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Computational
Sensorimotor
Systems Lab

Neural speech processing in the aging auditory brain

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http://www.isr.umd.edu/Labs/CSSL/simonlab

ISAAR, 25 August 2021

Acknowledgements

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Funding & Support

NIH NIA
NIDCD
NSF
DARPA
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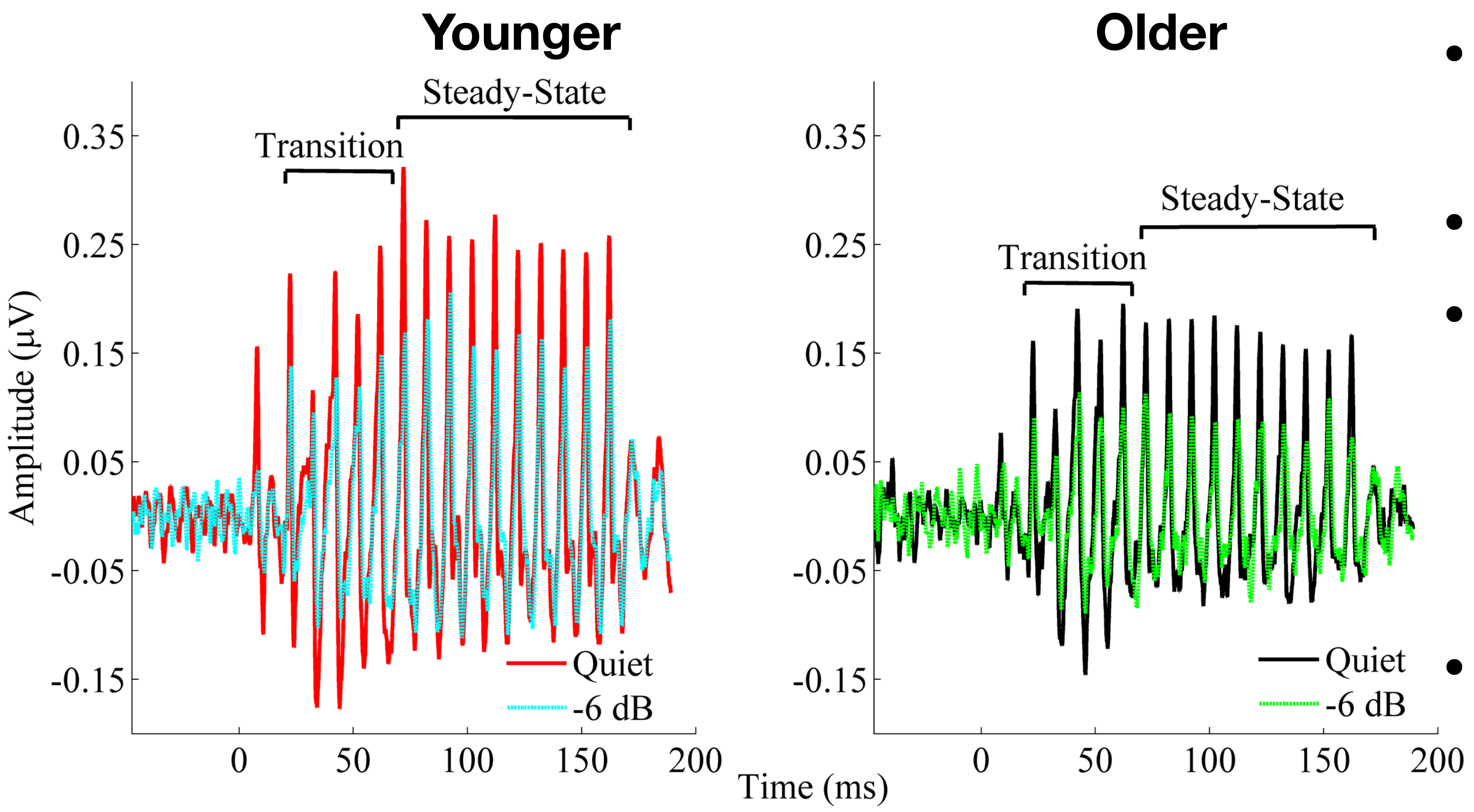
Introduction

- Older adults have speech comprehension difficulty in presence of other talkers
  - even with clinically normal hearing
- Subcortical neural speech representations: **worse** for older listeners (expected)
- Cortical neural speech representations: **better** for older listeners (**unexpected)**
- Results presented here from two experiments,
  - *Expt A* (2016): EEG-FFR & MEG (led by Presacco)
  - *Expt B* (2019-2020) MEG & Pupillometry
  - Younger (18–27 yr) & Older (61–78 yr); thresh ≤ 25 dB HL (125 to 4000 Hz)
  - MEG with **60 s** trials of continuous speech, clean & with simultaneous talkers
    - “cocktail party” distinguishes between bottom-up and task-related activity

Subcortical Frequency Following Response



- FFR: 2300 repetitions of /da/
- dominantly subcortical
- representation weakens with aging
  - lower amplitude?
  - timing variability?
- as might expect

Presacco et al. (2016) *Evidence of Degraded Representation of Speech in Noise …*, J Neurophysiol

Expt A

Continuous Speech Stimuli

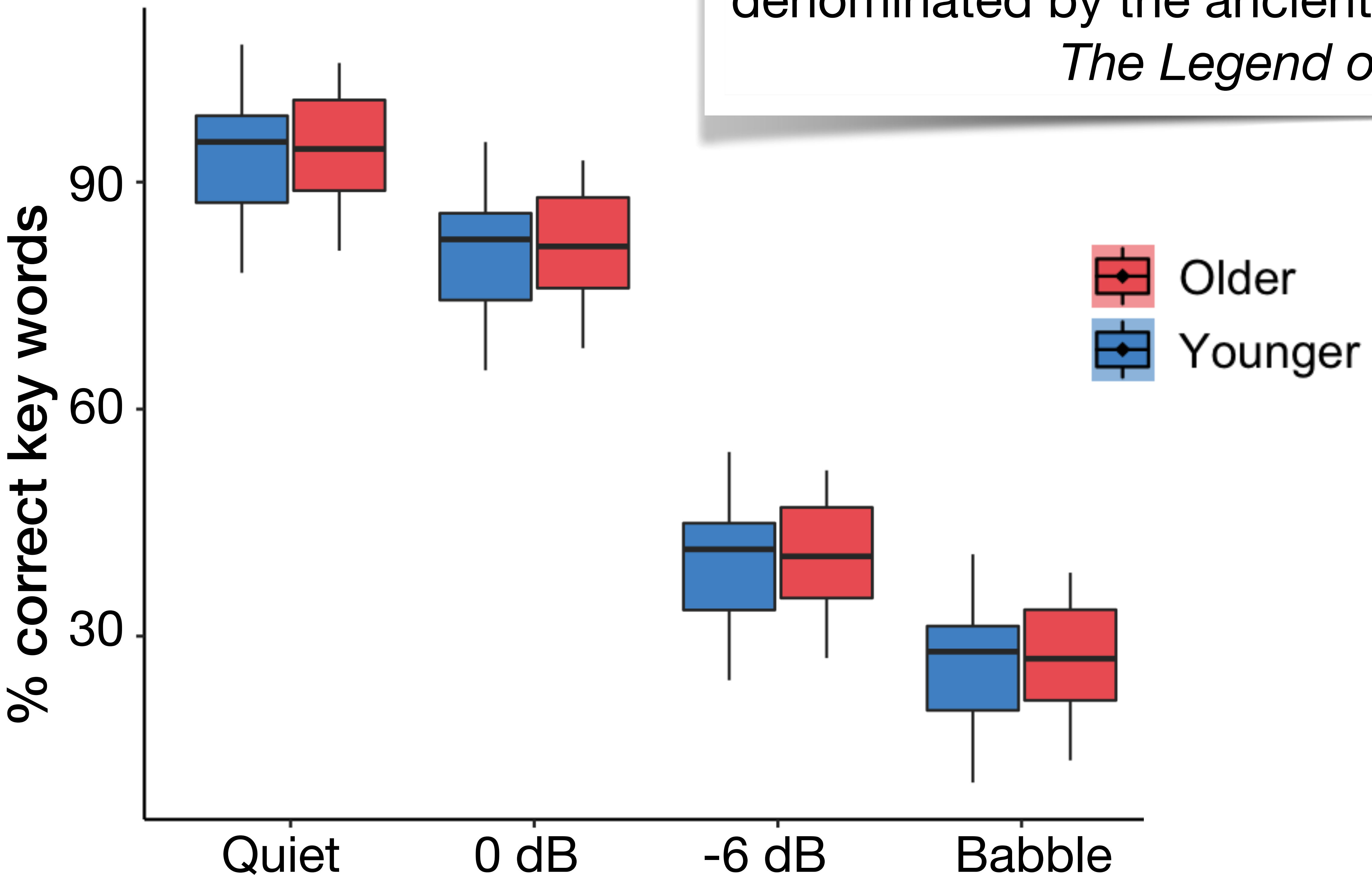
Alfred the Great was a young man, three-and-twenty years of age, when he became king. Twice in his childhood, he had been taken to Rome, where the Saxon nobles were in the habit of going on journeys which they supposed to be religious; …

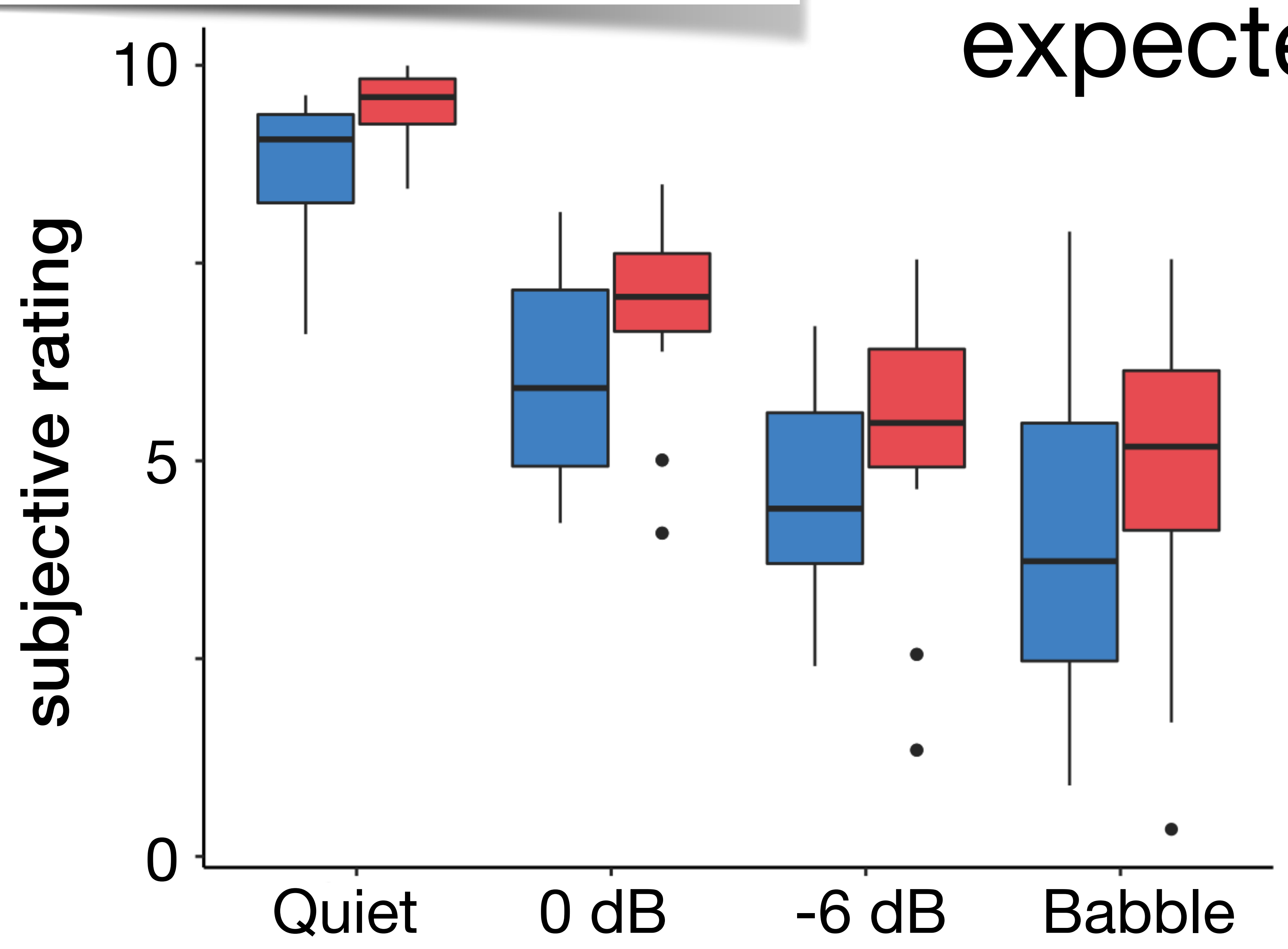
A Child's History of England — Charles Dickens

In the bosom of one of those spacious coves which indent the eastern shore of the Hudson, at that broad expansion of the river denominated by the ancient Dutch navigators …

The Legend of Sleepy Hollow — Washington Irving

- Used to drive cortical responses
- Task difficulty increases ~as expected

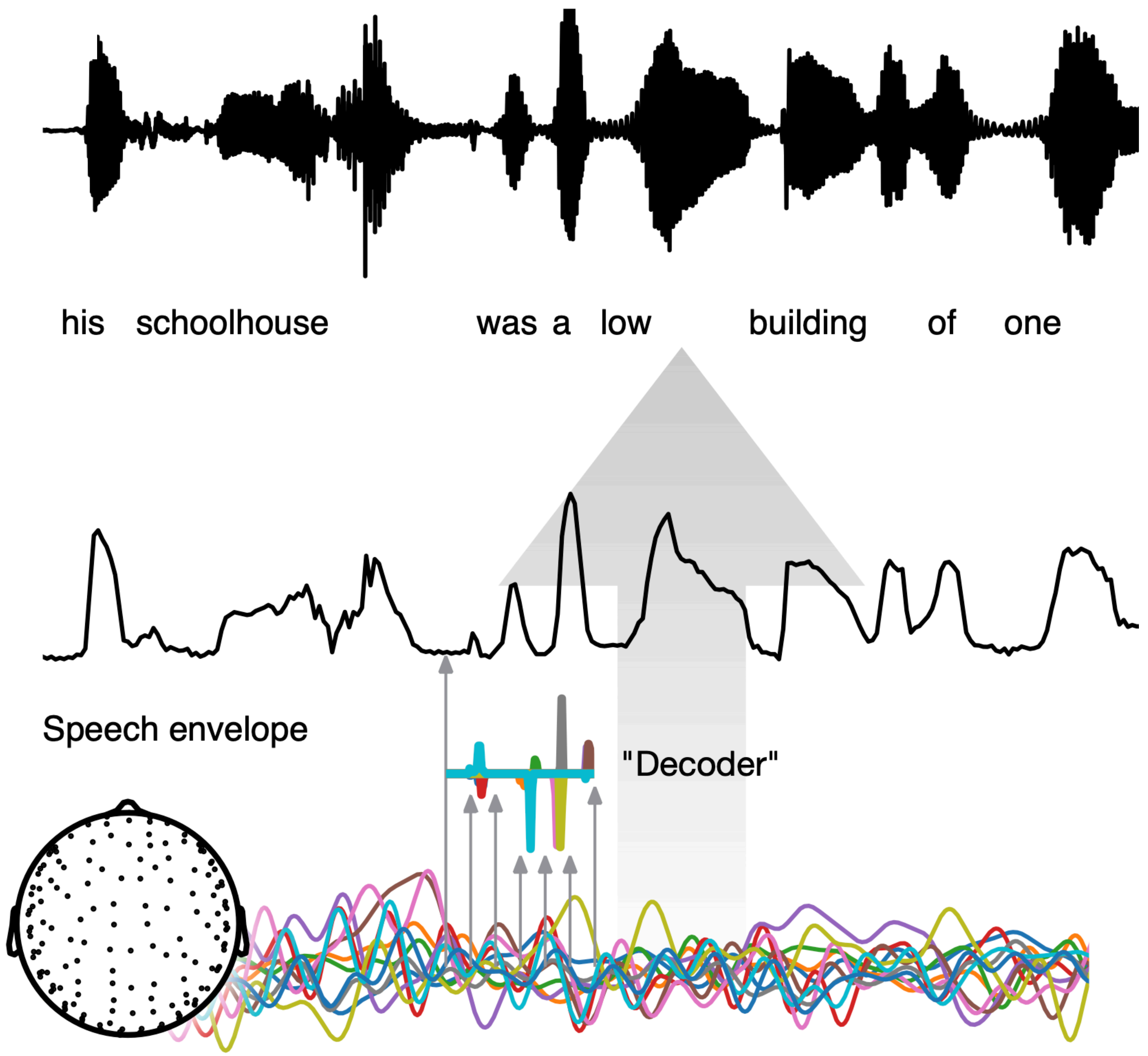




Expt B

Cortical Representations: Decoding

- Reconstruct past stimulus features (from present neural responses)
  - how much information, regarding this stimulus feature, is visible in the brain?
- Typically speech envelope (dynamic, ongoing)
  - other features possible but less common
- Moderate time resolution (~50 ms)



Example: EEG/MEG Reconstruction of Speech Envelope

Brodbeck & Simon (2020) Continuous Speech Processing, Curr Op Physiol

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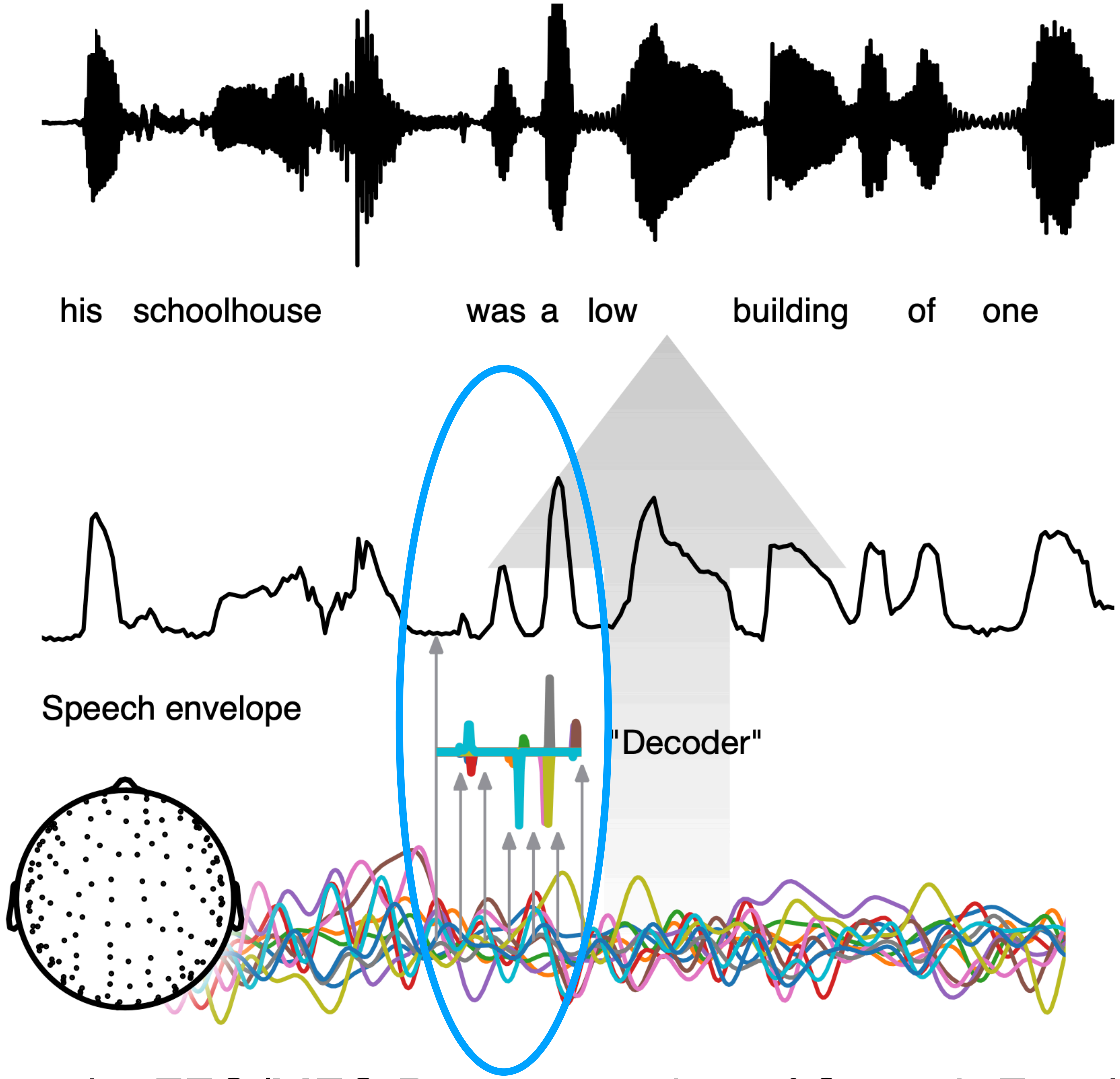

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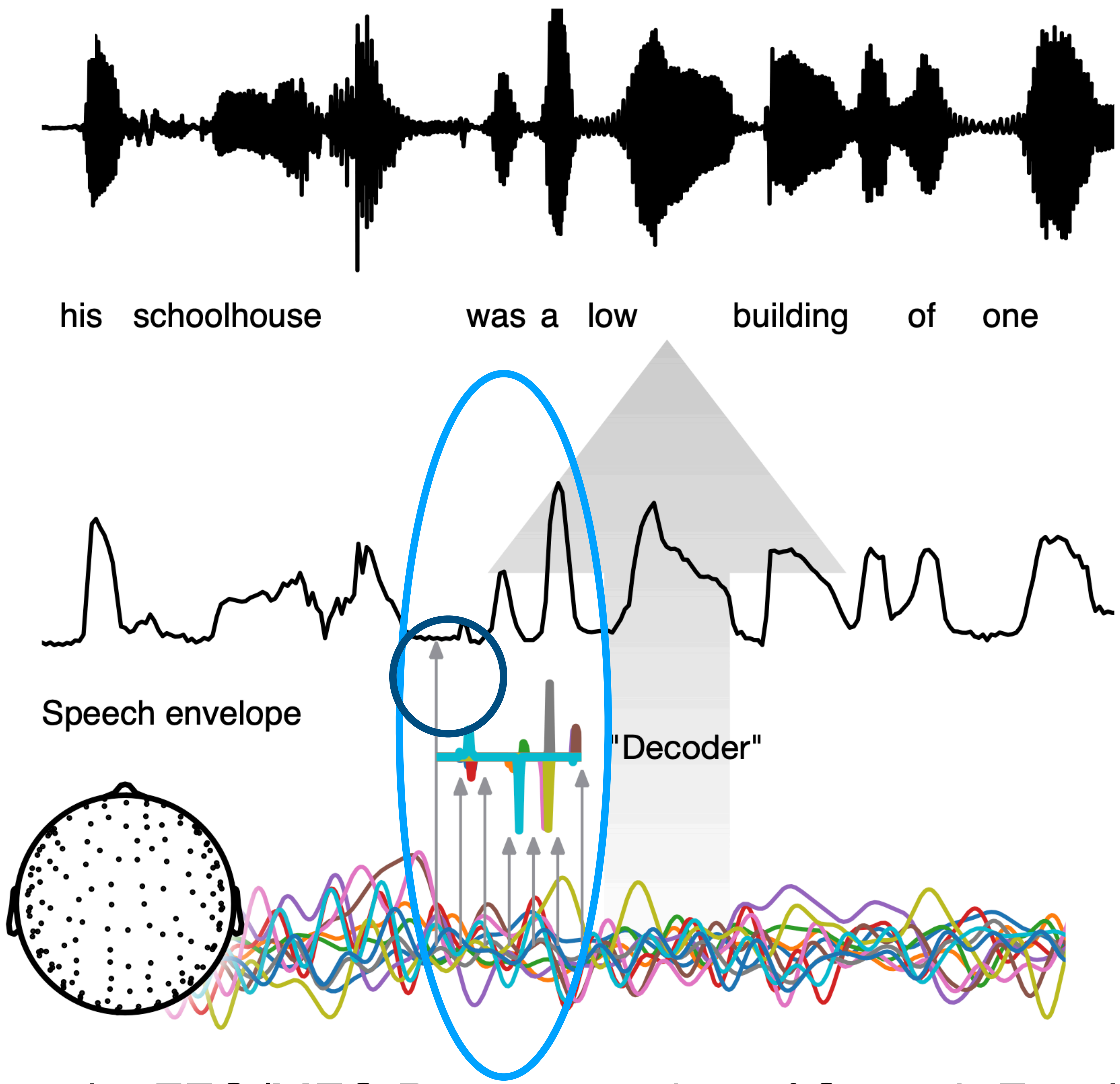

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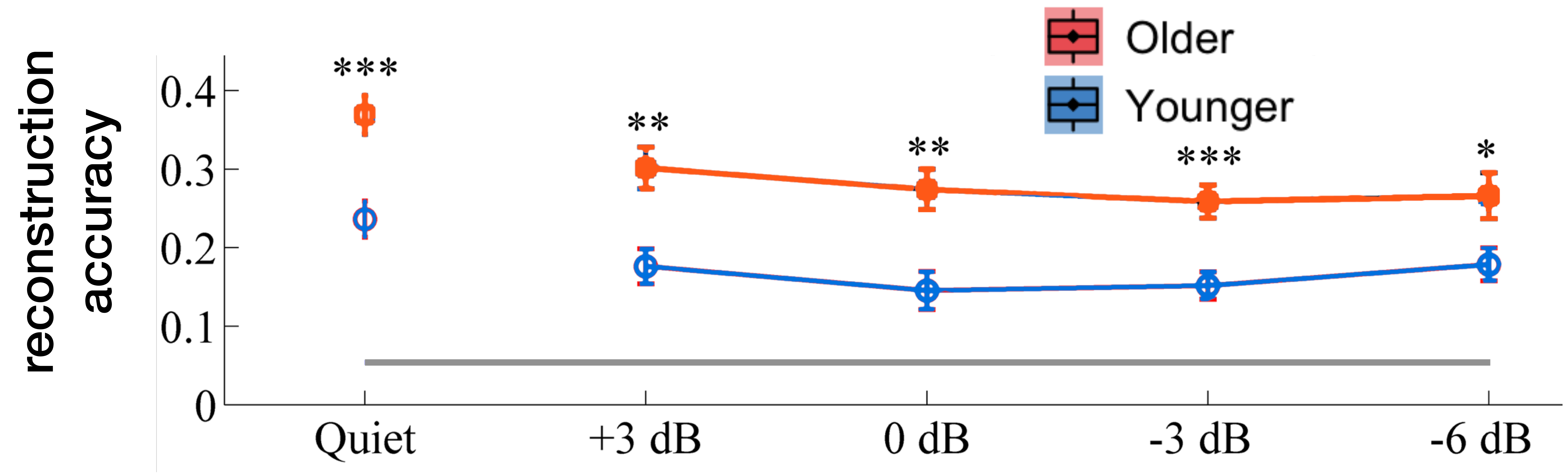
Brodbeck & Simon (2020) Continuous Speech Processing, Curr Op Physiol

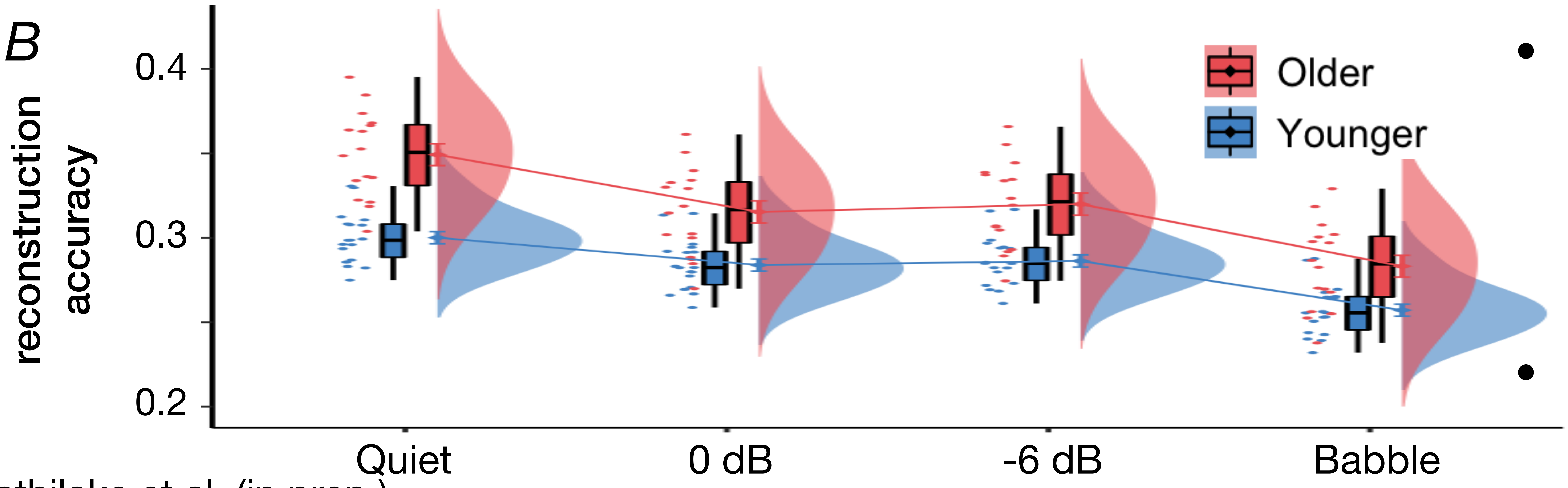
Speech Reconstruction Accuracy

Expt A



Presacco et al. (2016) *Evidence of Degraded Representation …*, J Neurophysiol

Expt B



Karunathilake et al. (in prep.)

- Neural speech envelope representation **larger** in **older** adults
- unexpected
- Also observed with EEG, e.g., Francart, Obleser labs
- (unchanged with repeated trials)

Possible Explanations

Increased (non-specific) cortical gain for bottom-up/early responses in older brains

- ***Prediction***: same neural origin for older and younger, but more current for older

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Low level physiological change: excitation/inhibition imbalance in older brains

- Reduction in inhibitory neurons in A1 (de Villers-Sidani et al., 2010)
- Increased firing rates in A1 (Overton & Recanzone, 2016)
- Faster recruitment of higher order regions (Engle & Recanzone, 2013)
- ***Prediction***: Enhanced early responses, possibly with higher order regions

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Top-down/strategic later processing in older brains

- Compensate for degraded input from the periphery
- Recruite additional frontal and temporal areas (Peelle et al., 2010), other hemisphere (Cabeza, 2002)
- Increased attentional gain?
- ***Prediction***: Response enhancement, possibly from higher order (greater latency) areas

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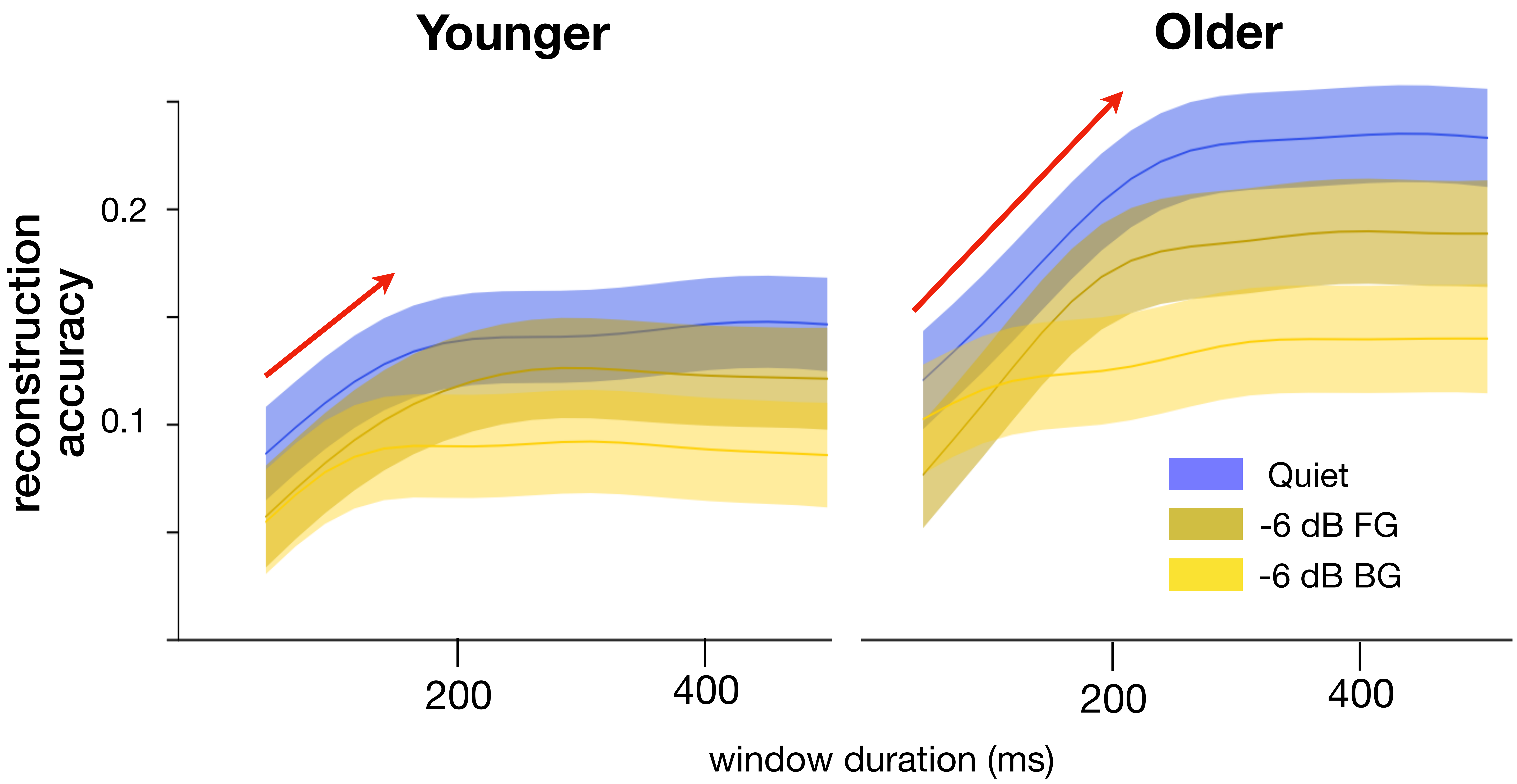
More …

Reconstruction Window Analysis



- Cortical representation more accurate with more integration time
    - Younger: until ~150 ms
    - Older: until ~250 ms
- Not just amplification

Karunathilake et al. (in prep.)

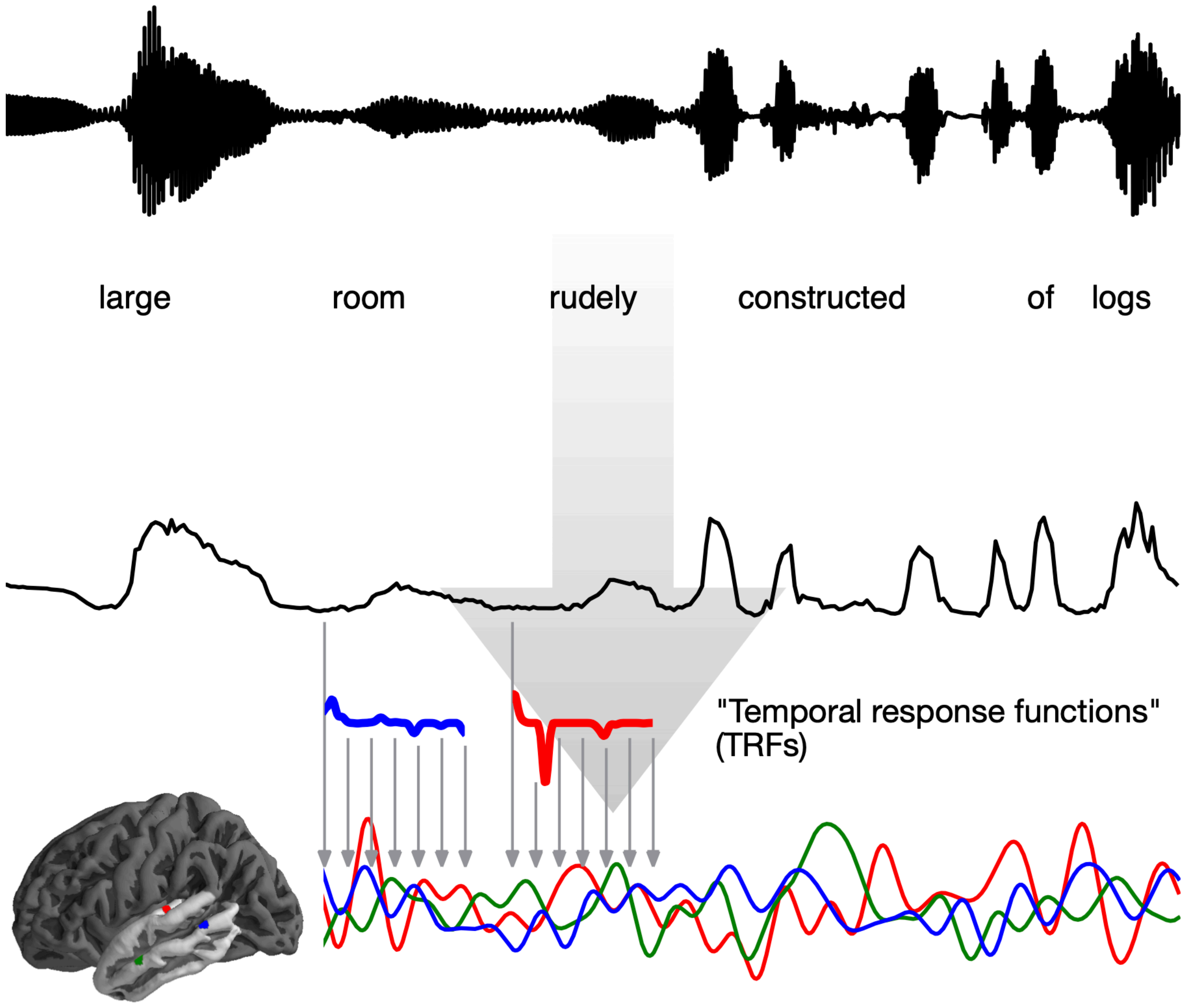
Expt B

Encoding Representations: TRF

- Predicting future neural responses from present stimulus features,
  - wide variety of stimulus features
  - via Temporal Response Function (TRF)

- Why look at encoding? It *often* tells us more about the brain
  - TRF analogous to evoked response
  - peak amplitude ≈ processing intensity
  - peak latency ≈ source location
  - multiple TRFs simultaneously

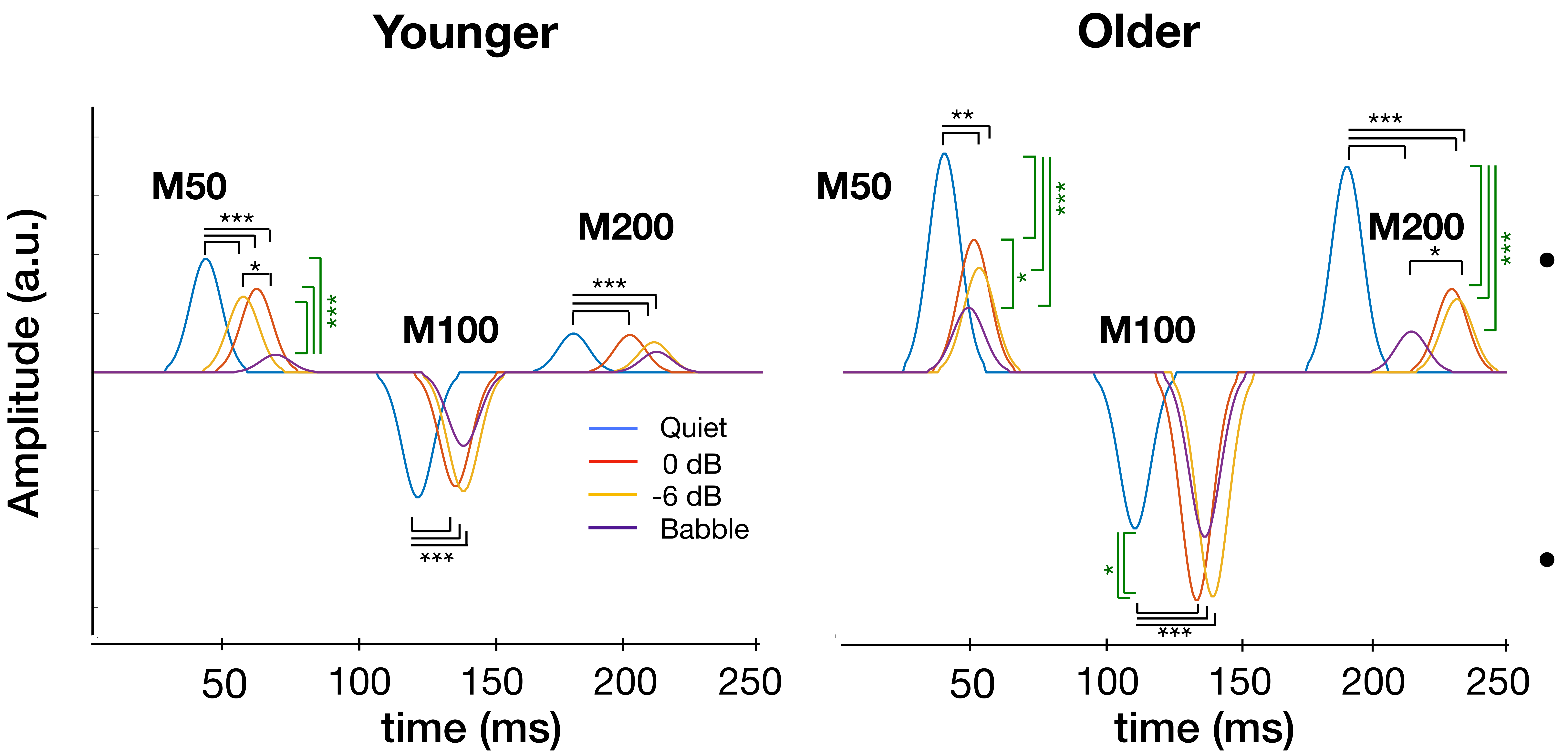
Temporal Response Function



Example: MEG Prediction of Voxel Responses

Brodbeck & Simon (2020) Continuous Speech Processing, Curr Op Physiol

TRF Analysis

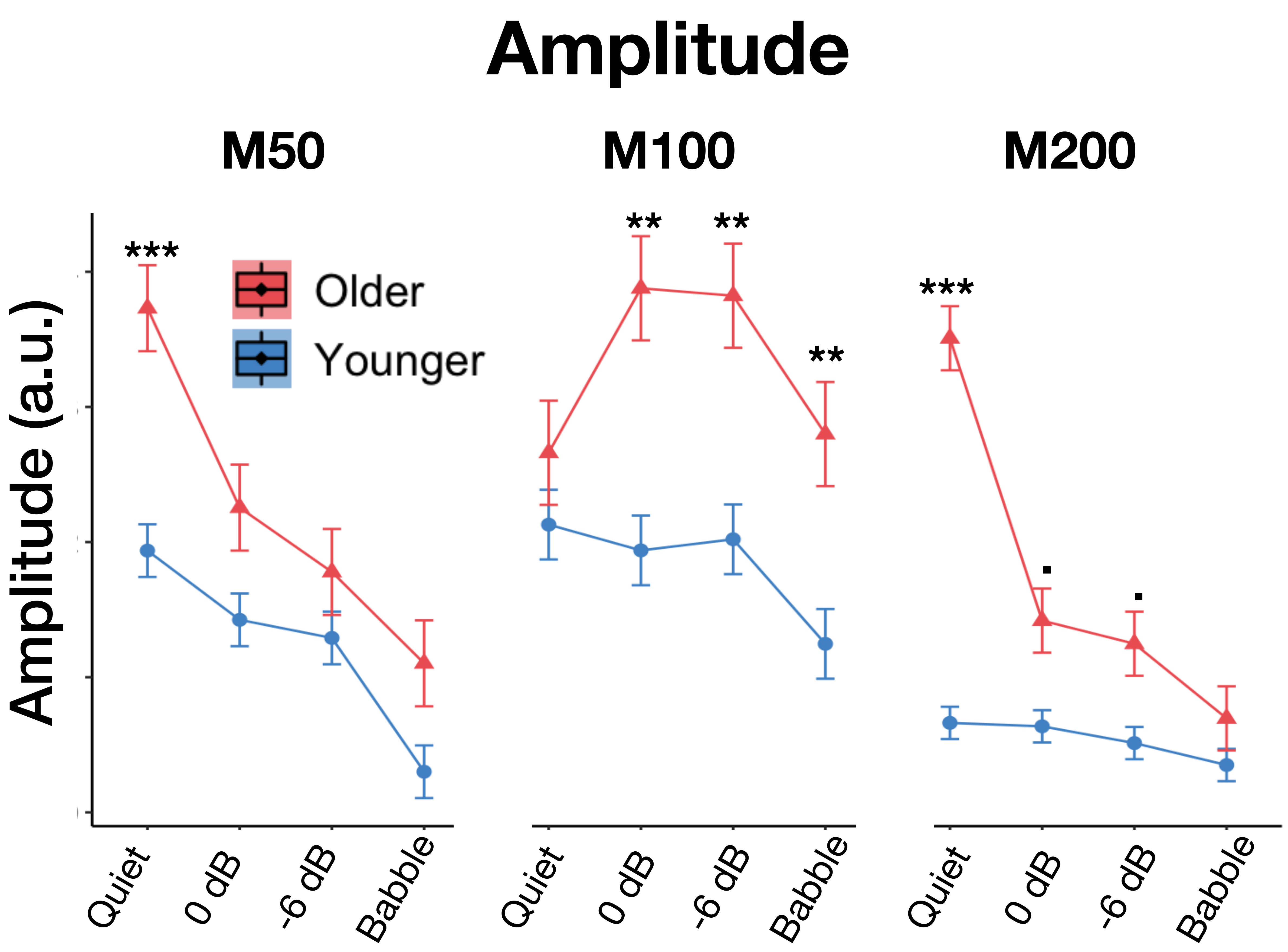


- Information on latencies (e.g., cortical processing stages)
- (Does not change with repeated trials)
- *See next slide for easier comparisons*

Expt B

Karunathilake et al. (in prep.)

Major TRF Peaks



- Older > Younger at every latency
- **but** very different dependence on SNR

Karunathilake et al. (in prep.)

Expt B

Major TRF Peaks

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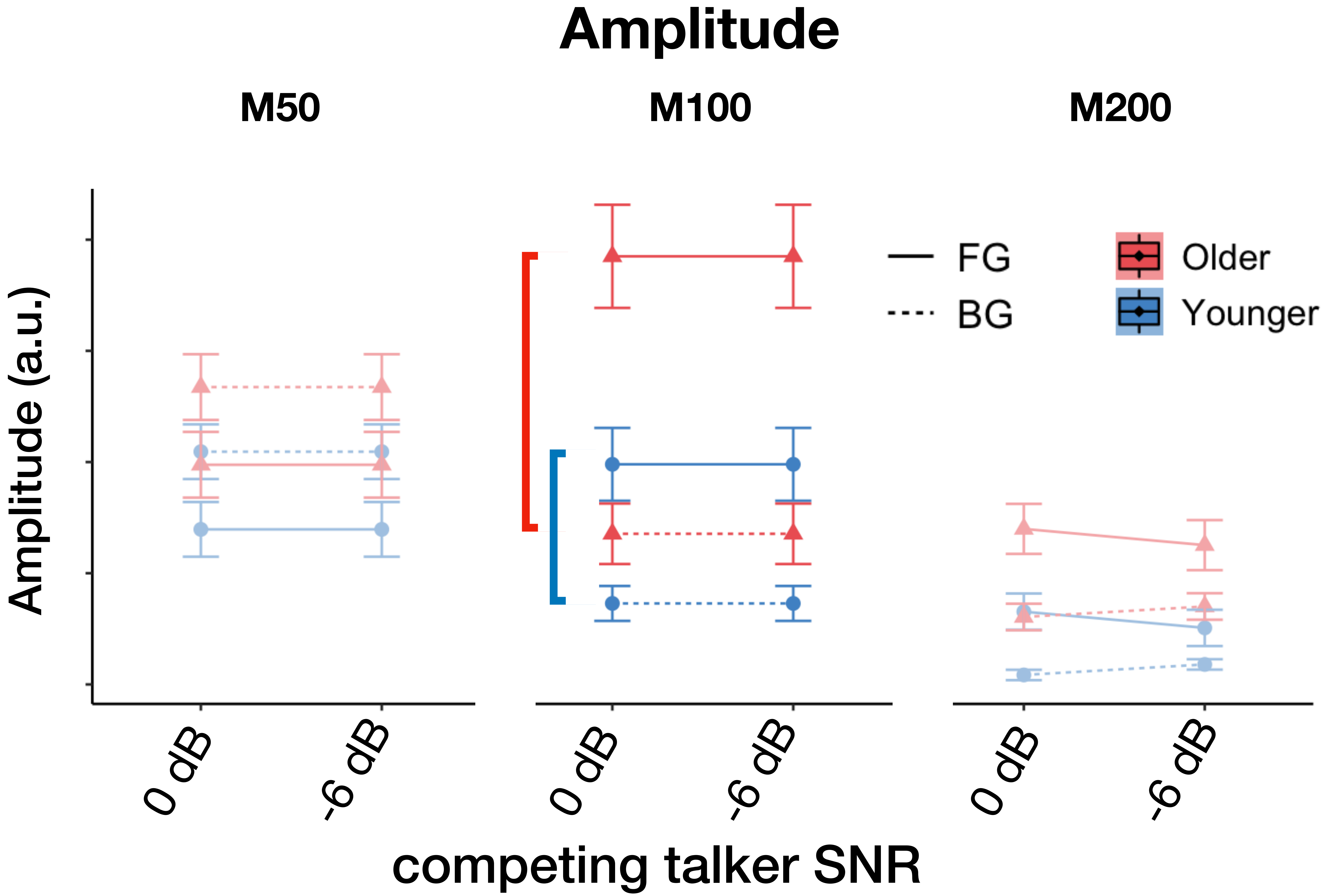
- **but** very different dependence on SNR

Karunathilake et al. (in prep.)

Expt B

TRF Peaks: Foreground vs Background



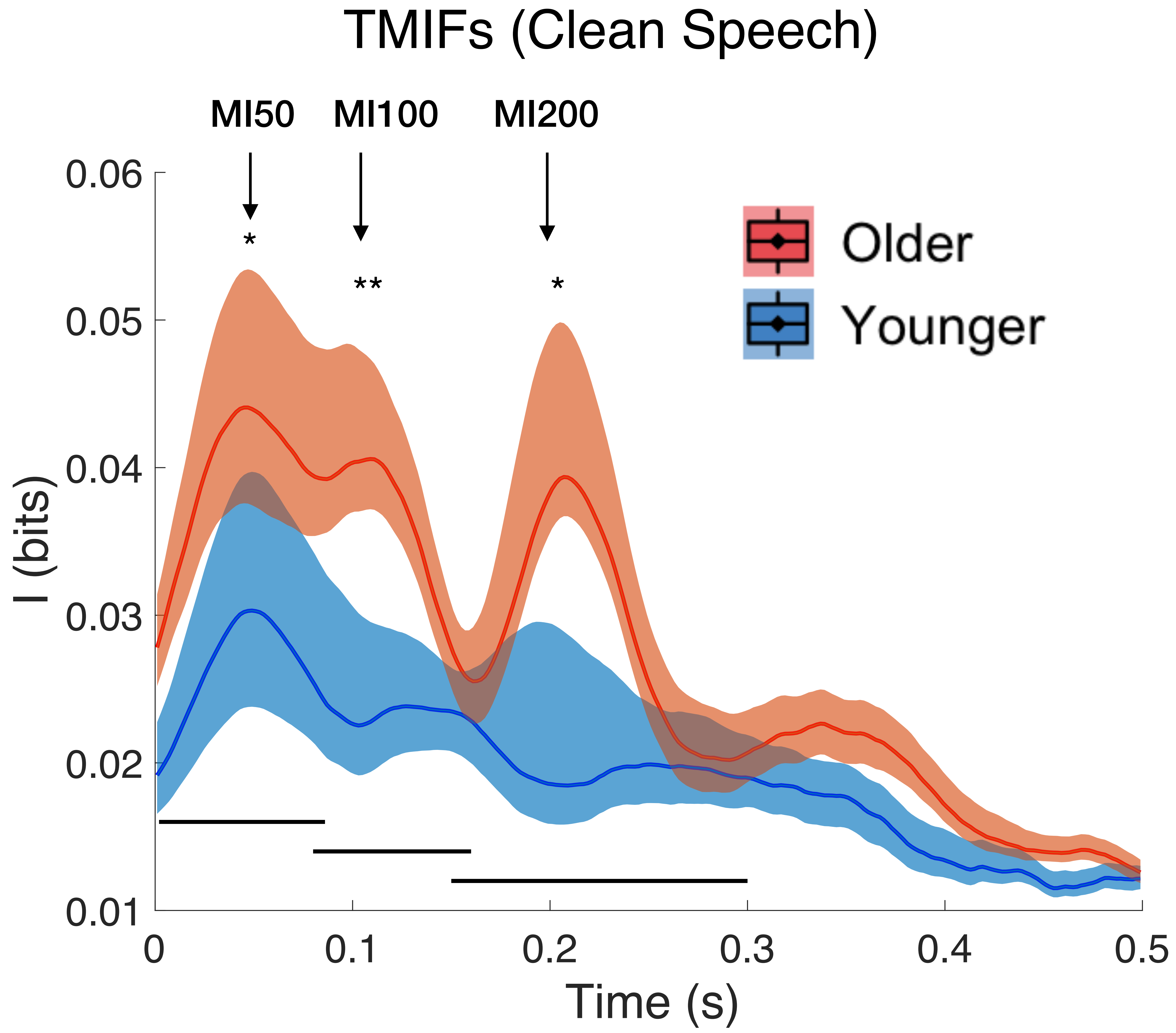
- Even background speech processing is greater in older adults

Expt B

Karunathilake et al. (in prep.)

Mutual Information

- Mutual Information
  - based on Shannon's information theory
  - links stimulus and response non-linearly
  - Mutual Information exaggerated in older listeners at ~50 ms, ~100 ms, and ~200 ms



Expt A

Zan et al. (2020) *Exaggerated Cortical…in Older Listeners: Mutual Information Analysis*, J Neurophysiol

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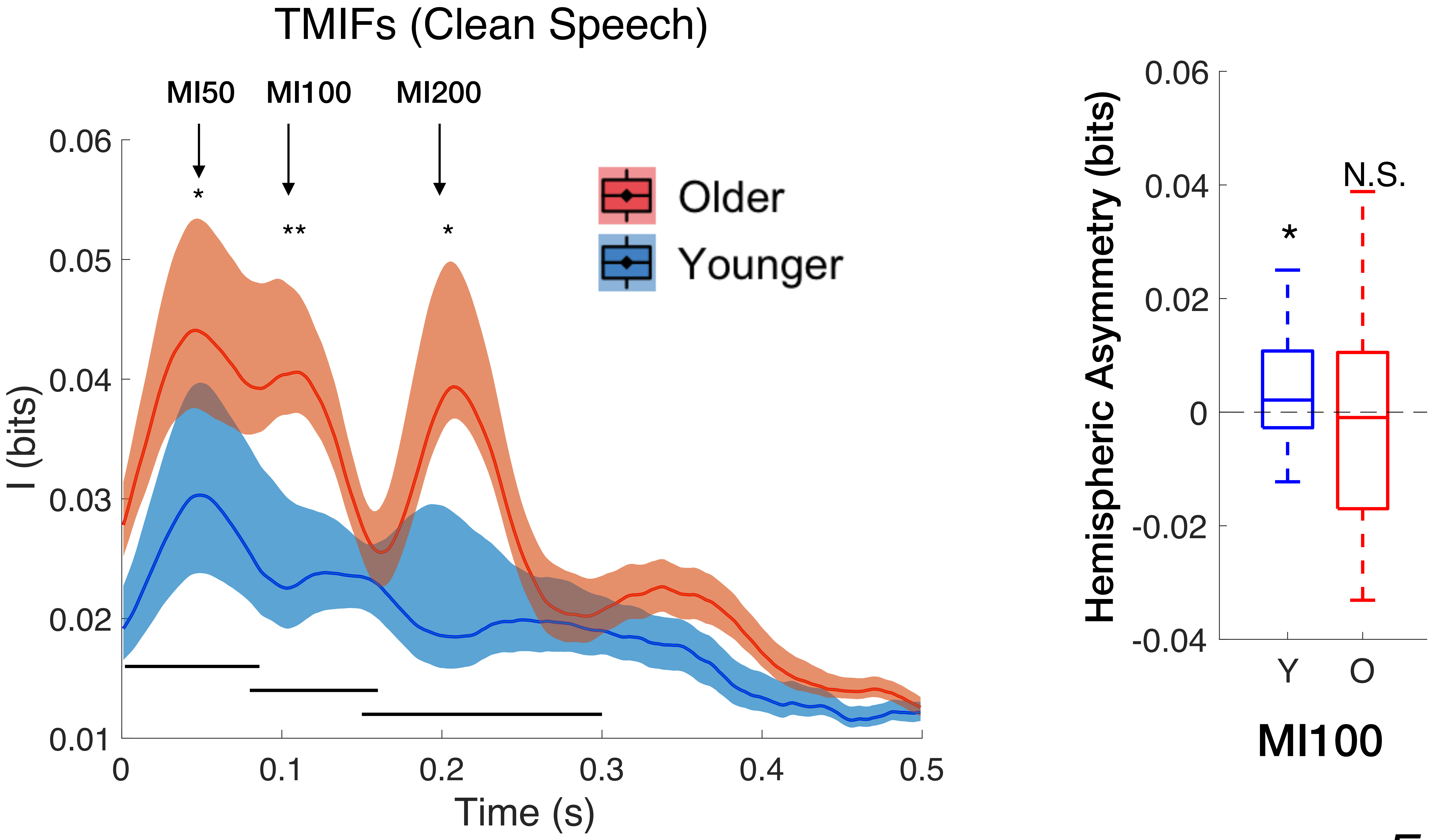

Expt A

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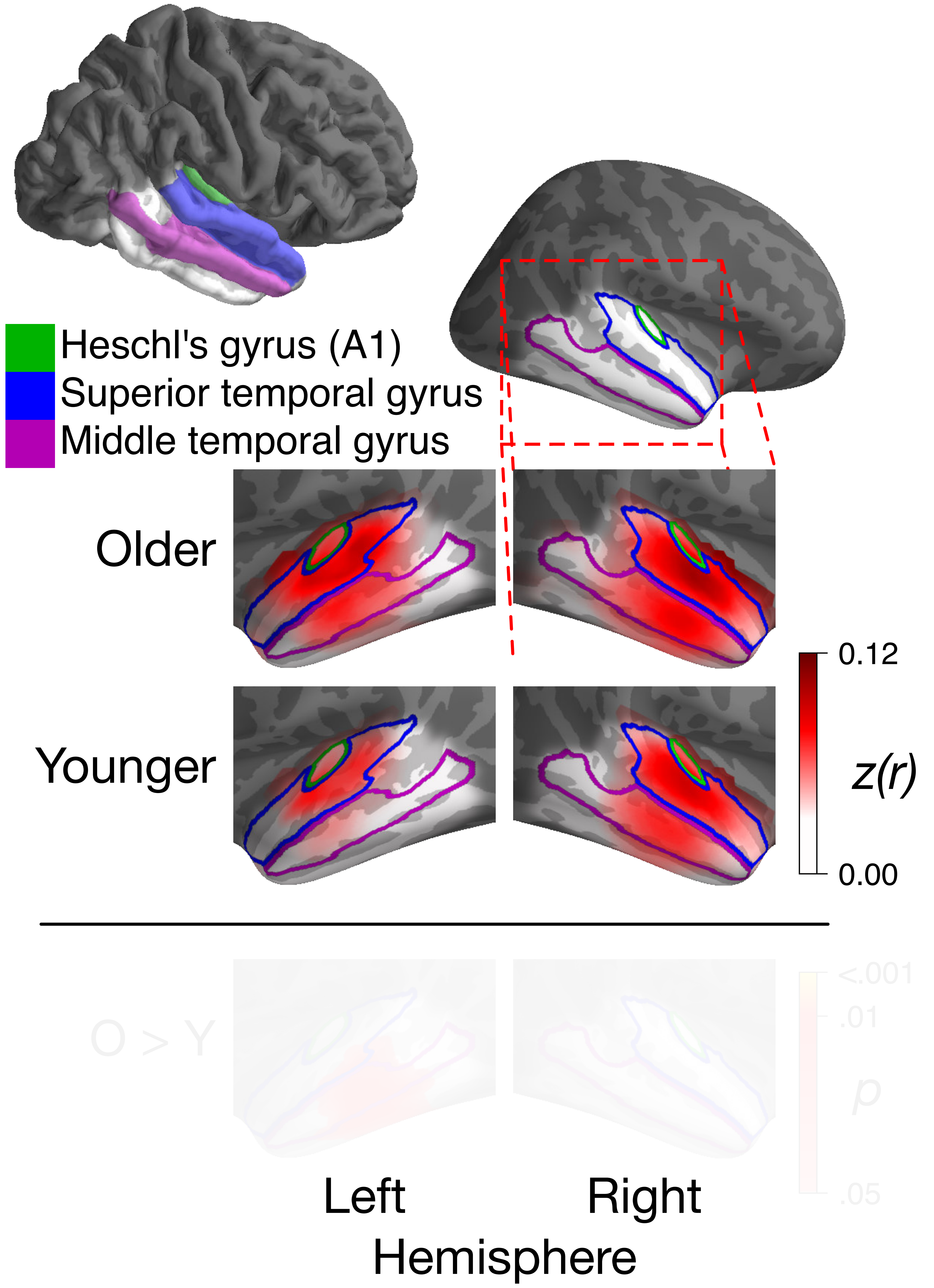
Neural Source Localization

Brain activity (MEG source estimate) predicted from acoustic envelope

- Maps of correlation (*r*) between actual and predicted neural time course



Brodbeck et al. (2018) *Over-Representation of Speech in Older …* Acta Acust united Ac

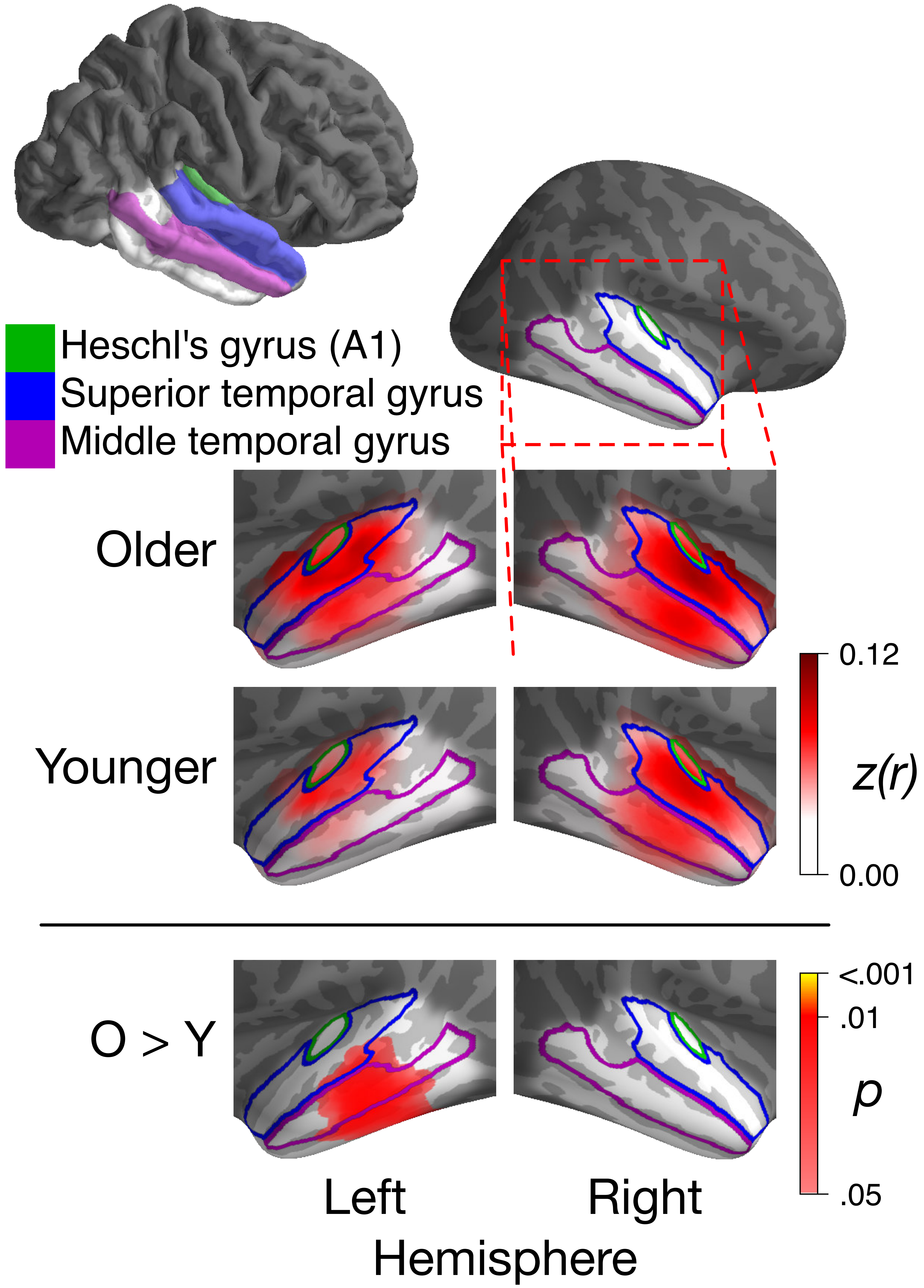
Neural Source Localization

Brain activity (MEG source estimate) predicted from acoustic envelope

- Maps of correlation (*r*) between actual and predicted neural time course

Older > Younger

- Significant difference ventral to core auditory cortex
- No significant difference between hemispheres



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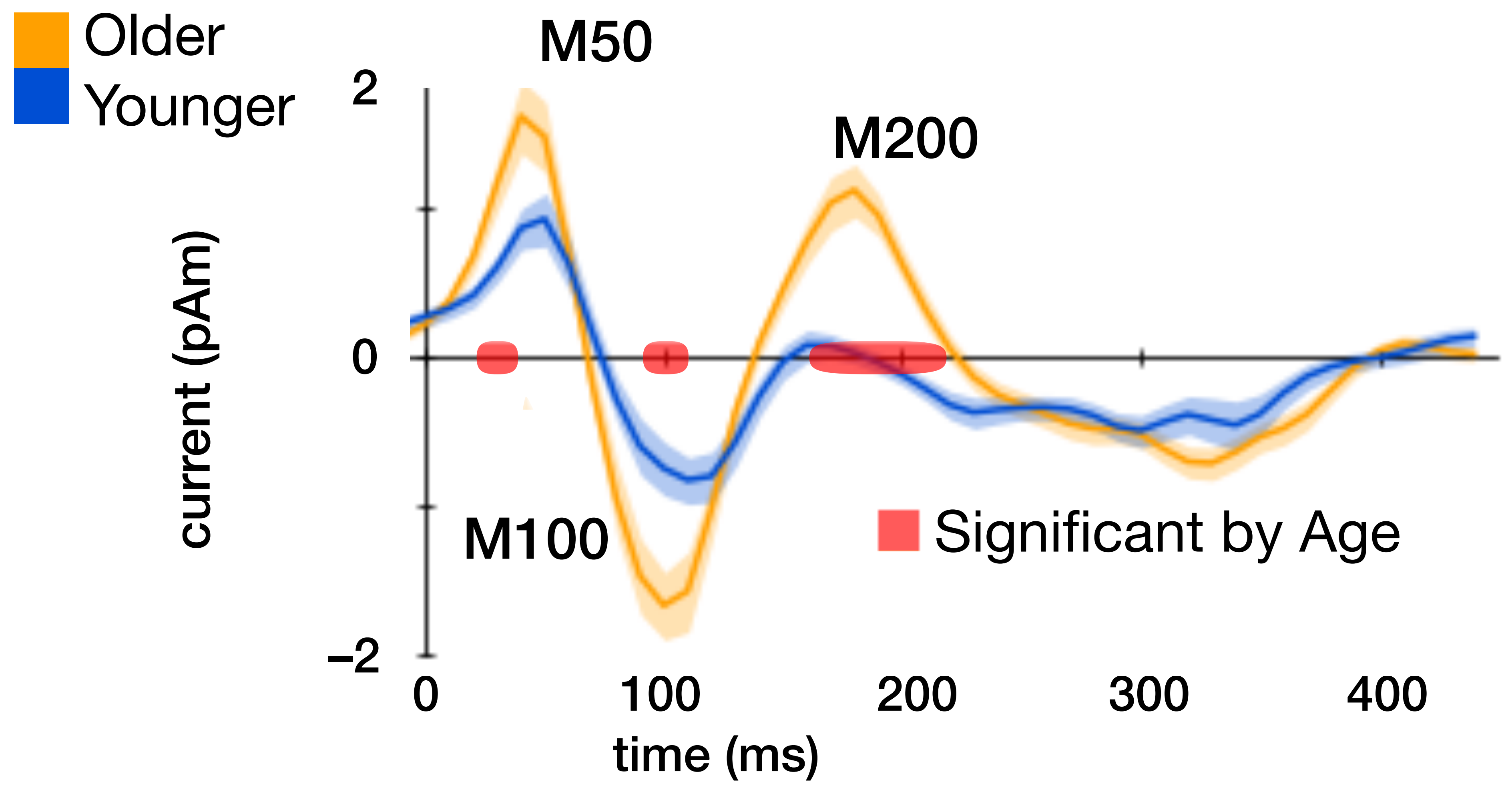

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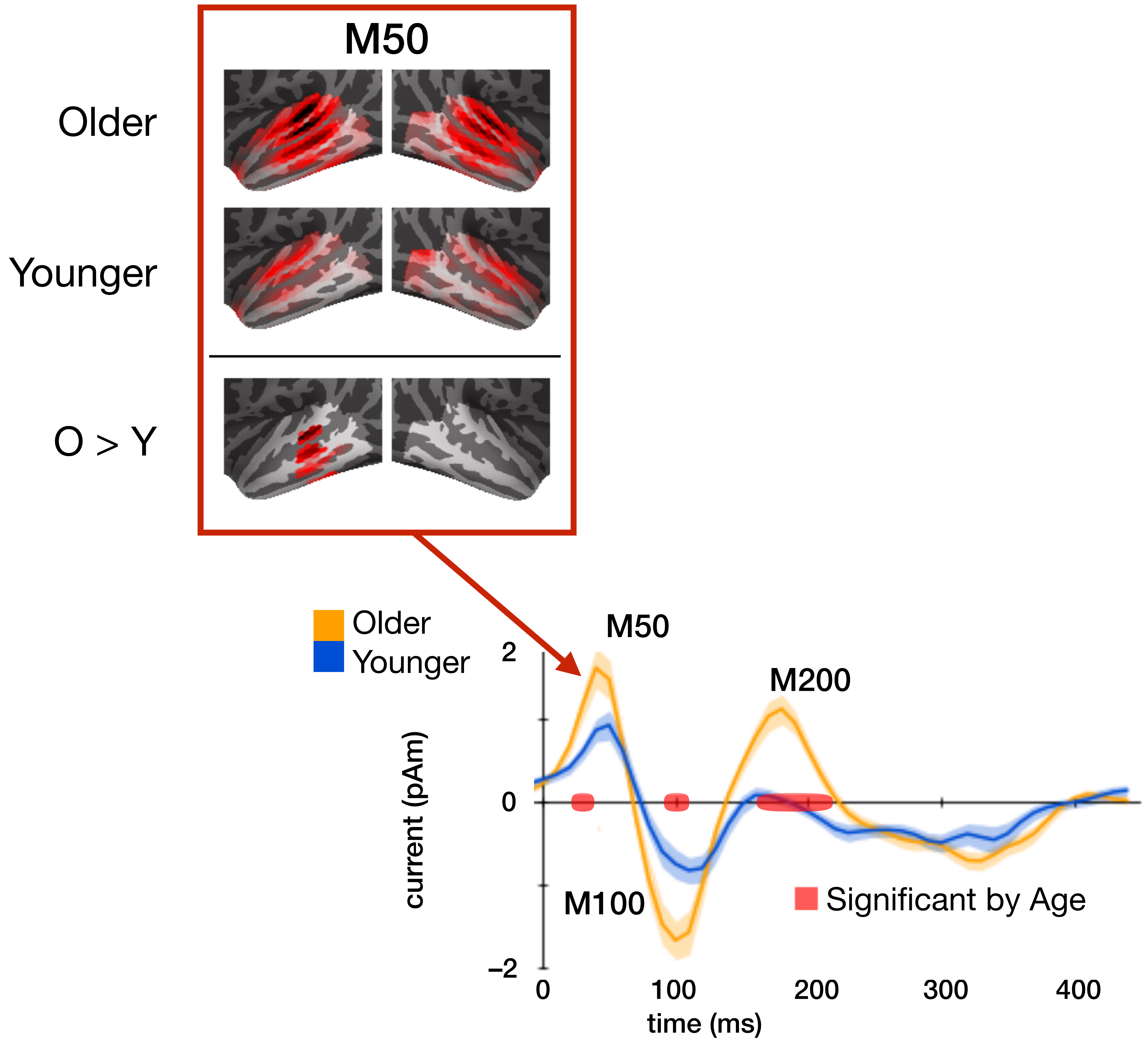
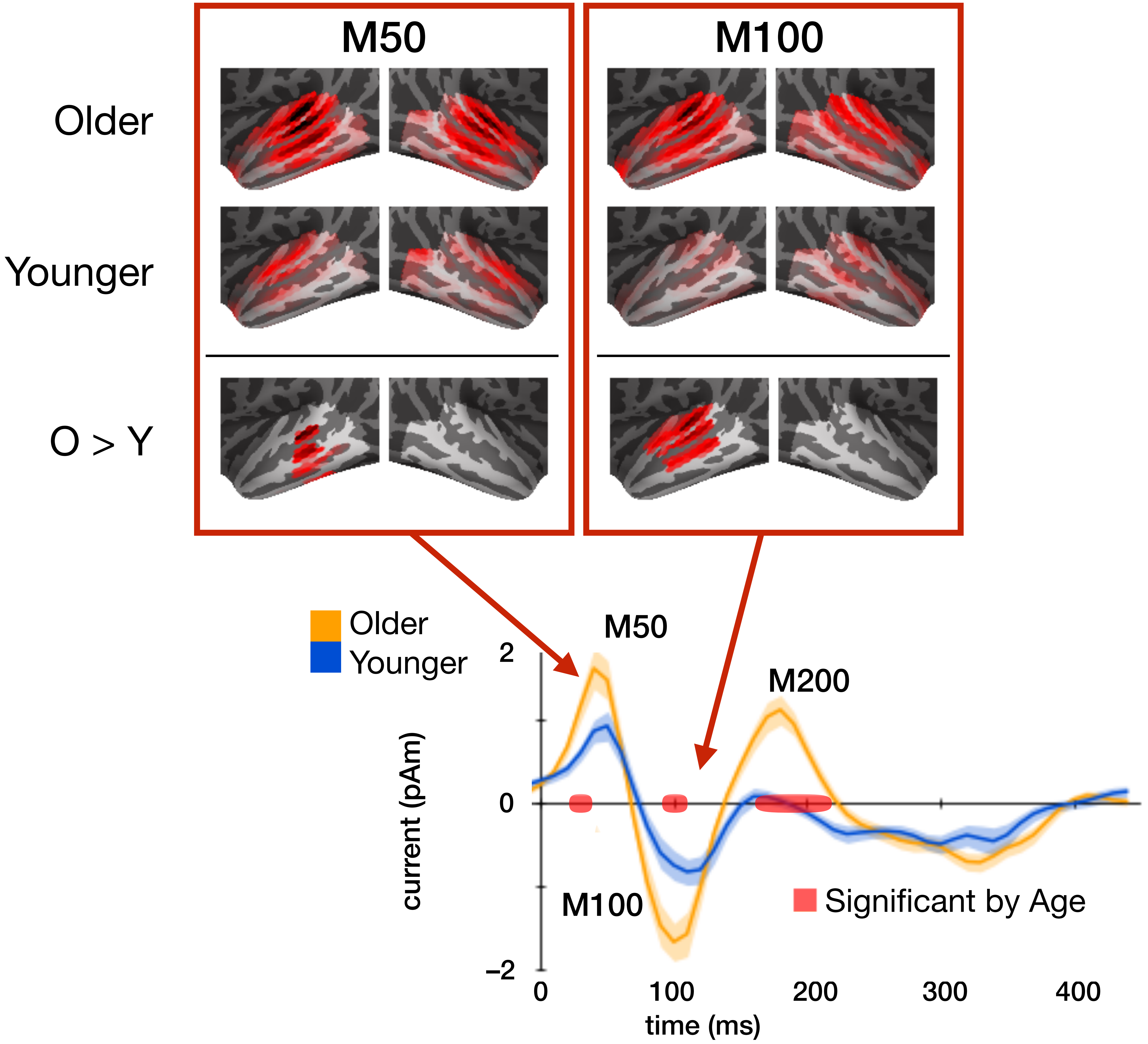


M50

- ~~Nonspecific gain~~ (non-core area)
- ~~Top-down~~ (early)

➡ Consistent with excitation/inhibition imbalance

Neural Source Localization



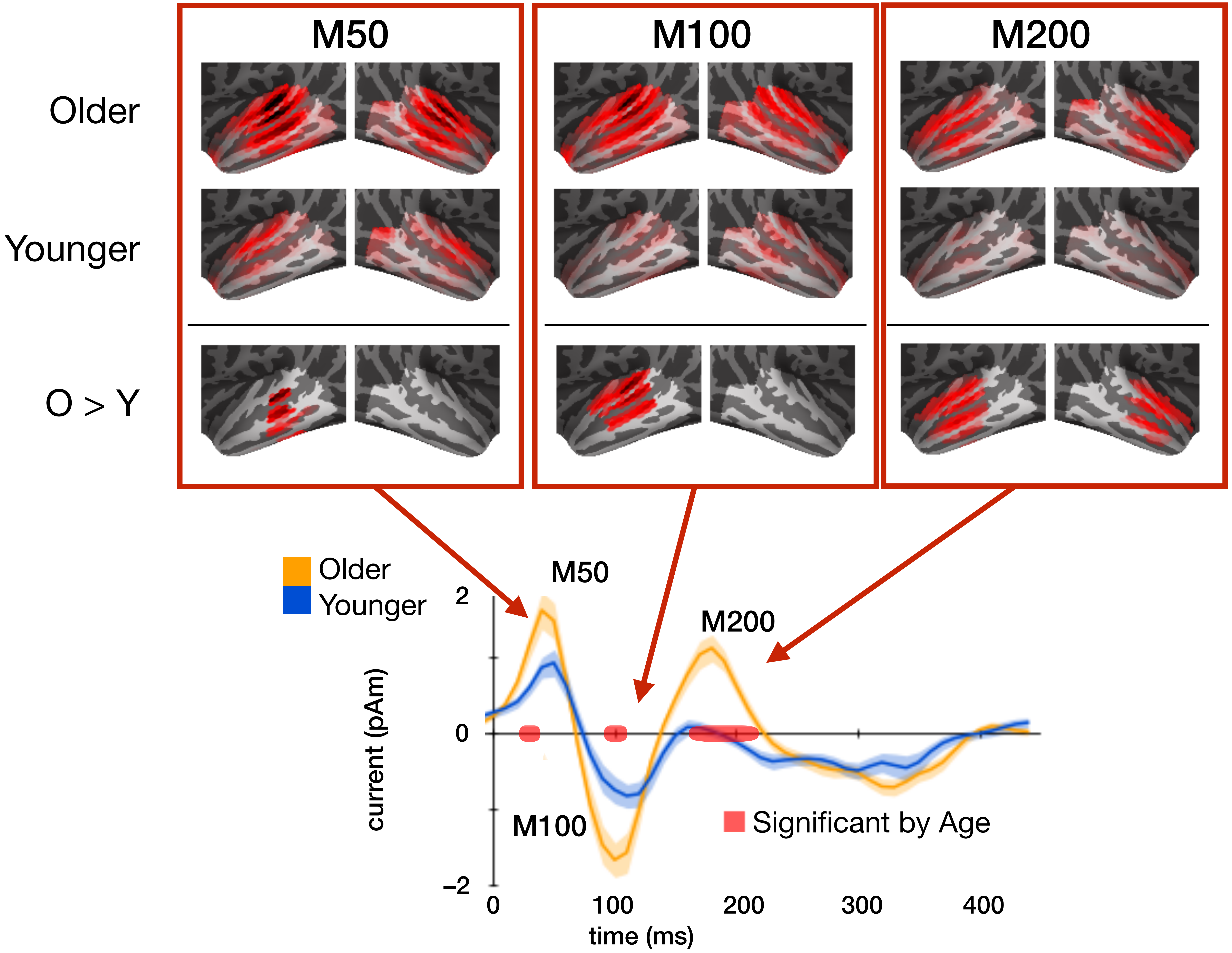
M50

- ~~Nonspecific gain~~ (non-core area)
- ~~Top-down~~ (early)
- ➡ Consistent with excitation/inhibition imbalance

M100

- Increased gain?
- Top down? (M100 associated with attention)

Neural Source Localization



M50

- ~~Nonspecific gain~~ (non-core area)
- ~~Top-down~~ (early)

➡ Consistent with excitation/inhibition imbalance

M100

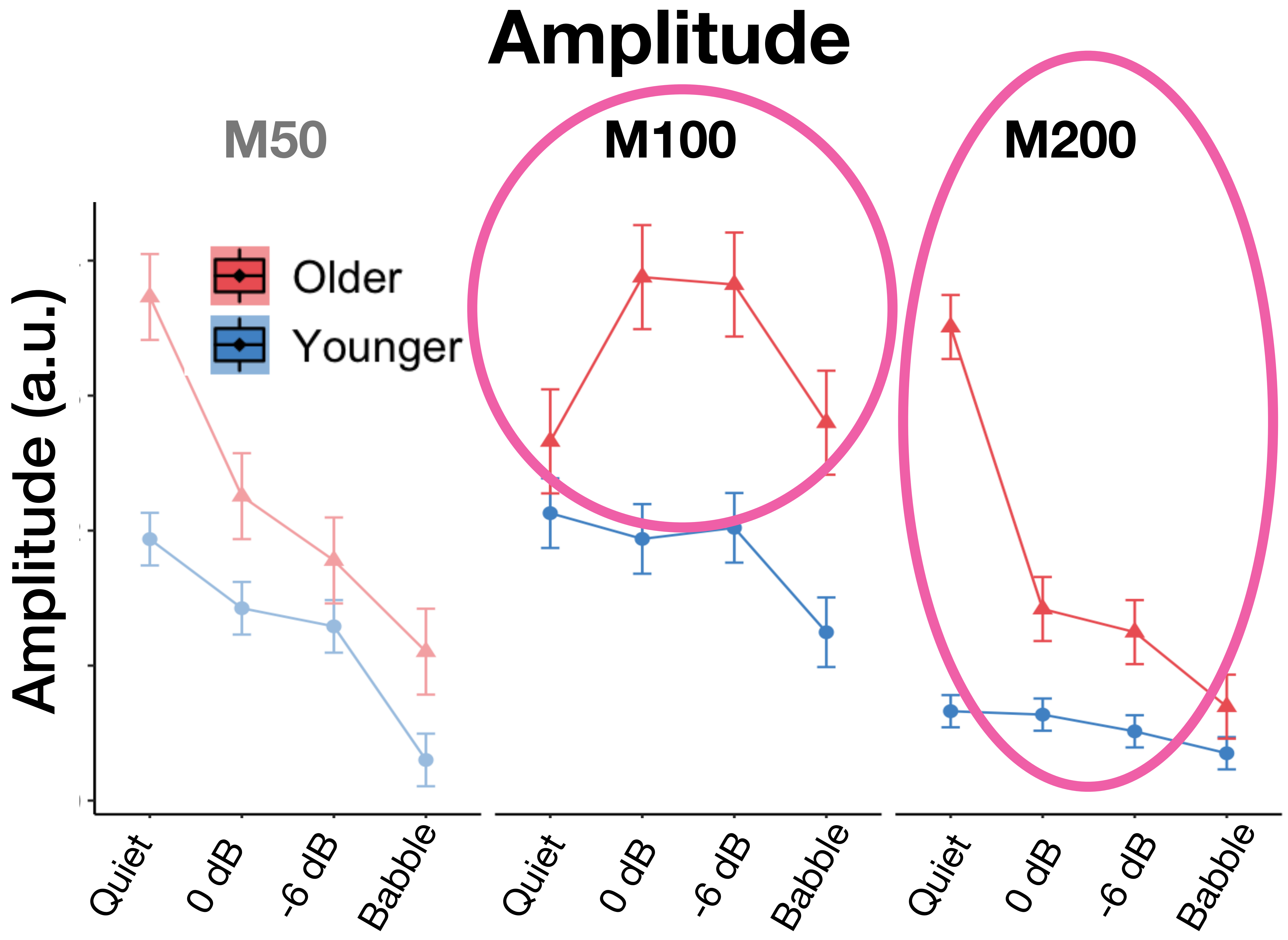
- Increased gain?
- Top down? (M100 associated with attention)

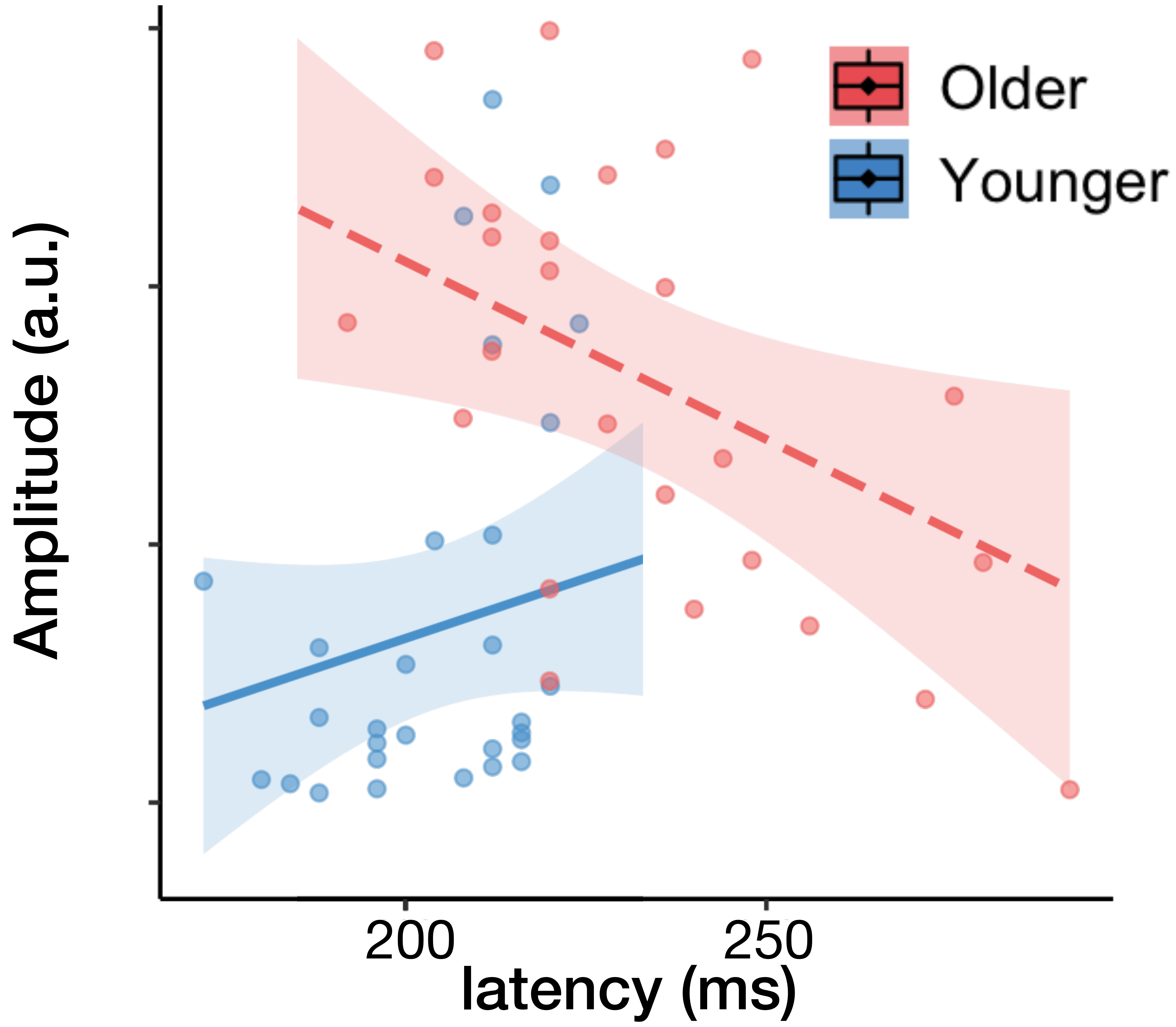
M200

- ~~Increased gain~~ (barely any comparable response in younger subjects)

➡ Recruiting additional neural resources?

M200 seems of Particular Interest





- sharp **decreases** when noise added
- negative correlation between amplitude and latency

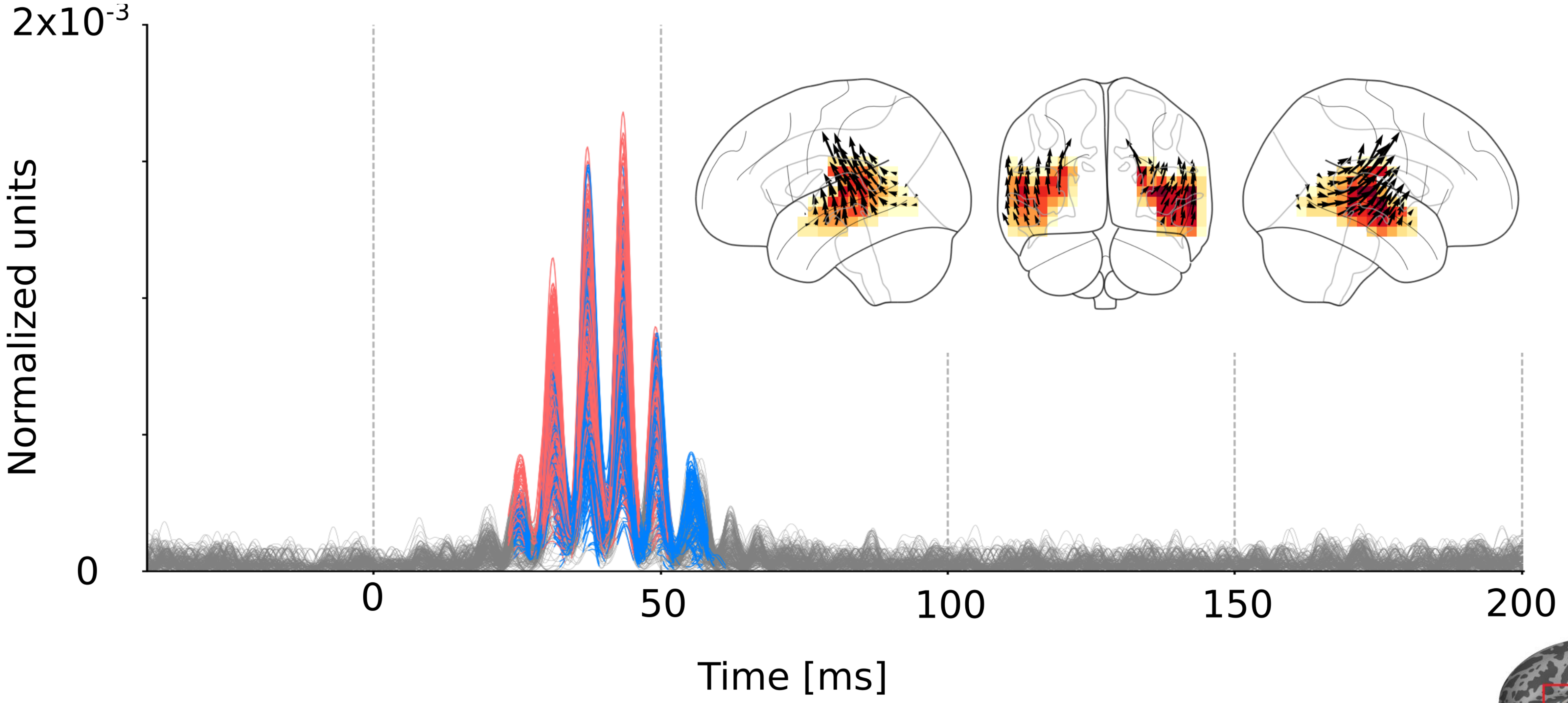
Karunathilake et al. (in prep.)

Subcortical to Cortical Transition?

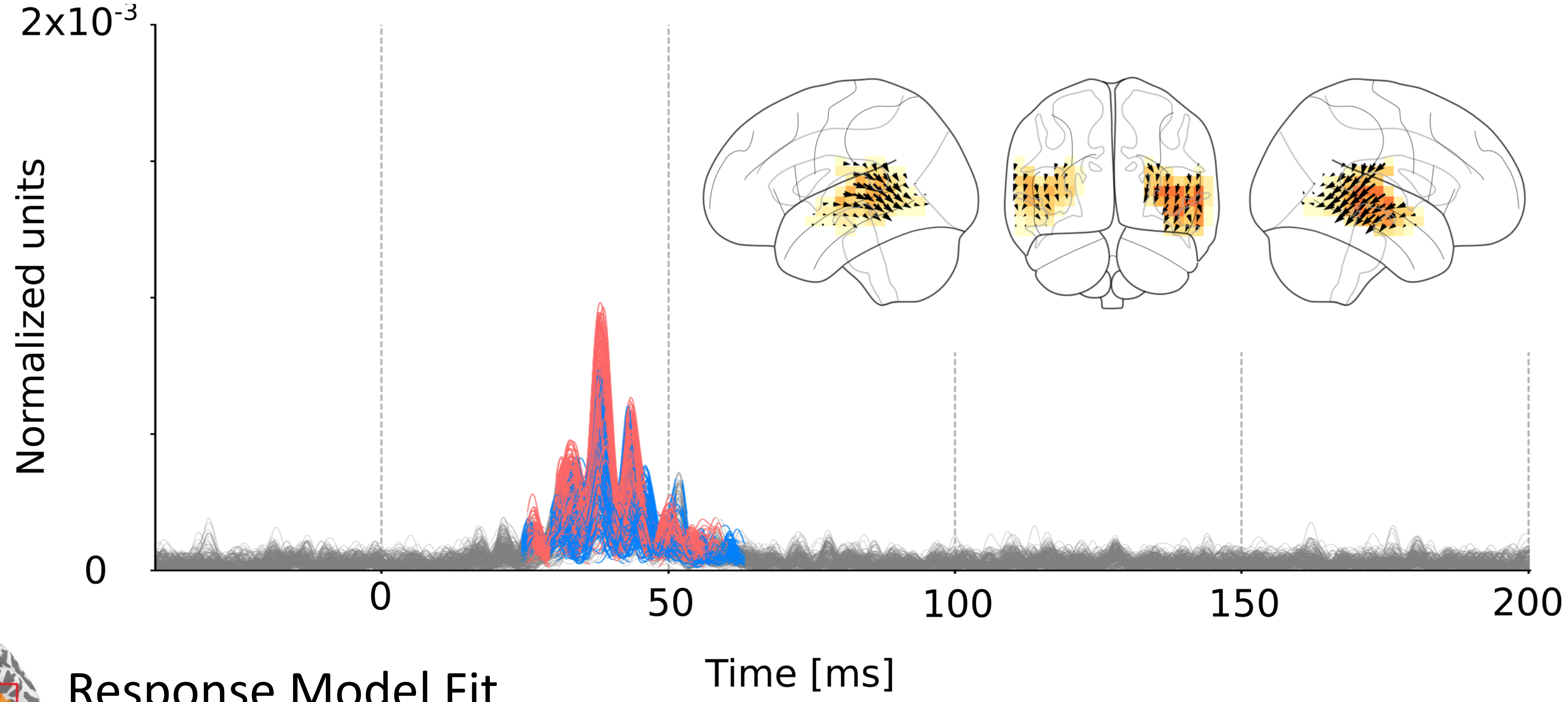
- **Subcortical** speech representations: **worse** for older listeners
- **Cortical** speech representations: **better** for older listeners
- Confound:
  - Subcortical speech representations = fast (pitch-like frequencies)
  - Cortical speech representations = slow (syllable rates)
- Can we meet in the middle? Yes:
  - Fast cortical speech representations (pitch-like frequencies)

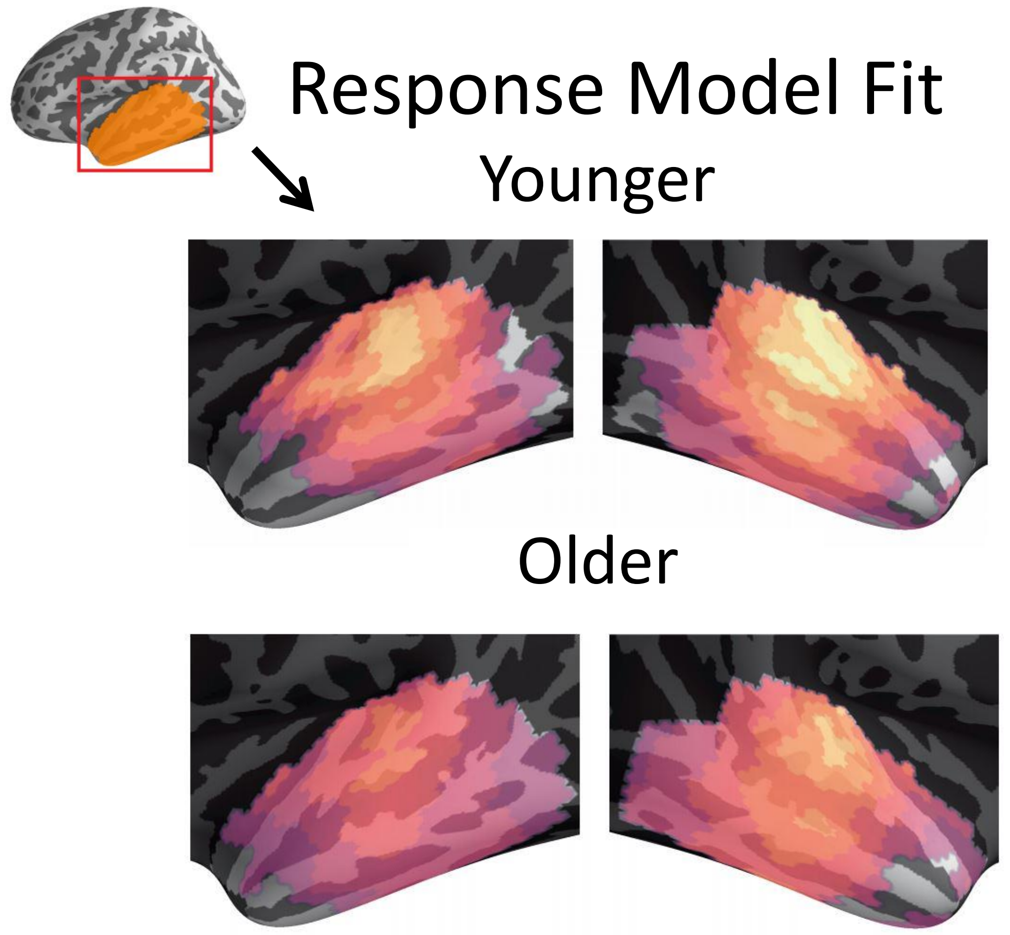
Fast (> 70 Hz) Cortical TRFs

Younger



Older

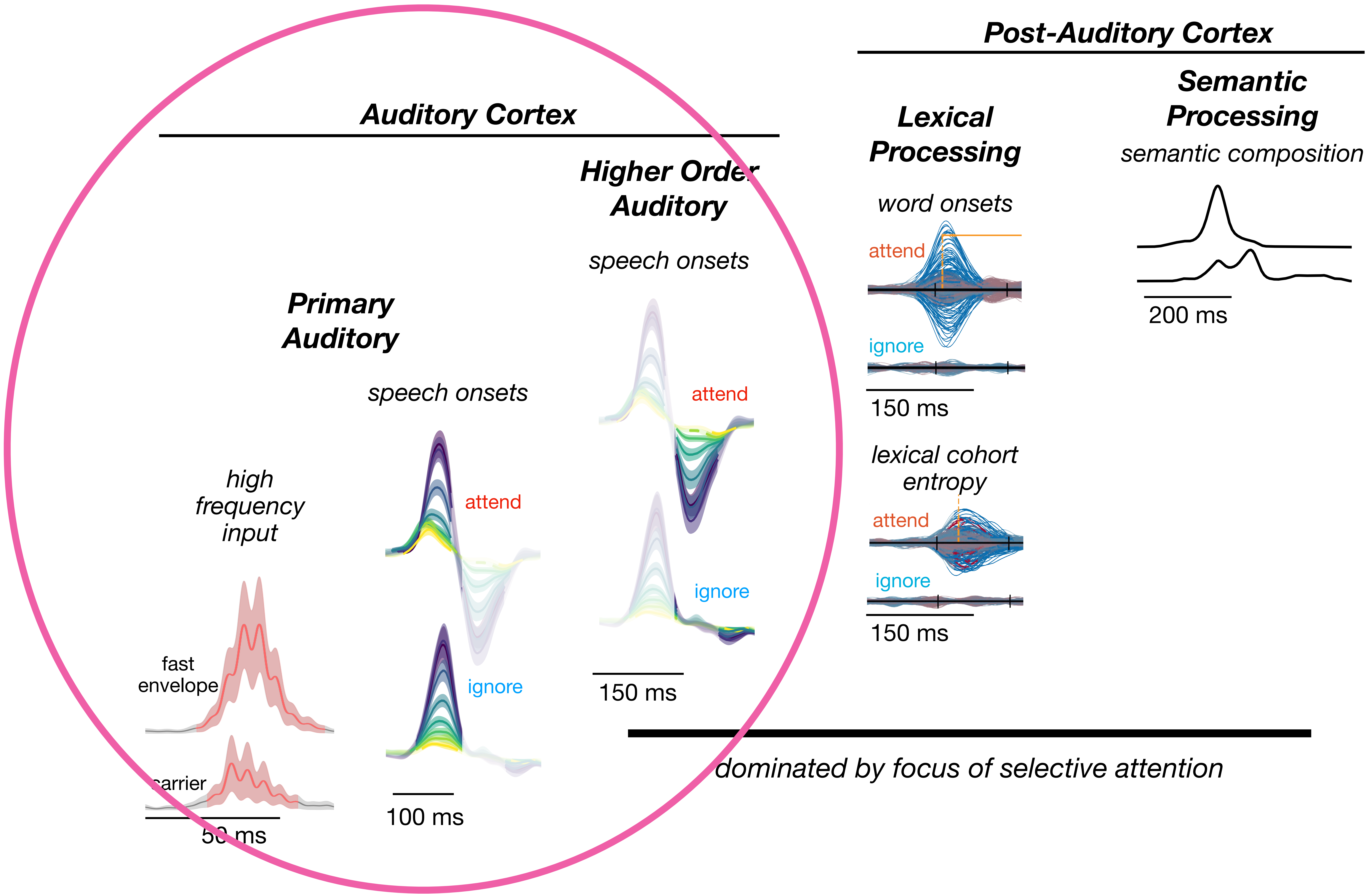




No significant age-related differences(!)

Kulasingham et al. (2020) *High Gamma Cortical Processing of Continuous Speech …*, NeuroImage

Cortical Representations Across Cortex



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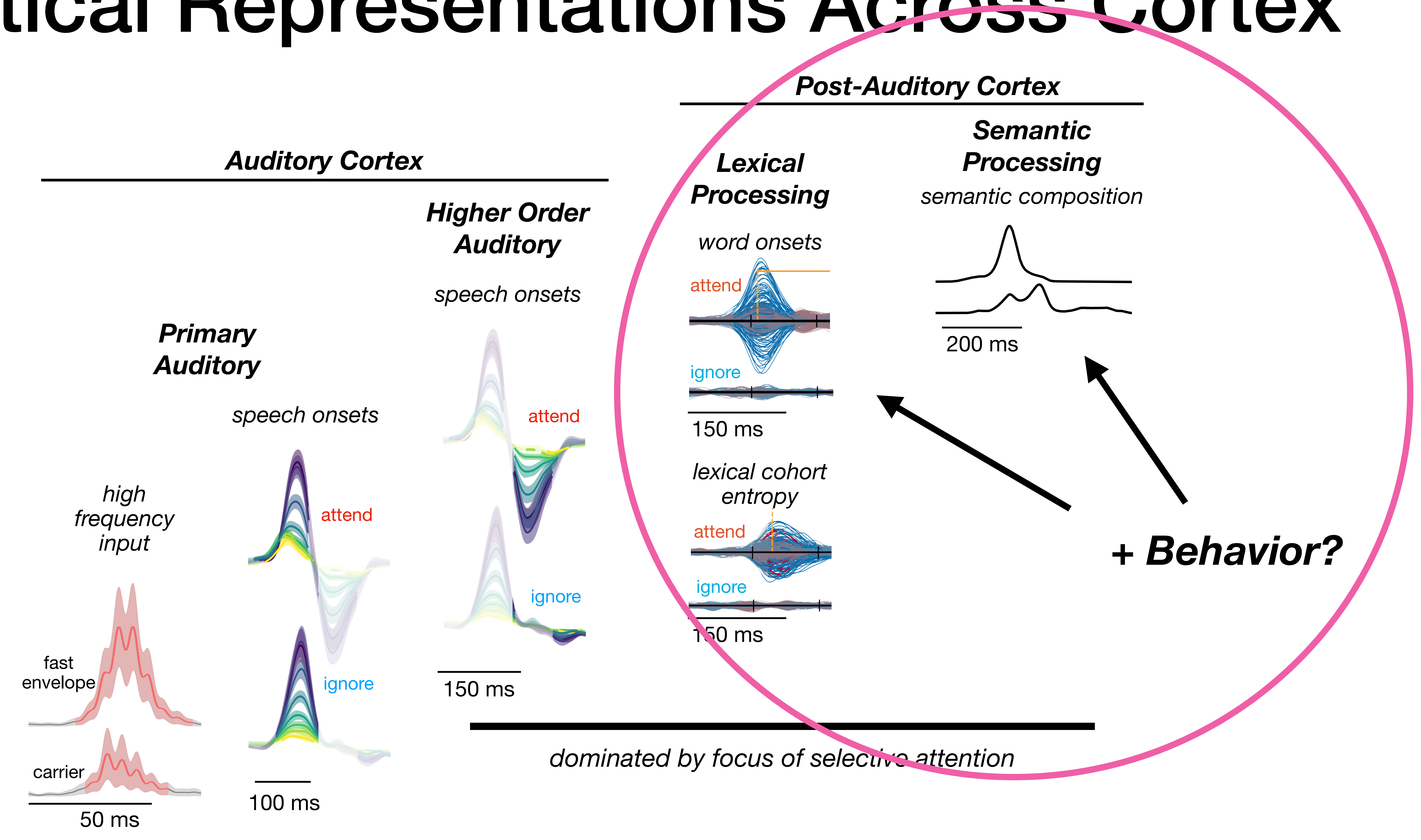

Summary

- **Midbrain** speech representations, as expected, **weaken** with aging
  - at frequencies $\gtrsim$ 100 Hz
  - What does “weaken” mean? less current? more jitter? both?
- Primary **cortex** ***high frequency*** speech representations ($\gtrsim$ 70 Hz) **change little** with age (if at all)

Summary

- **Slow cortical** speech representations, counter-intuitively, are **enlarged/exaggerated** with aging
- Exaggerations likely due to several mechanisms
  - Early exaggeration (~50 ms, primary) consistent with excitation/inhibition imbalance
  - Middle exaggeration (~100 ms, strongly attentional selective) consistent with increased “gain”, increased bilateral processing, and/or additional top-down processing
  - Late exaggeration (~200 ms, also attentional selective) consistent with additional processing, ~absent in younger adults, possibly from multiple similar latency sources

thank you

http://www.isr.umd.edu/Labs/CSSL/simonlab