Transformation from Auditory to Linguistic Representations, across Auditory Cortex, is Rapid and Attention Dependent

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Outline

- Background & motivation
  - Neural responses in time & space
  - Transformation from Acoustic speech processing to Linguistic speech processing
- Spatiotemporal representation transformation from Acoustic to Lexical

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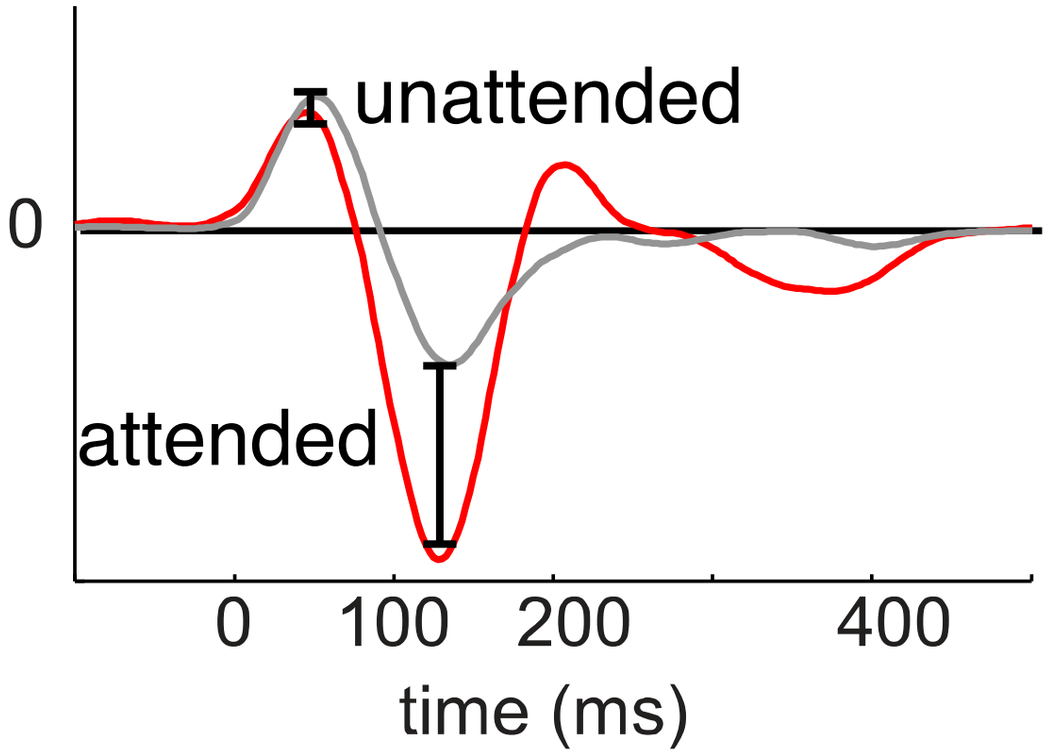
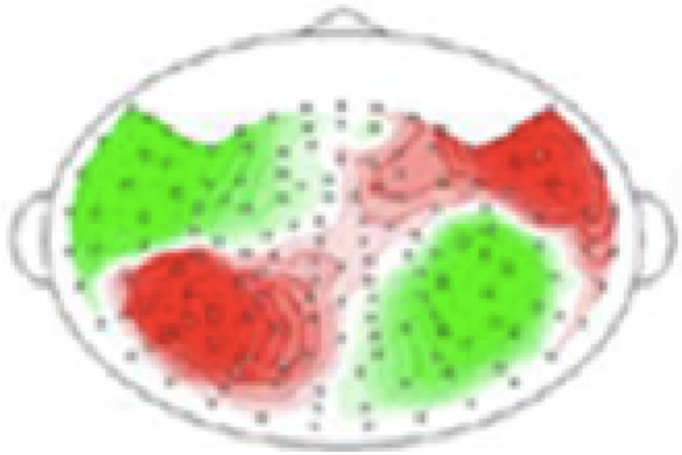
Time Course of MEG Response

Temporal Response Function
of dominant auditory component





- $M100_{TRF}$ strongly modulated by attention, *but not* $M50_{TRF}$

Ding & Simon, PNAS (2012)

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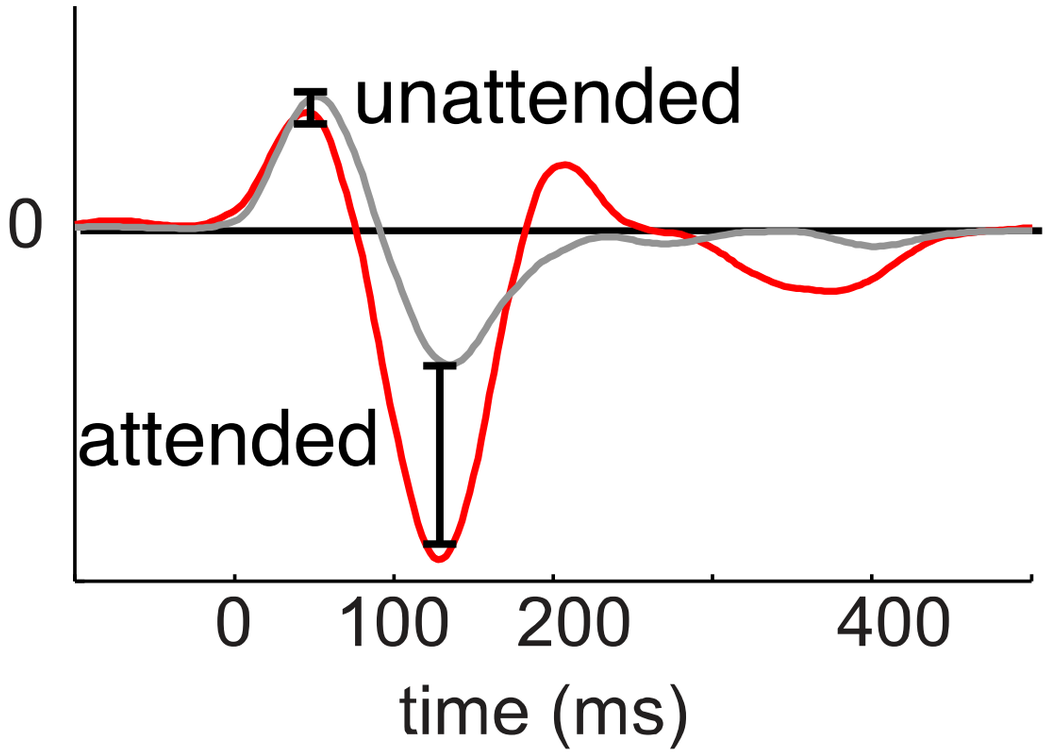
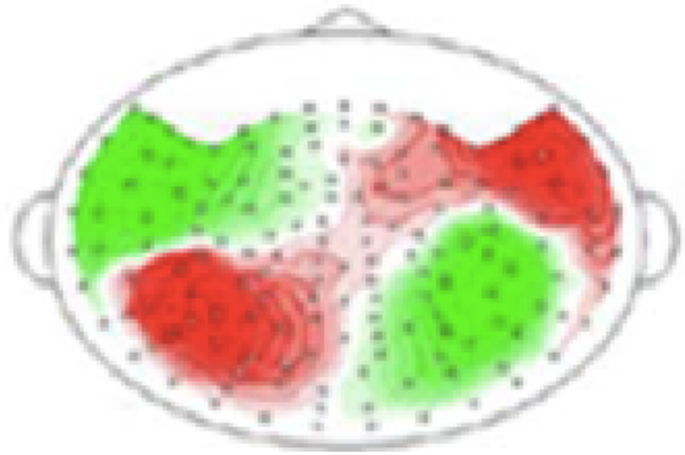




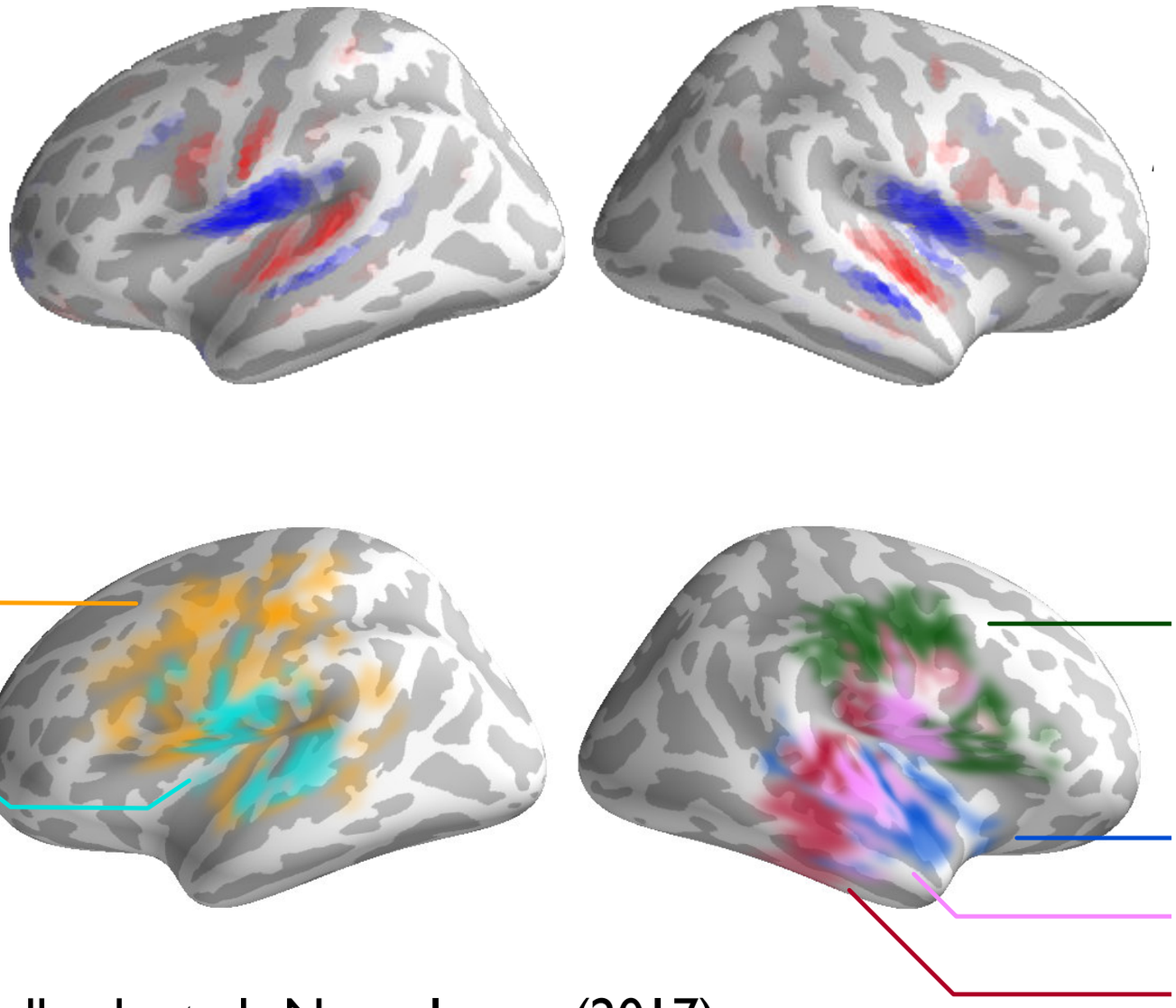
Time course analysis of single response component is

- useful
- simplifying
- a good start

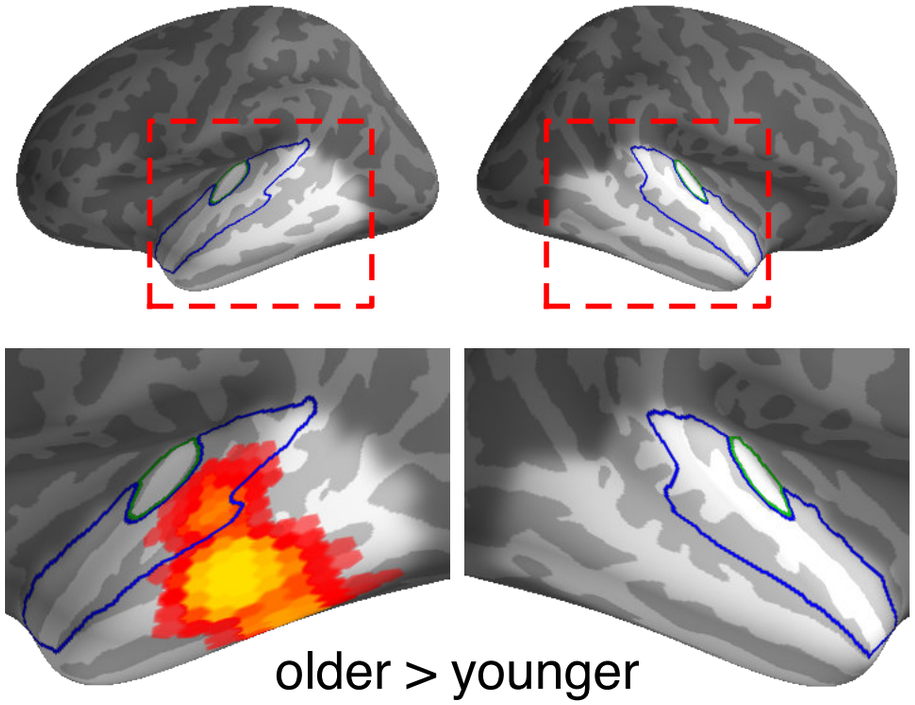
- $M100_{TRF}$ strongly modulated by attention, *but not* $M50_{TRF}$

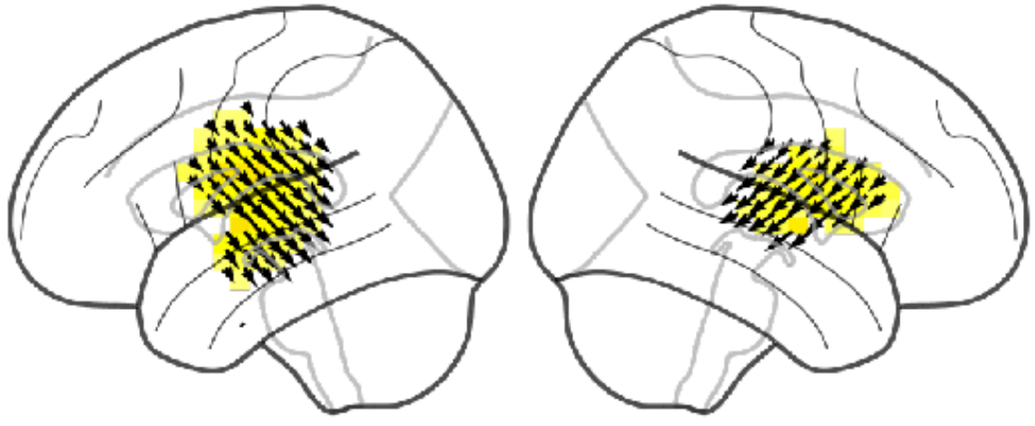
Ding & Simon, PNAS (2012)

Spatial Distributions of MEG Neural Currents



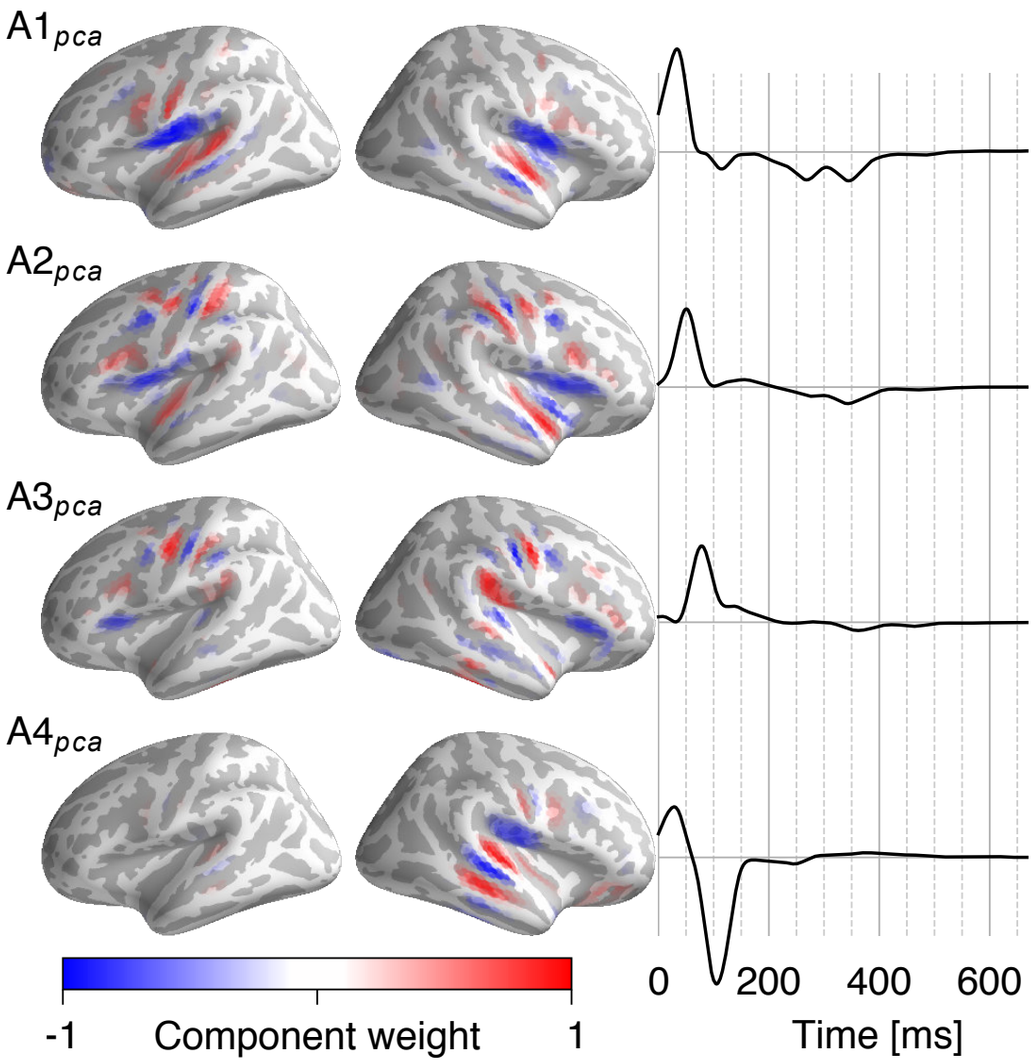
Brodbeck et al., NeuroImage (2017)
Brodbeck et al., Acta Acust united Ac (2018)

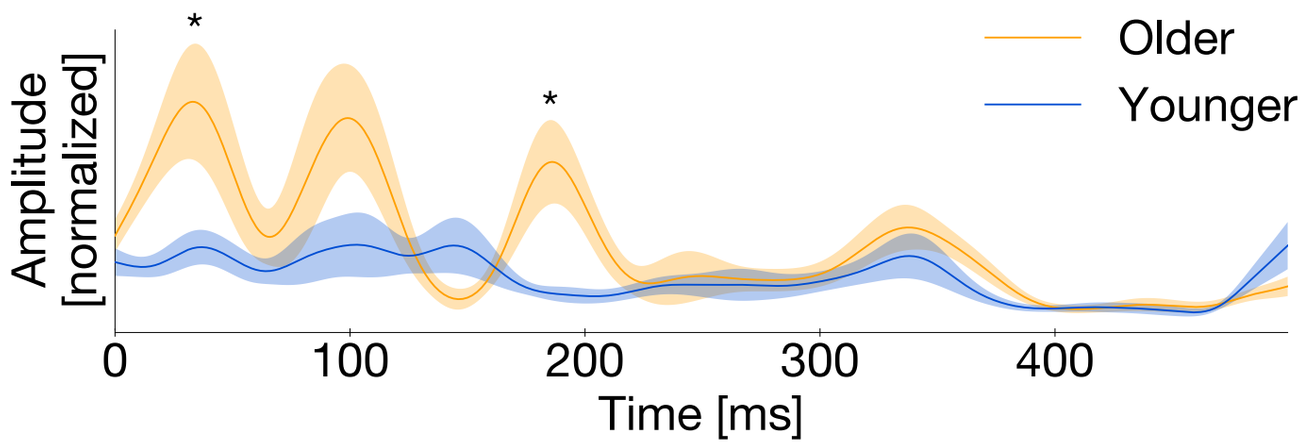


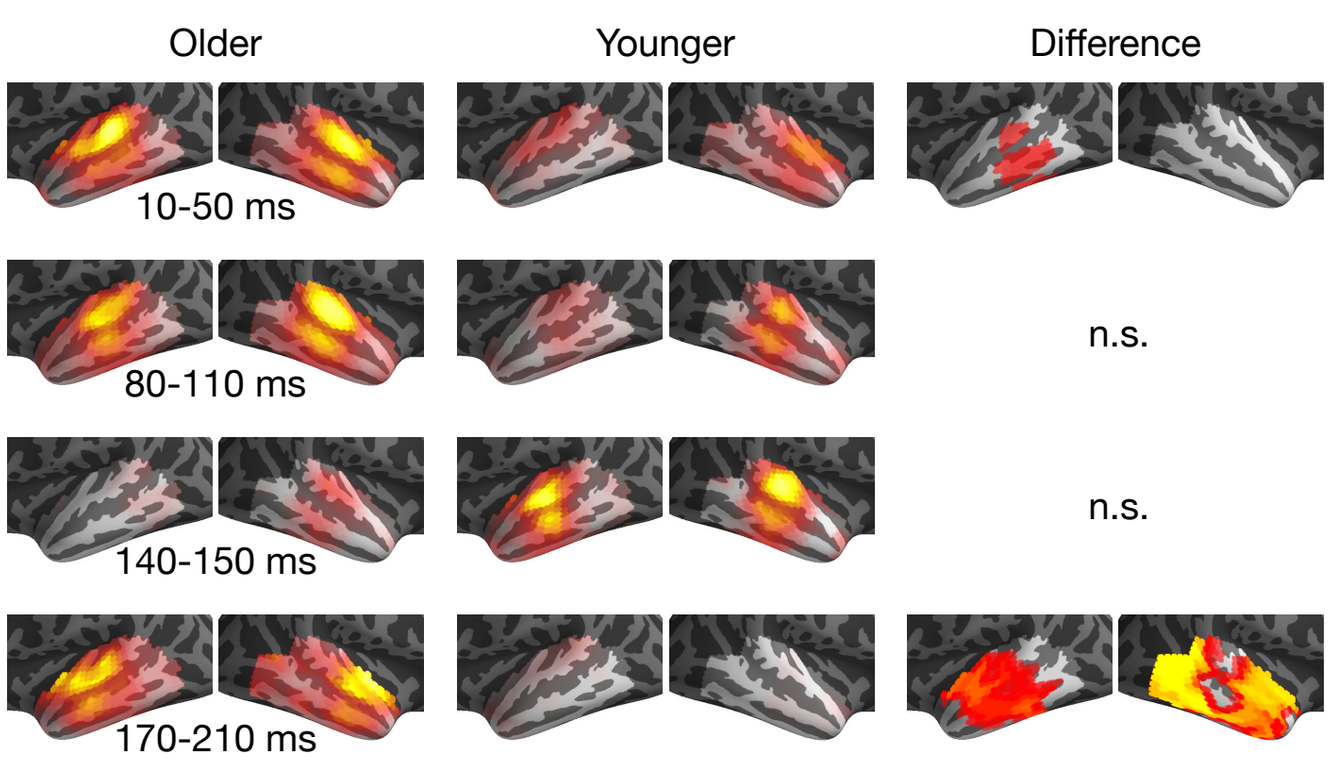


Das et al., SfN Poster (2018)

Spatiotemporal Distribution of Neural Currents







Brodbeck et al., NeuroImage (2017)
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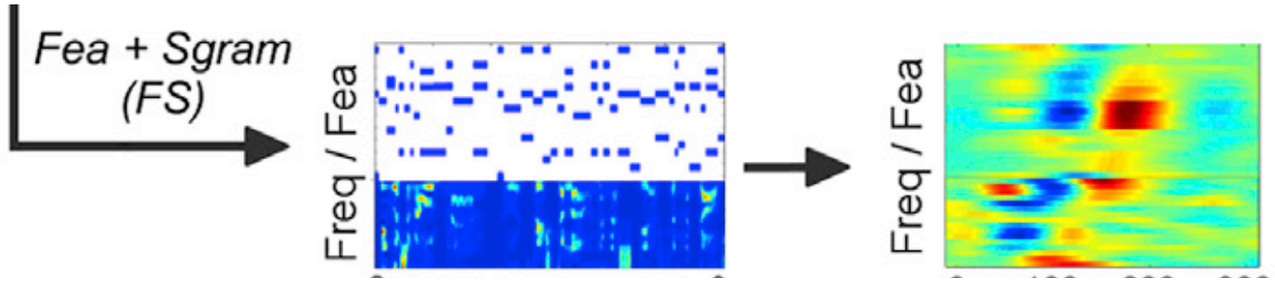
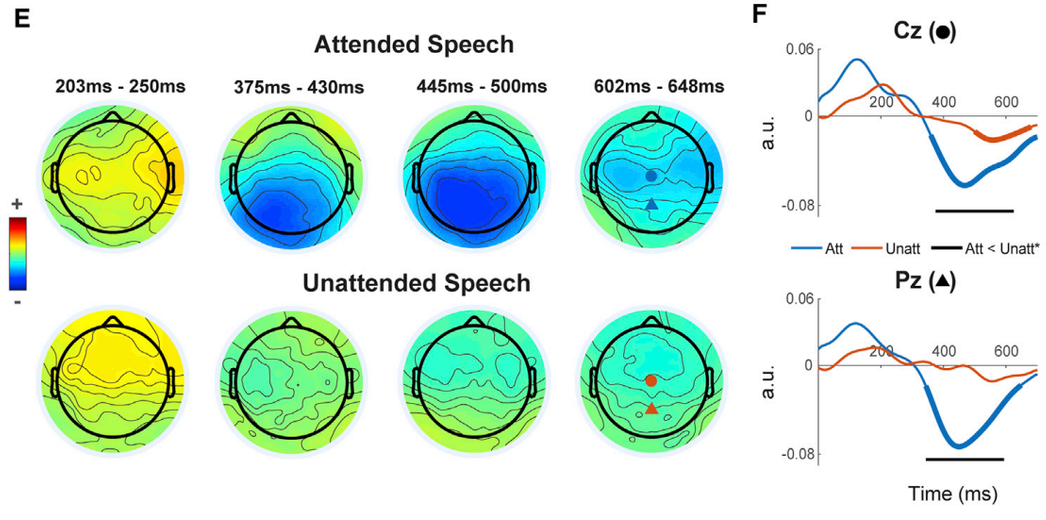
Acoustic Speech to Linguistic Speech

- Phonemes
  - Mesgarani et al., Science (2014)
  - Di Liberto et al., Curr Biol (2015)



- Semantic Information & Role of Attention
  - Broderick et al., Curr Biol (2018)



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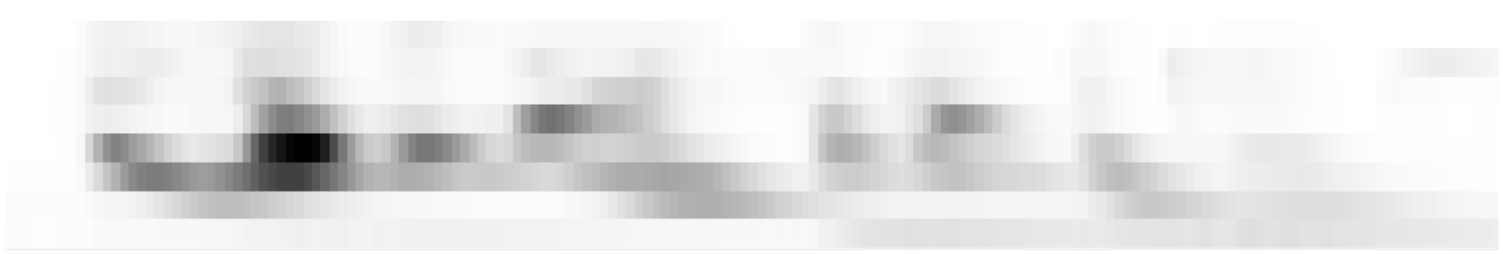
Brodbeck et al., Curr Biol (in press)

Acoustic to Lexical Speech Processing

his noble mind forgot the cakes

Acoustic Envelope (8 bands)



Acoustic envelope (8 bands)

Acoustic Onset (8 bands)

Acoustic to Lexical Speech Processing

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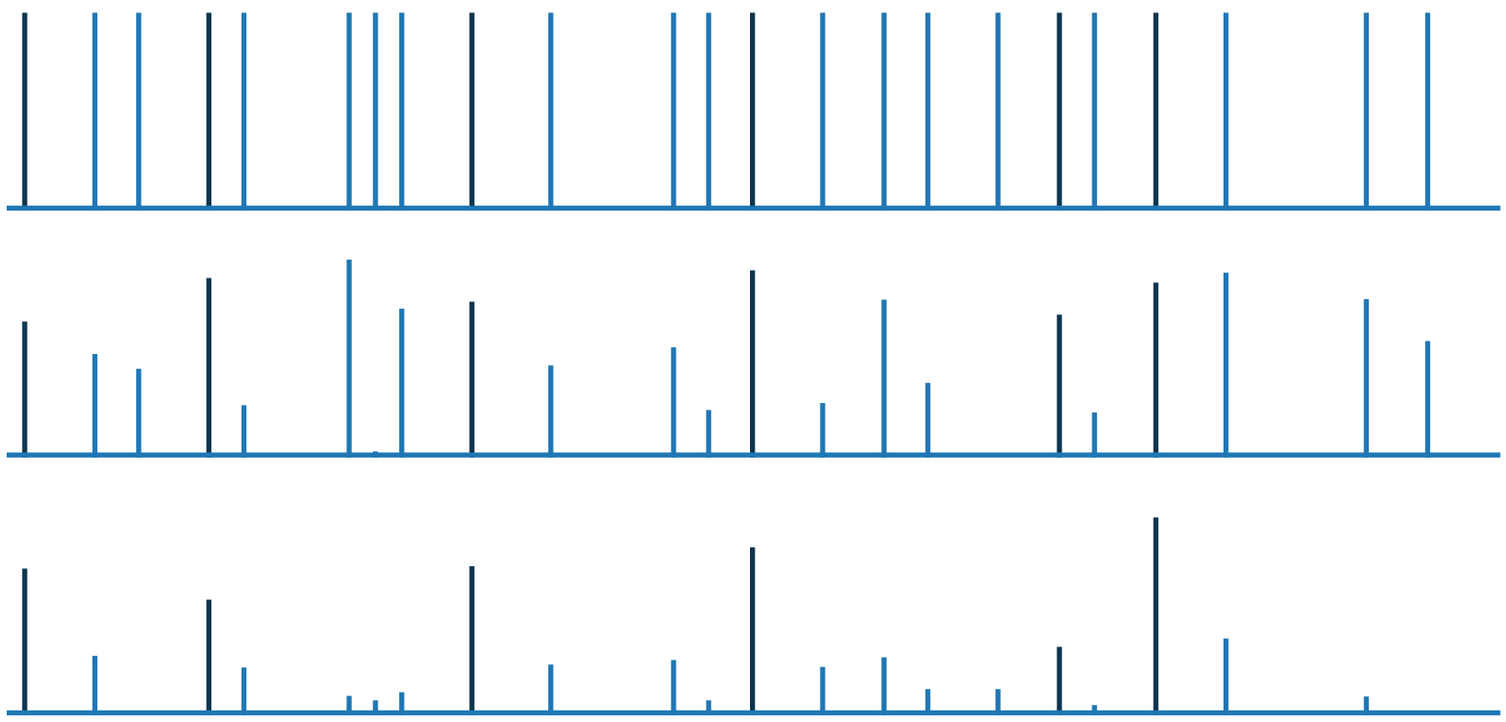

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Phoneme Onset

Phoneme Surprisal

$$surprisal_i = -\log_2\left(\sum_{word \in cohort_i} freq_{word}(i) \Big/ \sum_{word \in cohort_{i-1}} freq_{word}(i-1)\right)$$

Cohort Entropy

Acoustic to Lexical Speech Processing

his noble mind forgot the cakes

h ɪ z n oʊ b əl m aɪ n d f ɝ g ɑ t ð i k eɪ k s

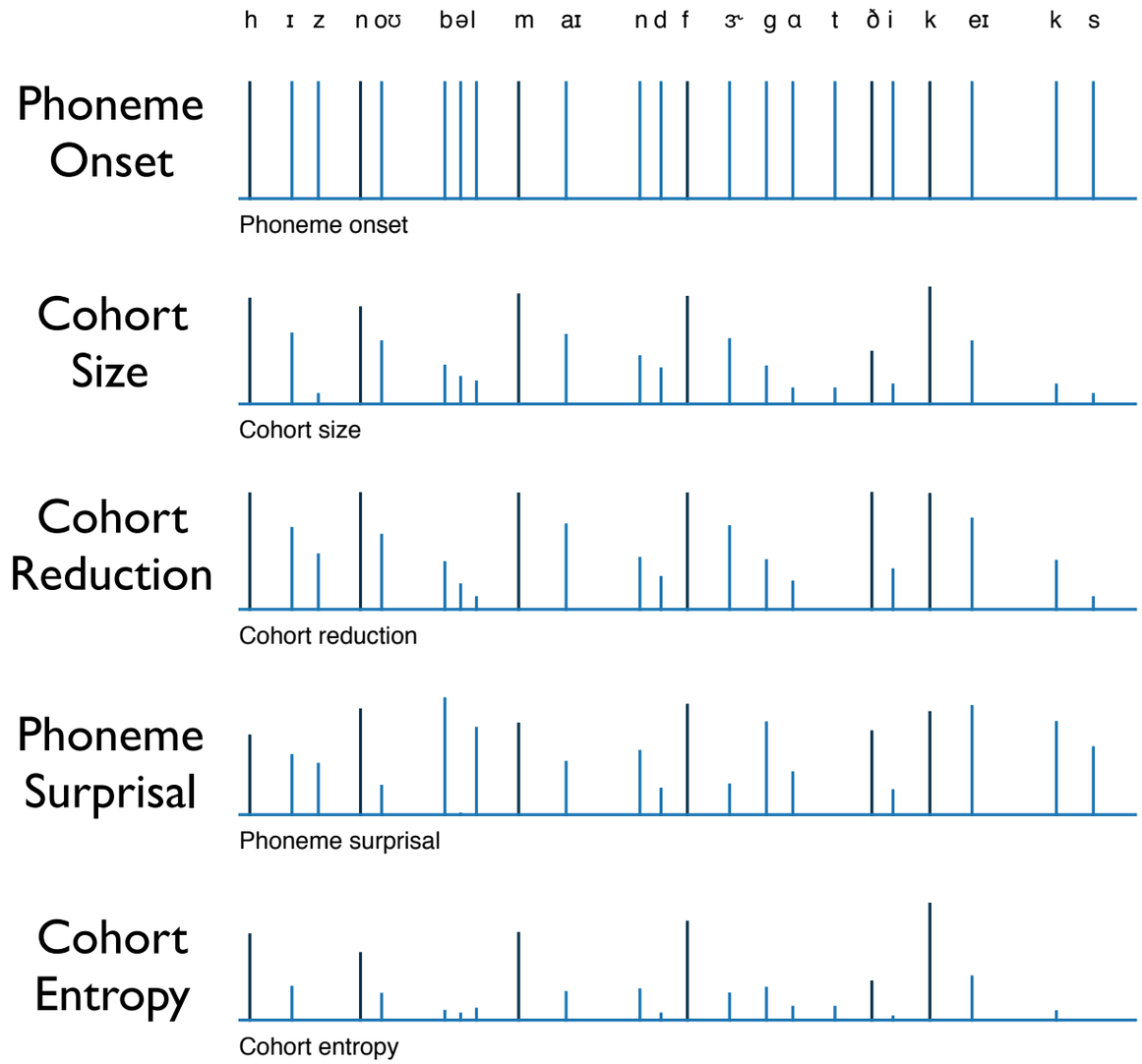
Phoneme Onset

Phoneme Surprisal

Cohort Entropy

$$H_i^{cohort} = -\sum_{word \in cohort_i} p_{word} \log_2 p_{word}$$

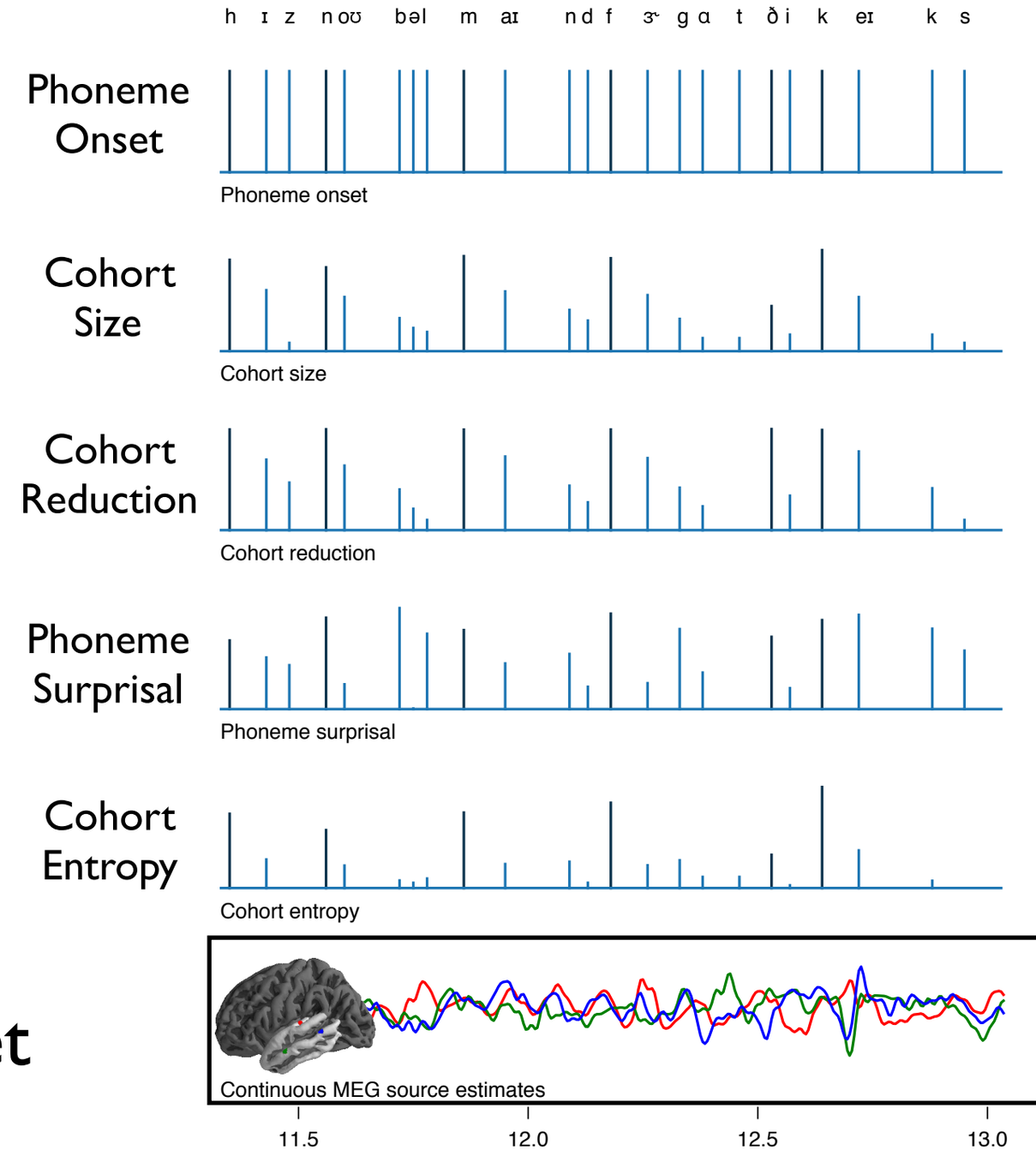
Acoustic to Lexical Speech Processing



- 16 acoustic
- 8 lexical
  - 4 medial (+ 4 initial)
- 1 word onset
- 1 (non-initial) phoneme onset

Brodbeck et al., Curr Biol (in press)

Acoustic to Lexical Speech Processing



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Brodbeck et al., Curr Biol (in press)

Methods Details

26 adults, mean age 45 (range 22 - 61)

One-minute-long segments (8 solo, 16 mix) from *A Child's History of England* by Dickens

Acoustic time-frequency representation: 8-band auditory spectrogram

Word frequencies: movie subtitle database SUBTLEX (stress info stripped)

Distributed MNE source estimates, restricted to temporal lobe (314 L, 313 R)

Sources in *fsaverage* brain (individual anatomical MRI not used)

Multivariable TRF at each source element via boosting (10 ms resolution; 50 ms Hamming window basis)

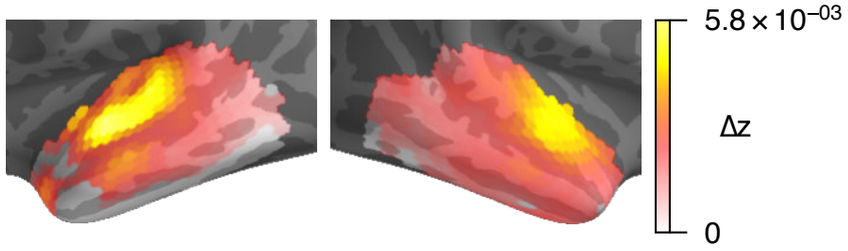
Significance of each representation with respect to shuffled stimulus x 3

Localization uses threshold-free cluster enhancement, 10,000 permutation null distribution

Model reduction: iteratively remove largest *p*-value (non-significant) variable

Acoustic Results

Acoustic Envelope



Brodbeck et al., Curr Biol (in press)

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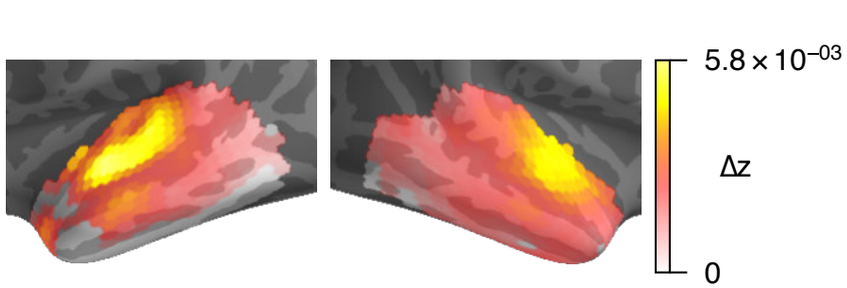

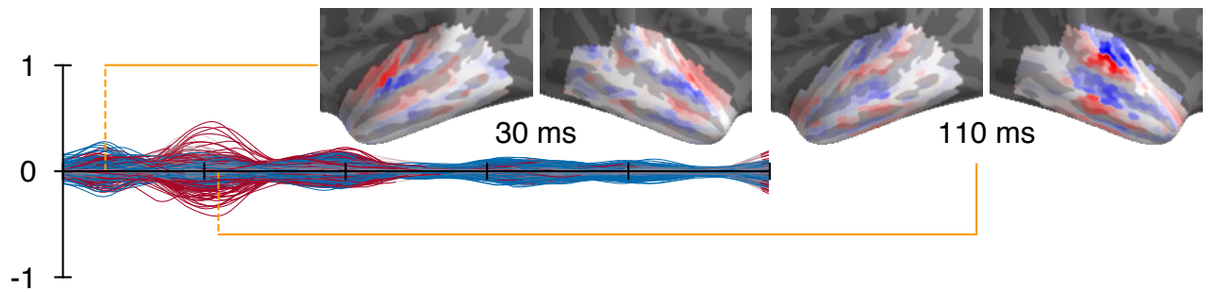

Brodbeck et al., Curr Biol (in press)

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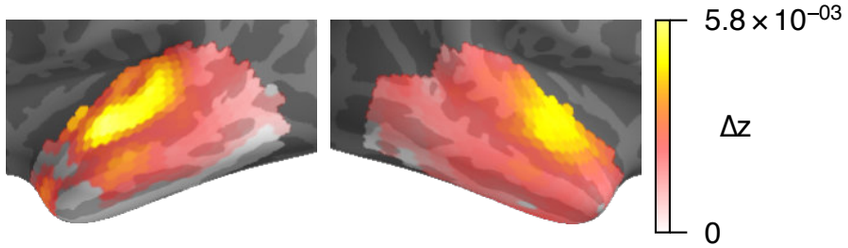
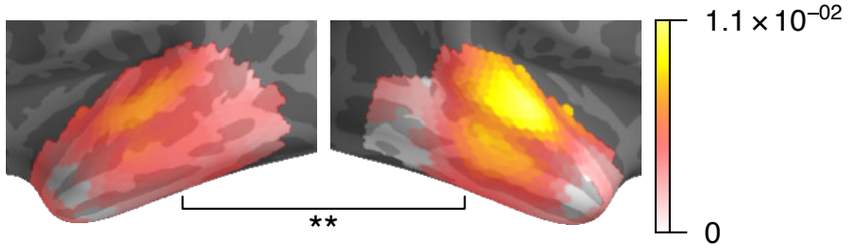
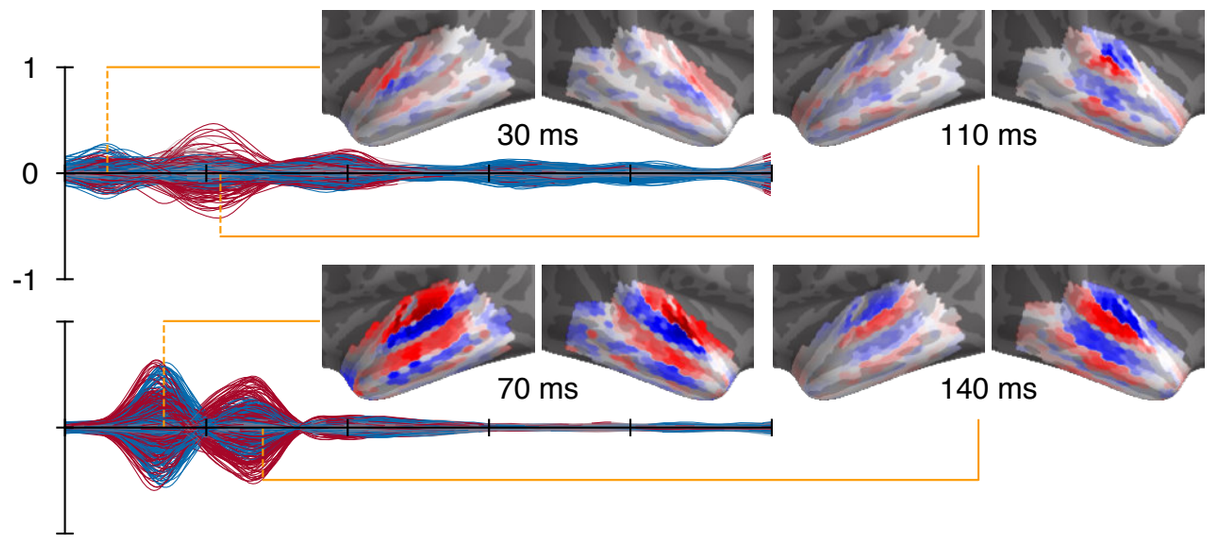


Acoustic Onset





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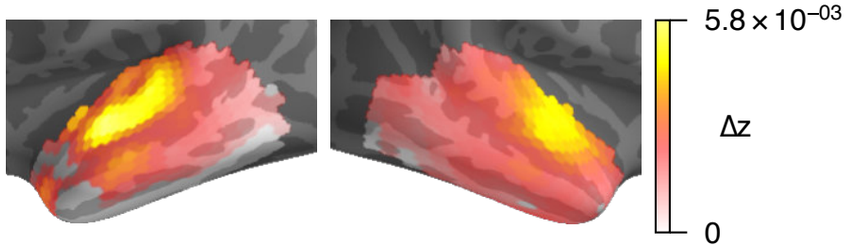

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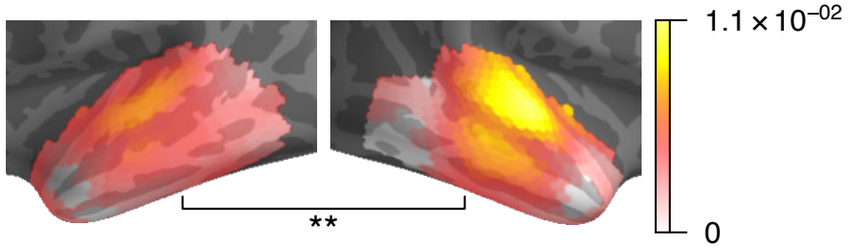

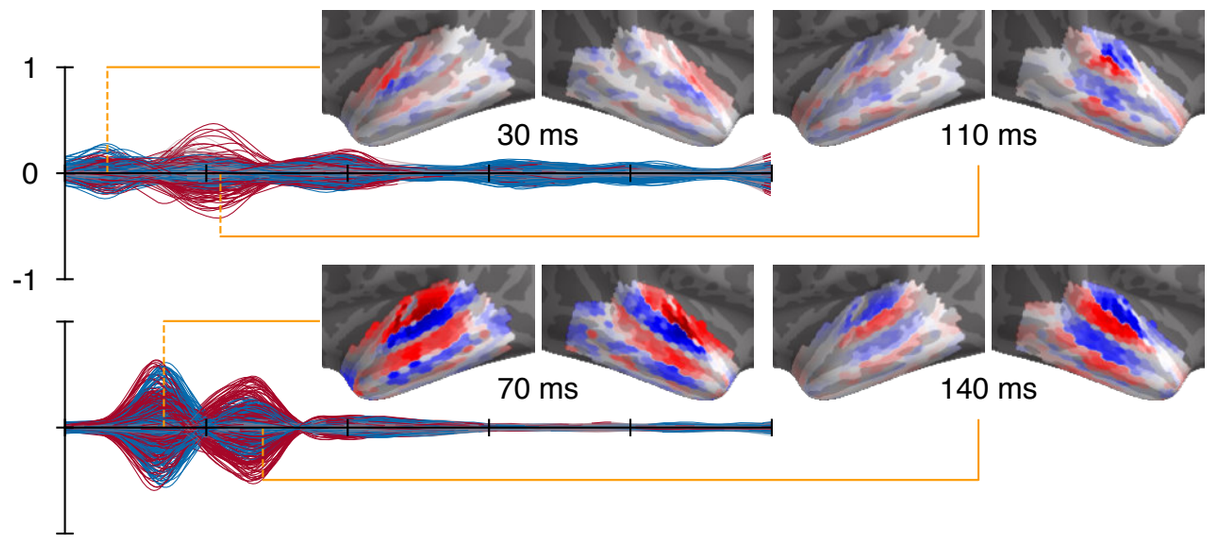

cf. Hamilton et al., 2018
See also Daube et al., bioRxiv 448134

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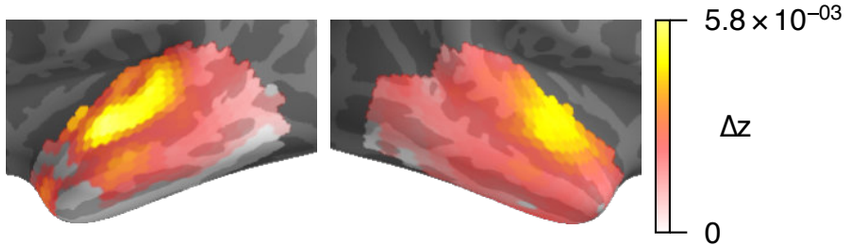

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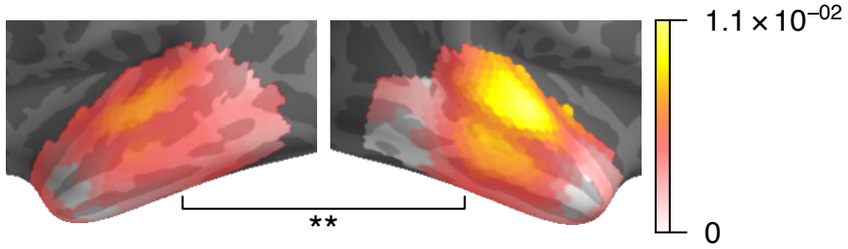

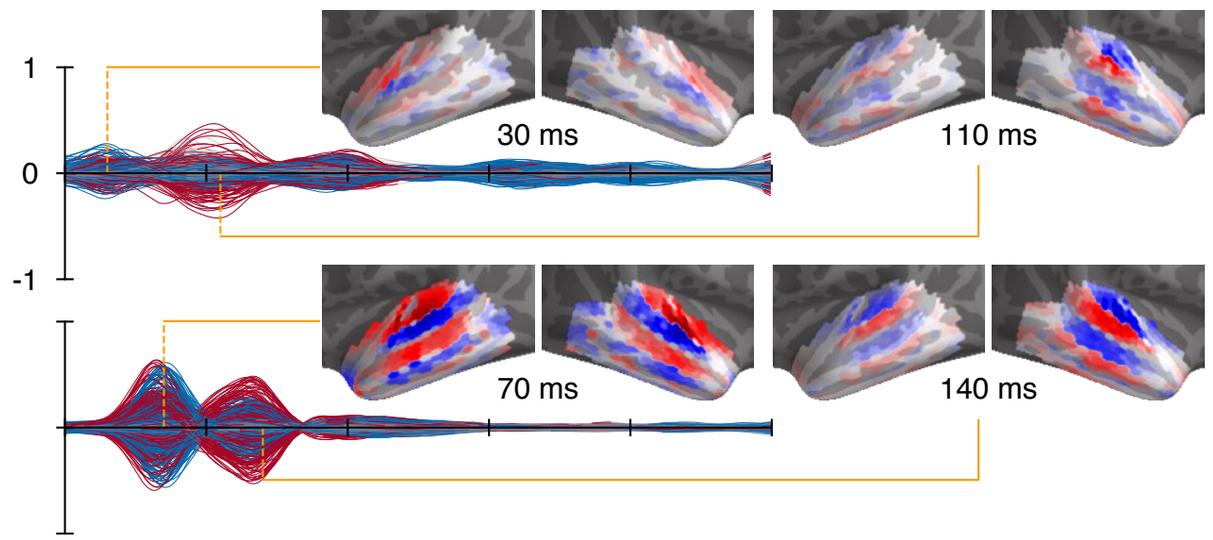

cf. Hamilton et al., 2018
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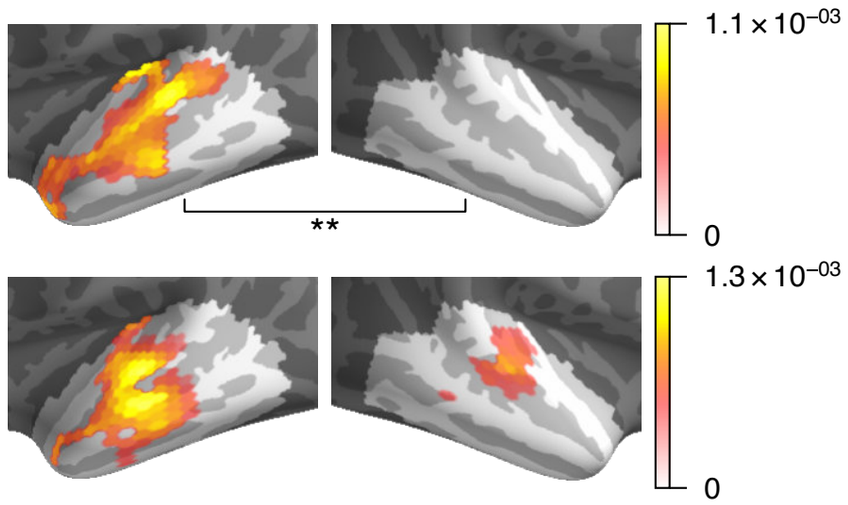
- Onset explains more variance
- Latency(ies) as expected
- Strongly bilateral
- Onset stronger in right hemisphere

Brodbeck et al., Curr Biol (in press)

Lexical Results

Phoneme Surprisal

Cohort Entropy



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Lexical Results

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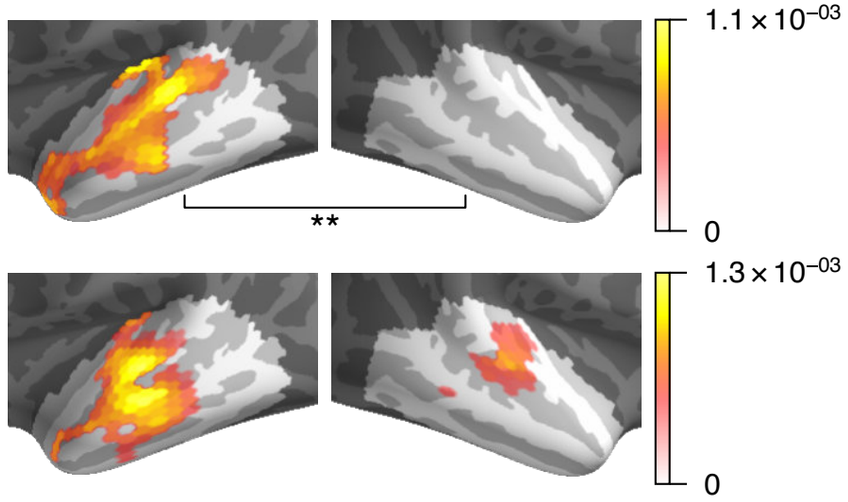

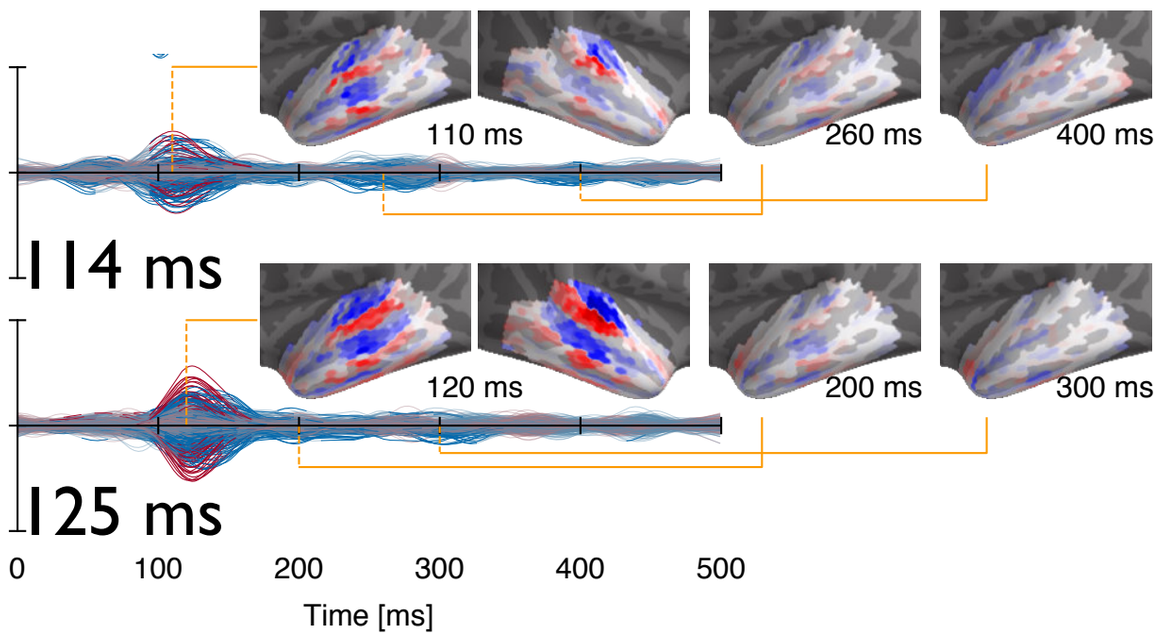

Brodbeck et al., Curr Biol (in press)

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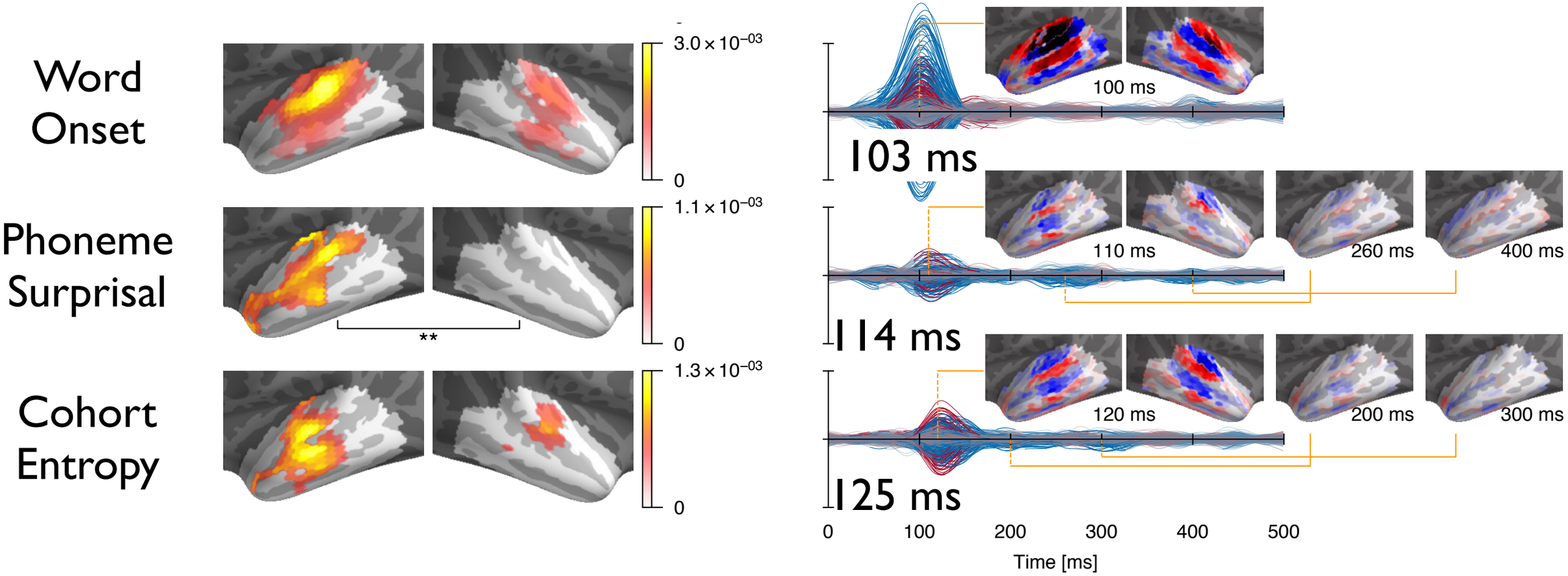

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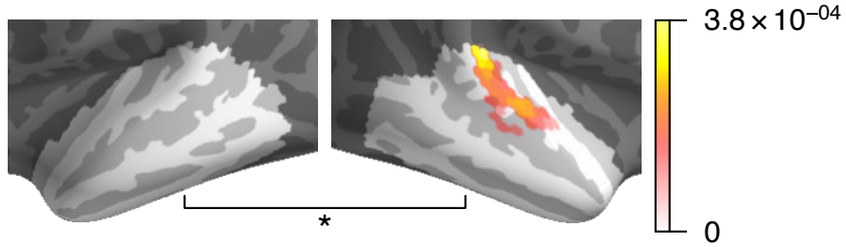
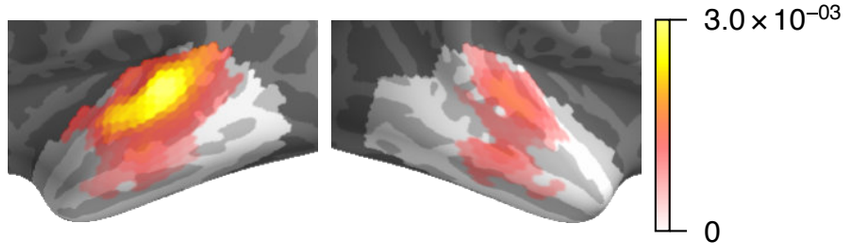
Lexical Results

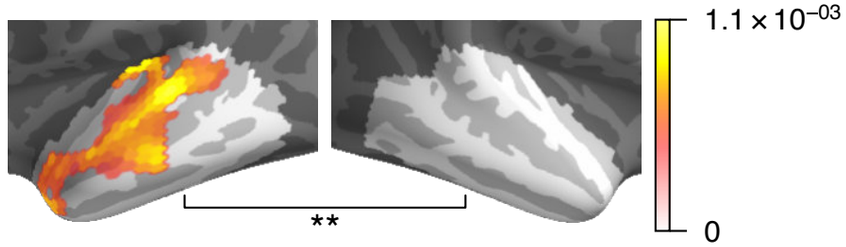
Phoneme Onset



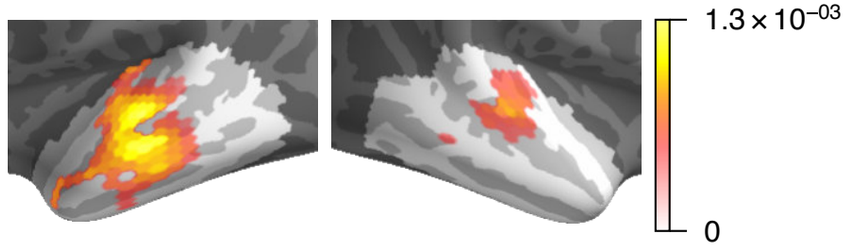
Word Onset

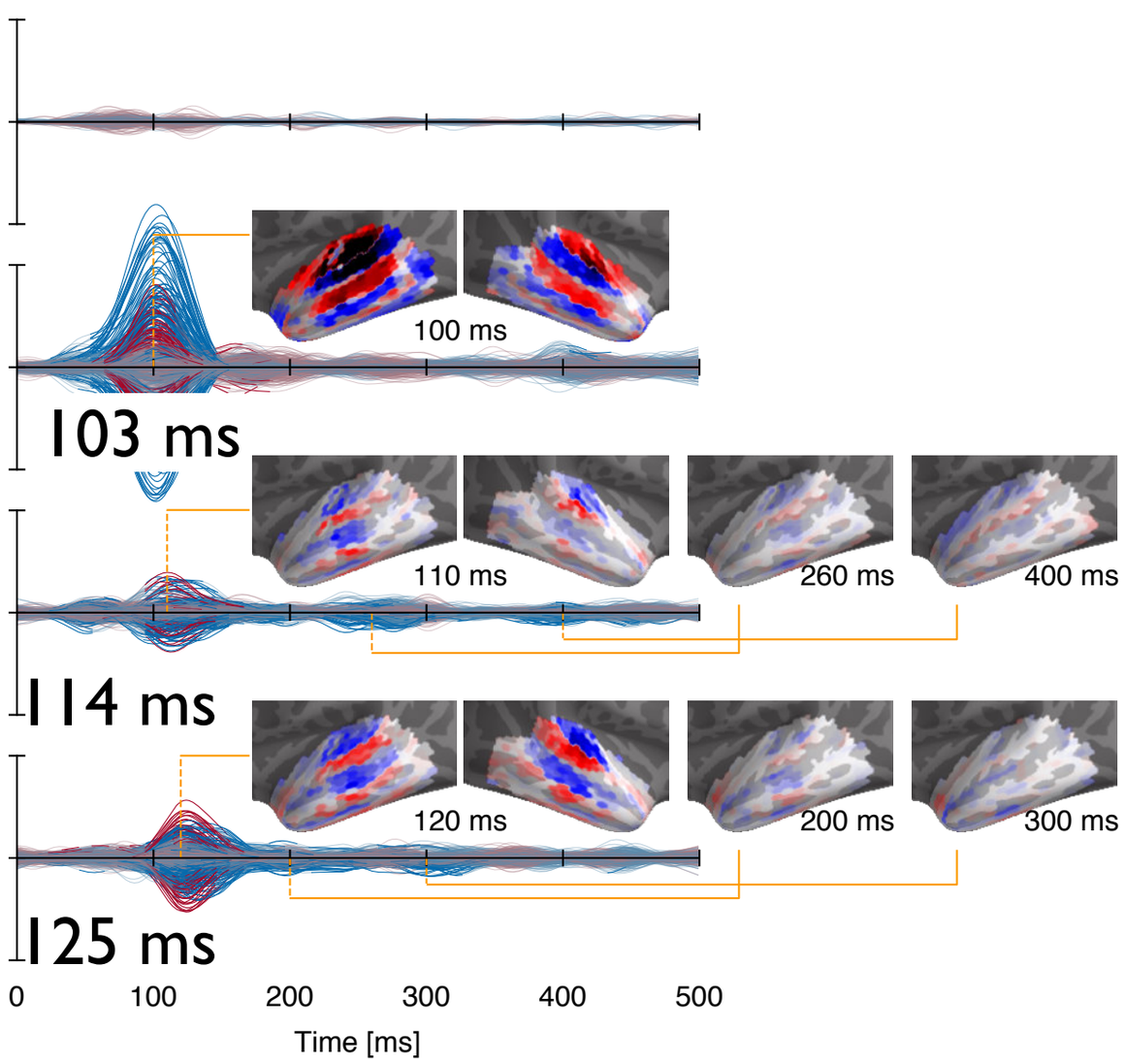


Phoneme Surprisal



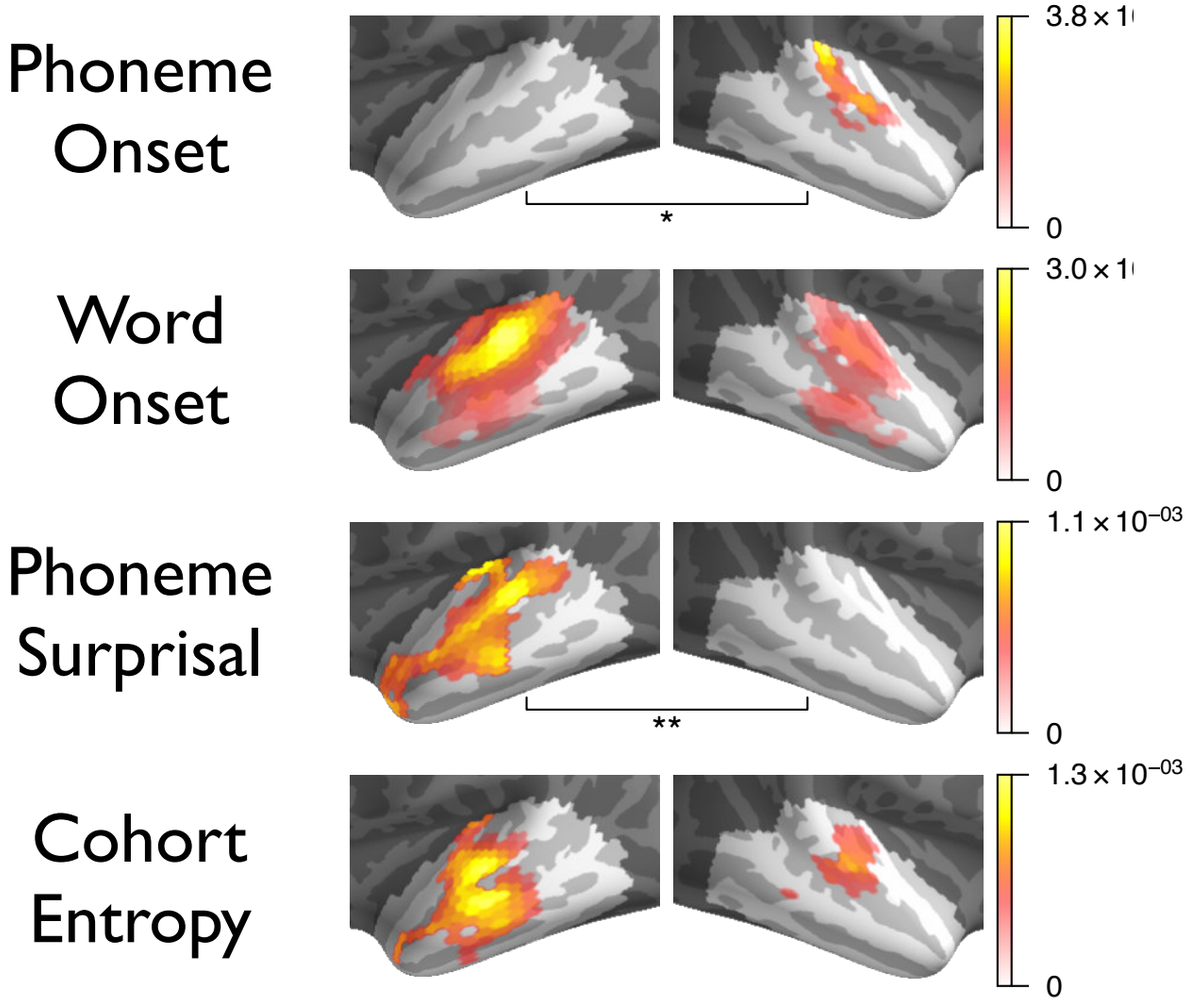
Cohort Entropy



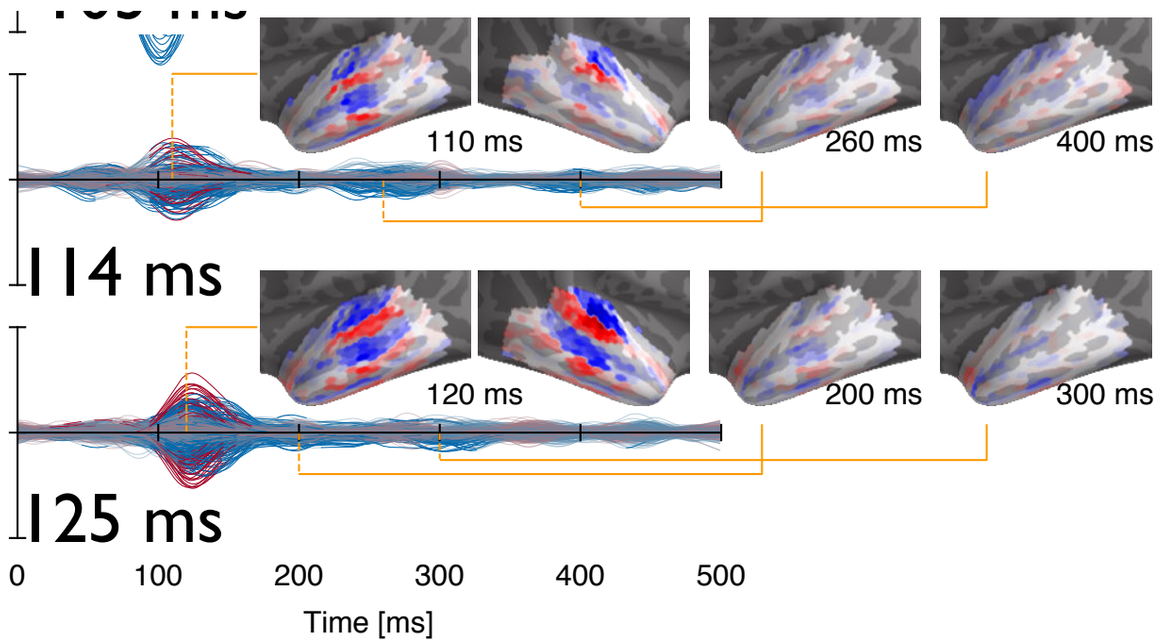


Brodbeck et al., Curr Biol (in press)

Lexical Results

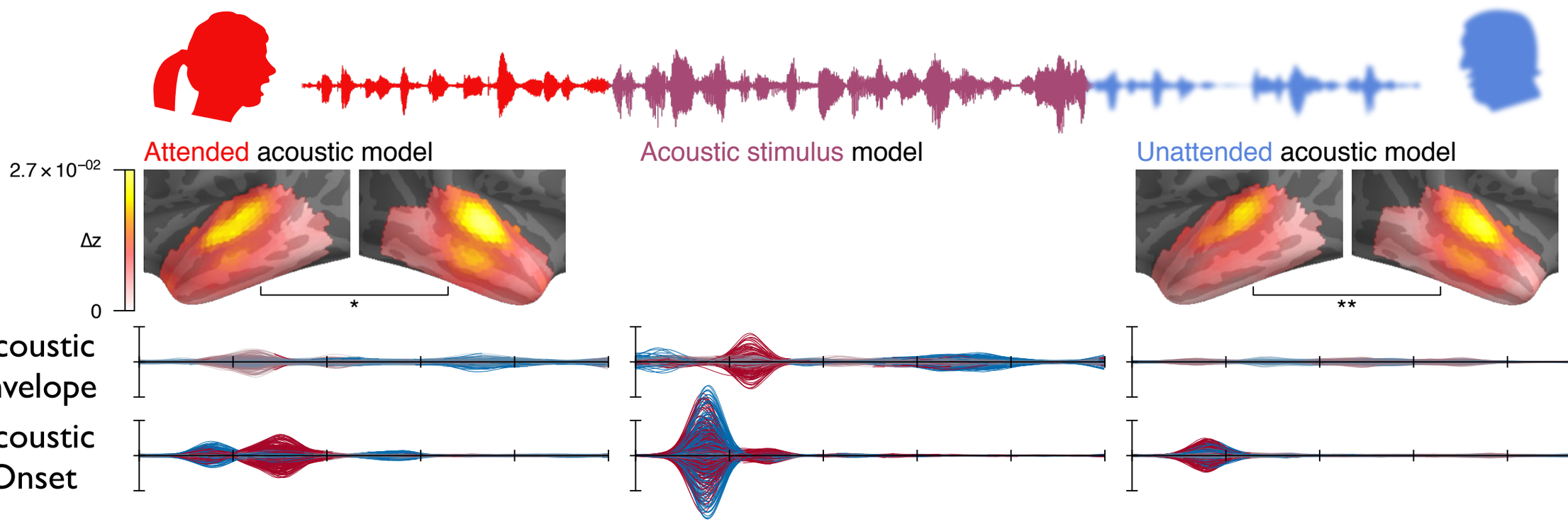


- Rapid transformation to lexical
- Surprisal = local measure of phoneme prediction error (predictive coding?)
- Cohort entropy = global measure of lexical competition across cohort
- Strongly left hemisphere dominant



Brodbeck et al., Curr Biol (in press)

Acoustic Attention



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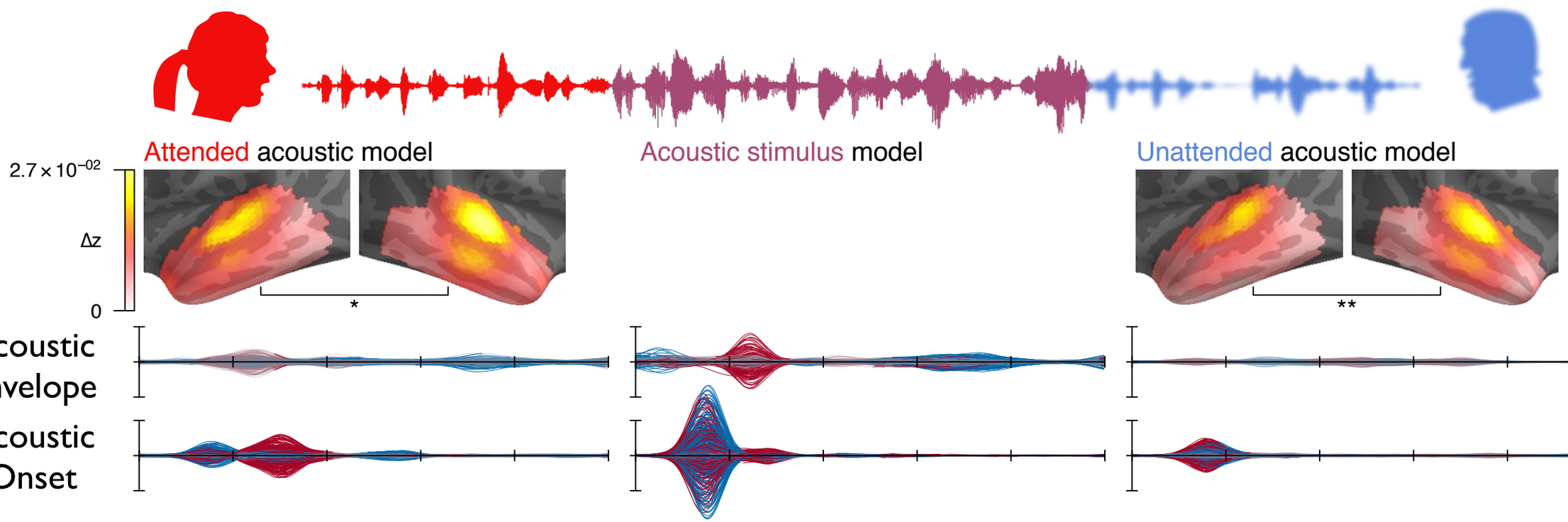
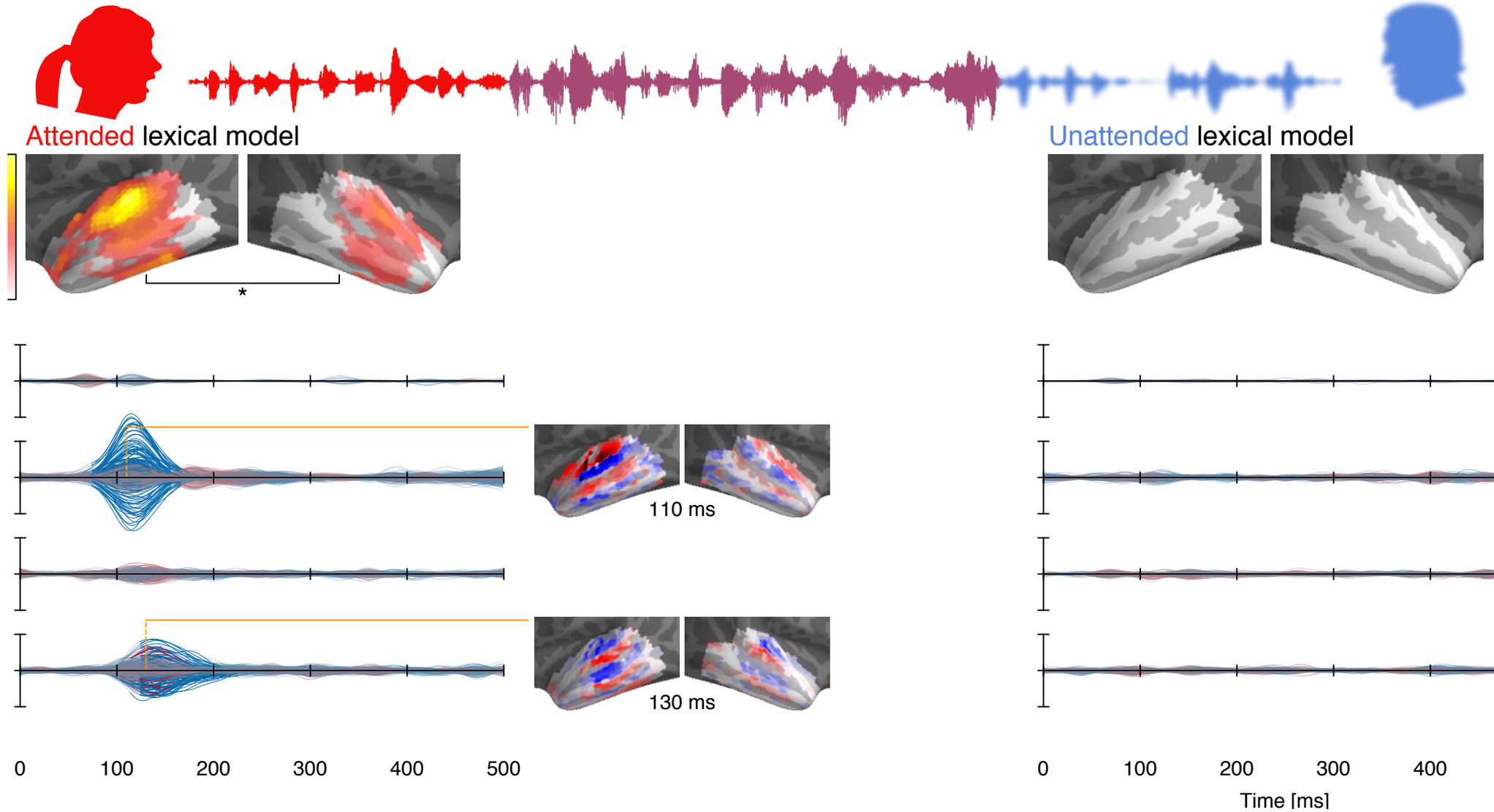


- Later Attended Representation Dominates
- Onset Representation Dominates

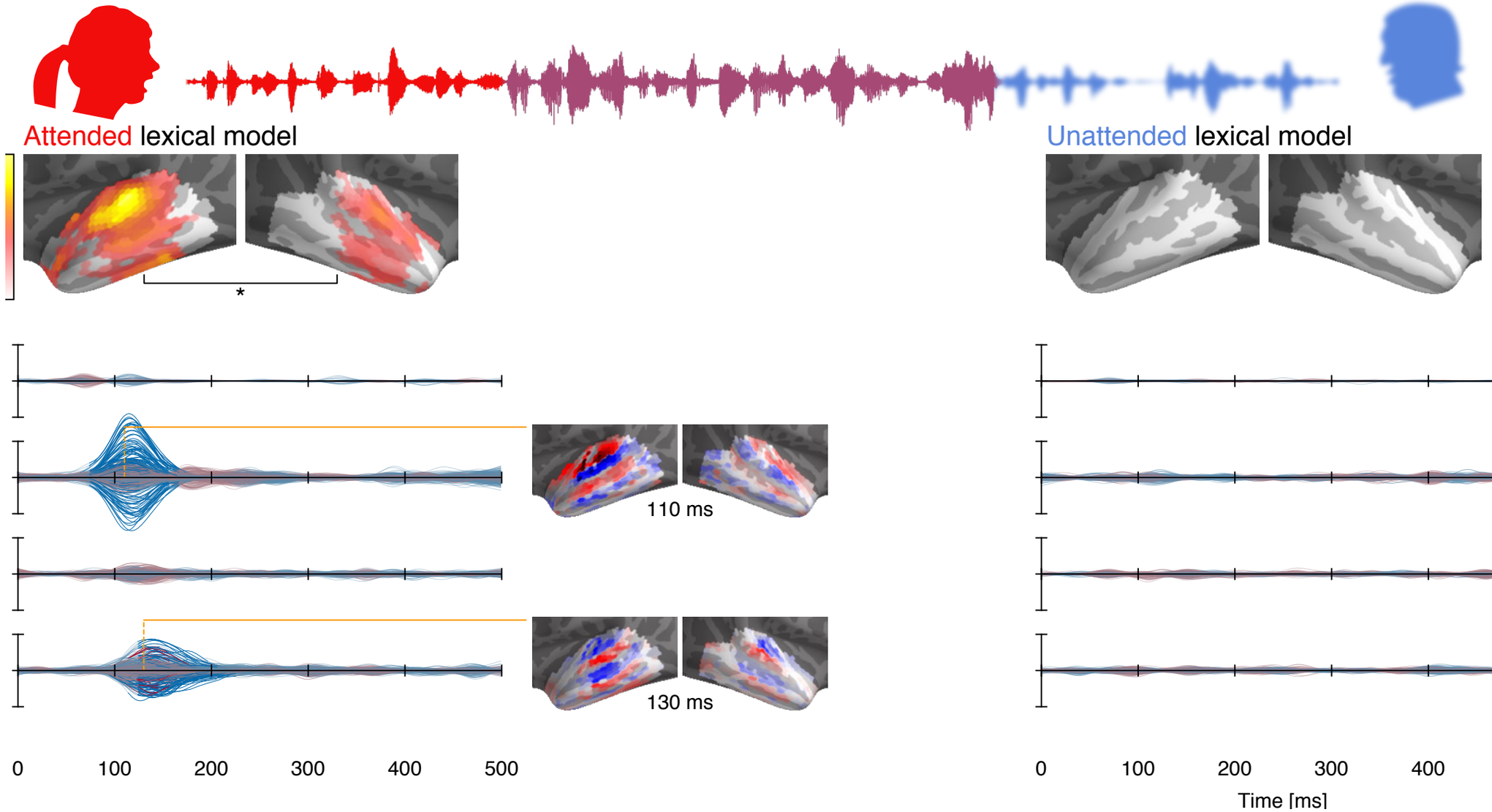
Brodbeck et al., Curr Biol (in press)

Lexical Attention



Brodbeck et al., Curr Biol (in press)

Lexical Attention



- Only attended speech processed lexically
- Lexical processing slowed by ~15 ms

Brodbeck et al., Curr Biol (in press)

Acoustic to Lexical Speech Processing

Acoustic envelope

Acoustic onset

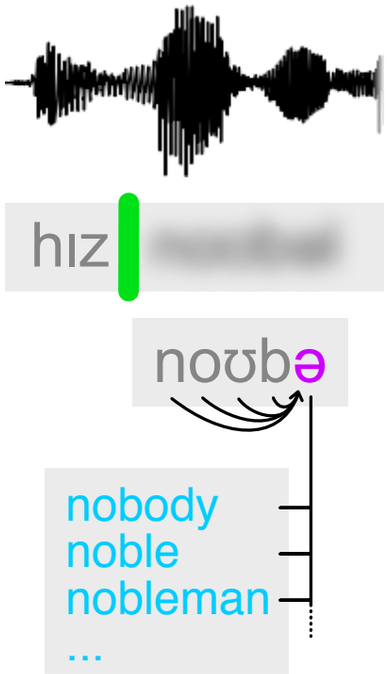
Word onset

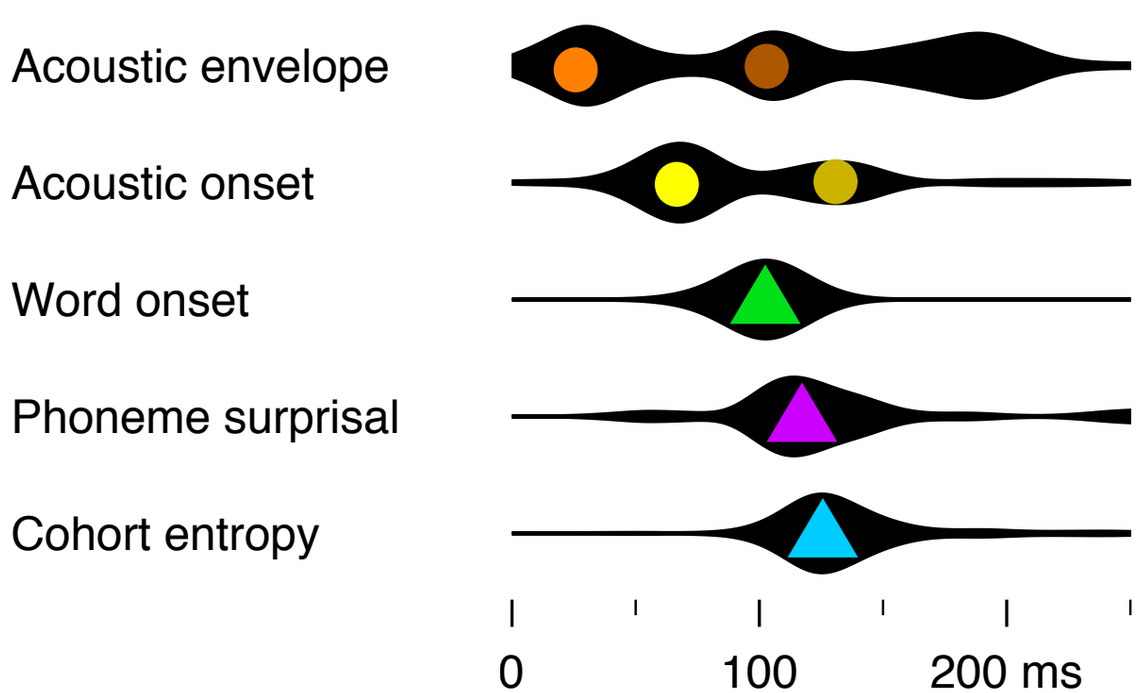
Phoneme surprisal

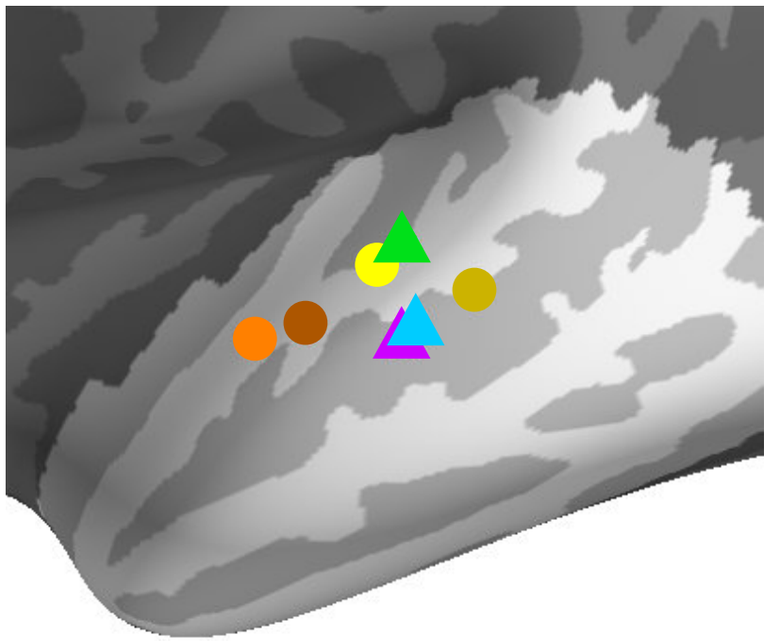
Cohort entropy

Brodbeck et al., Curr Biol (in press)

Acoustic to Lexical Speech Processing







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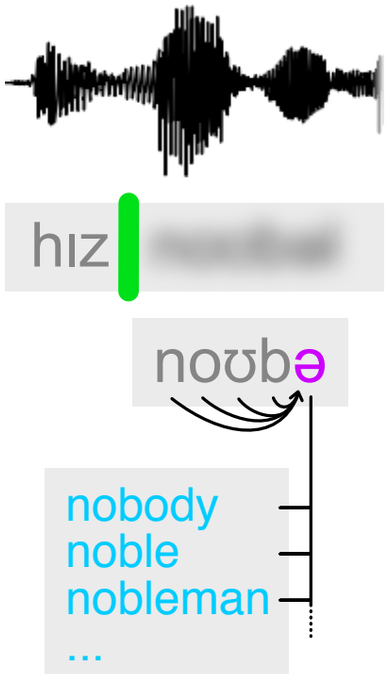
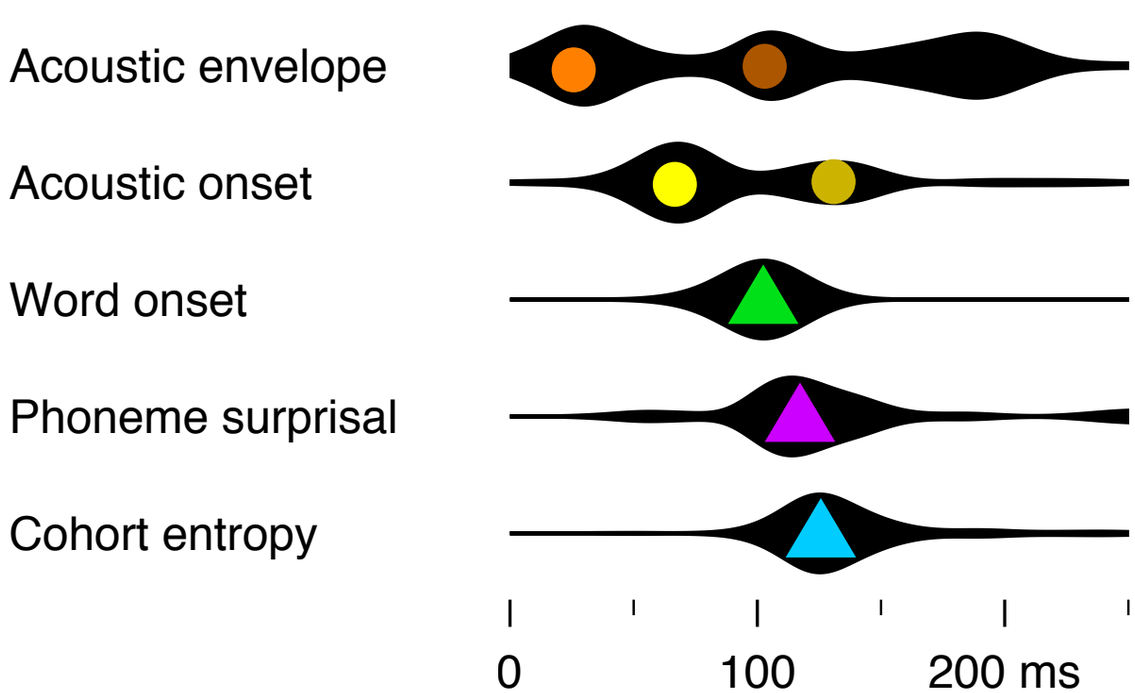
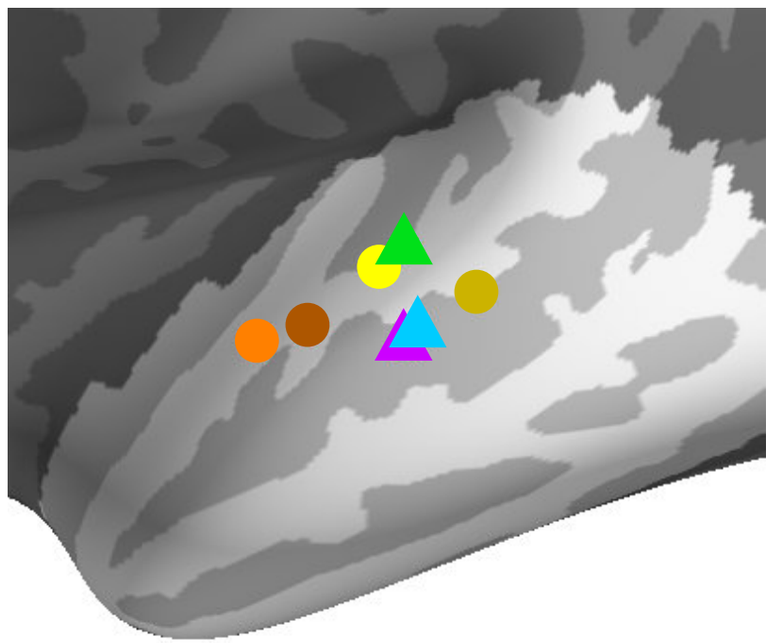
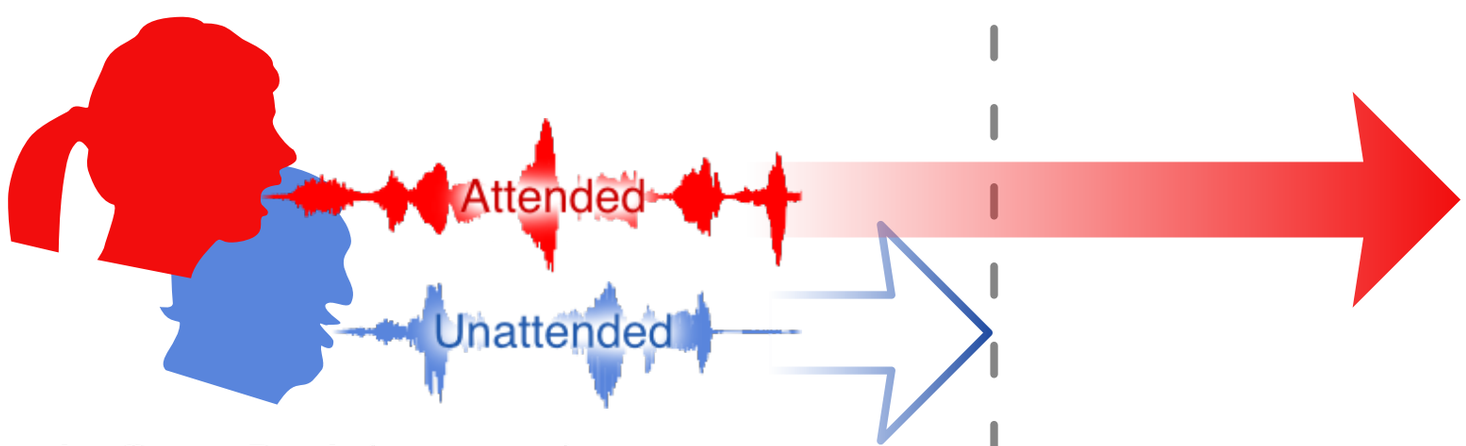


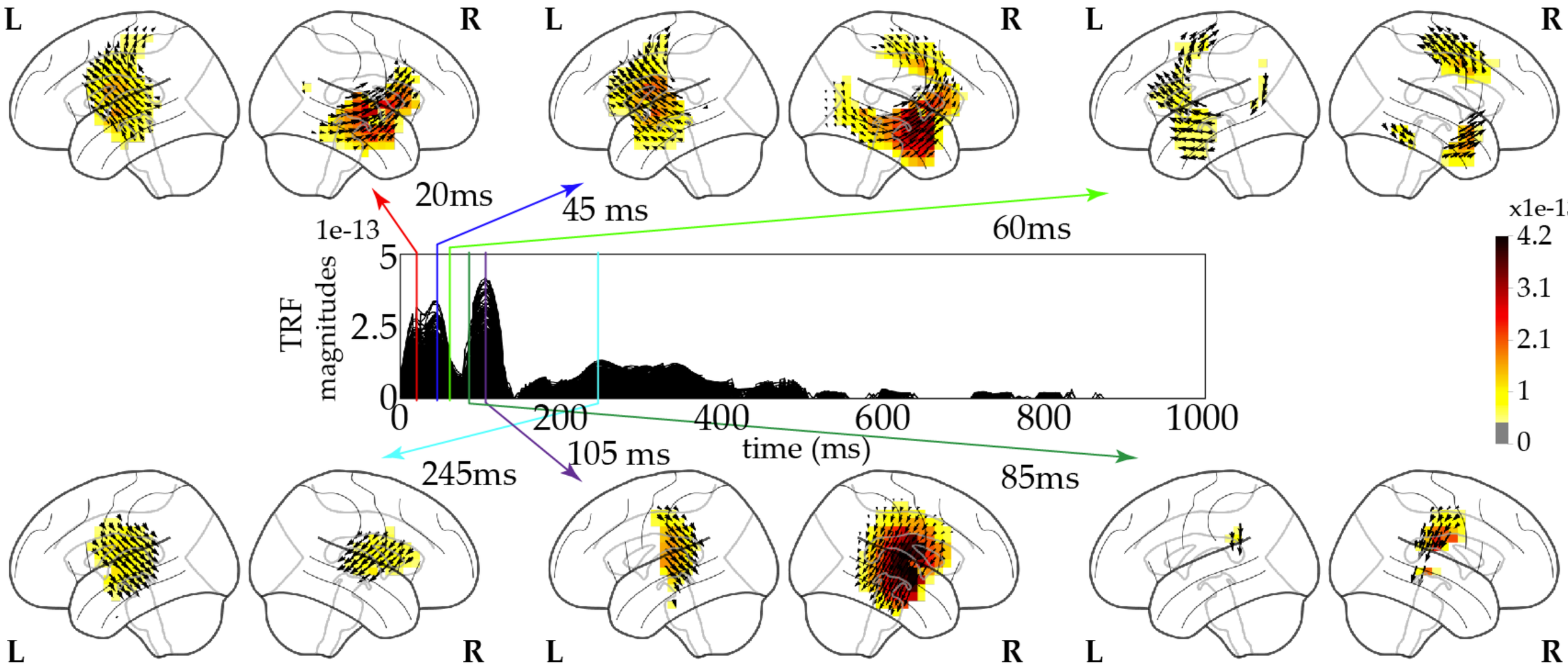






Brodbeck et al., Curr Biol (in press)

“Current Directions” in Spatiotemporal Distributions



Das et al., SfN Poster (2018)

Summary I

- Acoustic processing—Envelope vs. Onset
  - Allowed to compete against each other
  - Onset explains more response variance
    - Strongly bilateral with right-bias for onset
    - Similar latencies, but possibly different neural populations
- Evidence for rapid transformation from acoustic to lexical representations

Summary II

- Fast Lexical Phoneme-based processing
  - Surprisal (114 ms), local measure of phoneme prediction error (predictive coding?)
  - Cohort entropy (125 ms), global measure of lexical competition across cohort
  - Left hemisphere dominant
  - Strongly attention-dependent (bottleneck?)
- Low latencies
  - Coarticulation; prediction using context
  - ~15 ms extra delay from interfering speech


PLAY A HAPPY SONG
GUY LOMBARDO
AND HIS ROYAL CANADIANS
INCLUDING: DUMMY SONG / RED HEAD / IF I HAD A GIRL LIKE YOU / ON SAN FRANCISCO BAY / LAST NIGHT ON THE BACK PORCH / ACE IN THE HOLE / GOODNIGHT LITTLE GIRL, GOOD NIGHT
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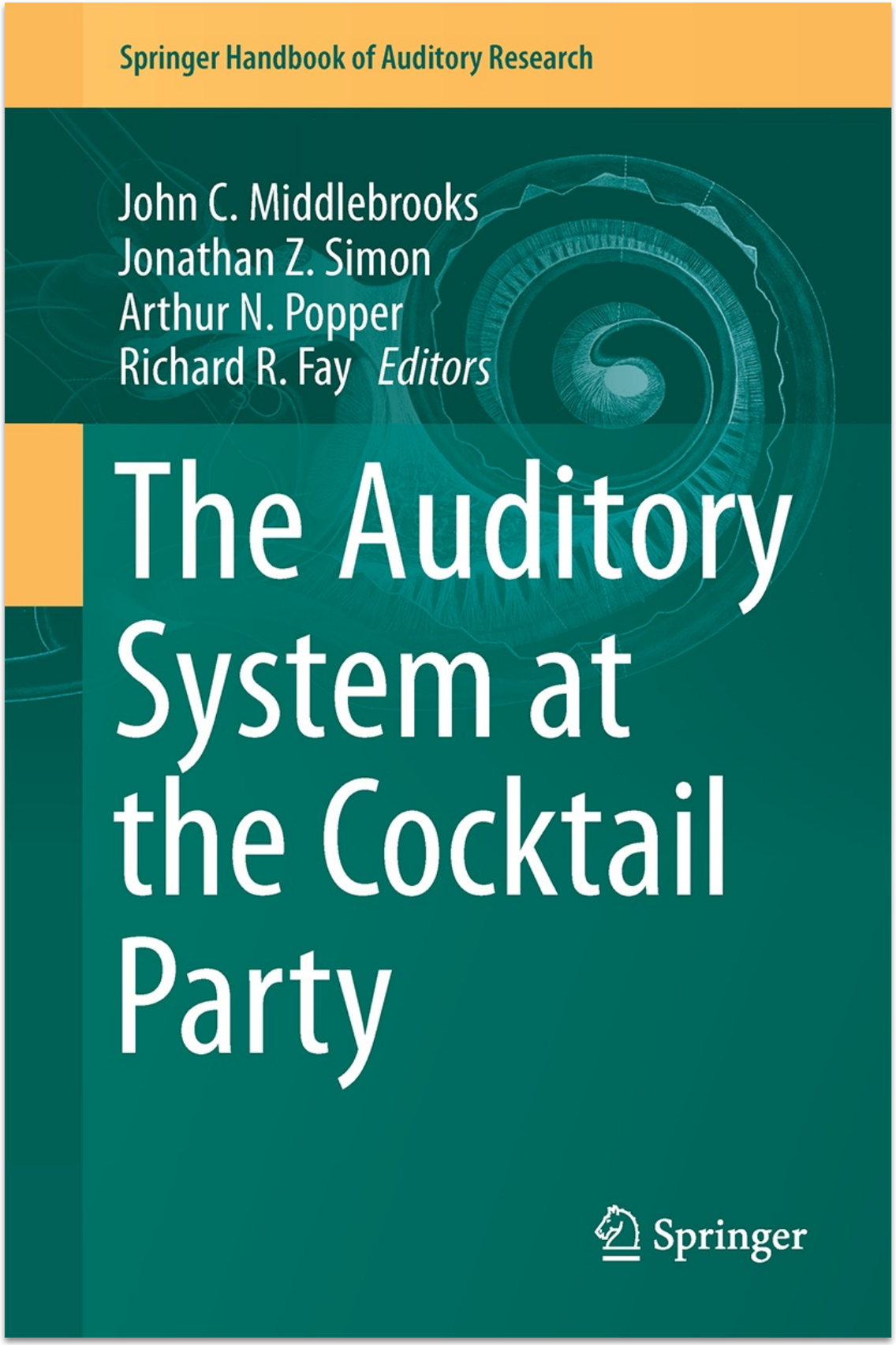
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