck et al., Curr Biol 2018

Decoding Language-based Features?

- Most investigations, so far, predictive of responses: via TRF
  - phonemes
  - words & word boundaries
  - semantic features

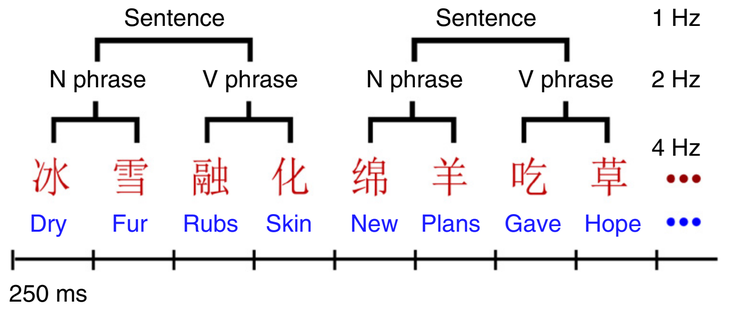


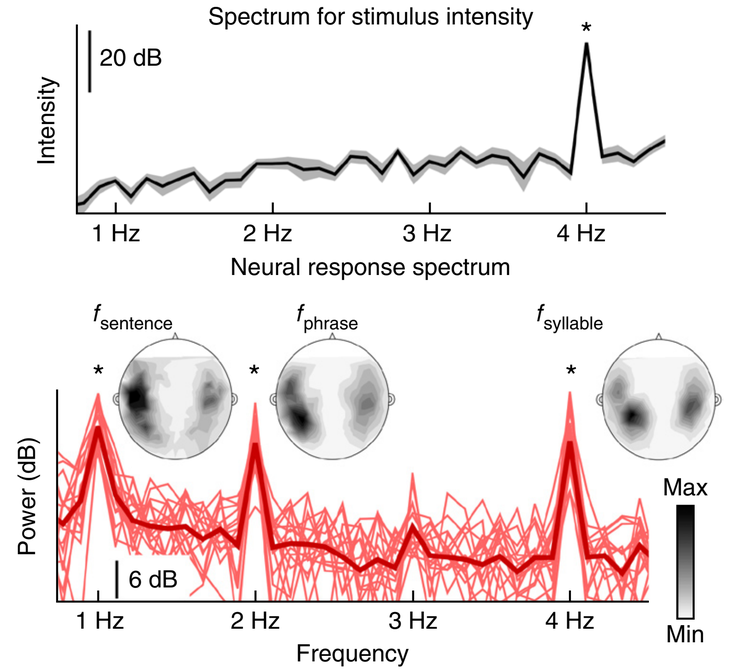
Broderick et al., Curr Biol 2018

Brodbeck et al., NeuroImage 2018

Decoding Language-based Features?

- Most investigations, so far, predictive of responses: via TRF
  - phonemes
  - words & word boundaries
  - semantic features
  - phrasal features





Ding et al., Nat Neurosci 2016

Decoding Understanding

- Detection of understanding
  - language comprehension
  - implied poetic meter
  - arithmetic

Ding et al., Nat Neurosci 2016

Teng et al., Curr Biol 2020

What Can We Decode?

- It’s amazing that non-invasive decoding can be done at all
- There are lots of things we can decode
- But also, not enough
- Will we see (create) a “killer app” for decoding via Cognitive Hearing?

(cough, cough, BMI)

Thank you