NEW YORK UNIVERSITY

Back to the future:
Tracking the neural computations supporting speech perception

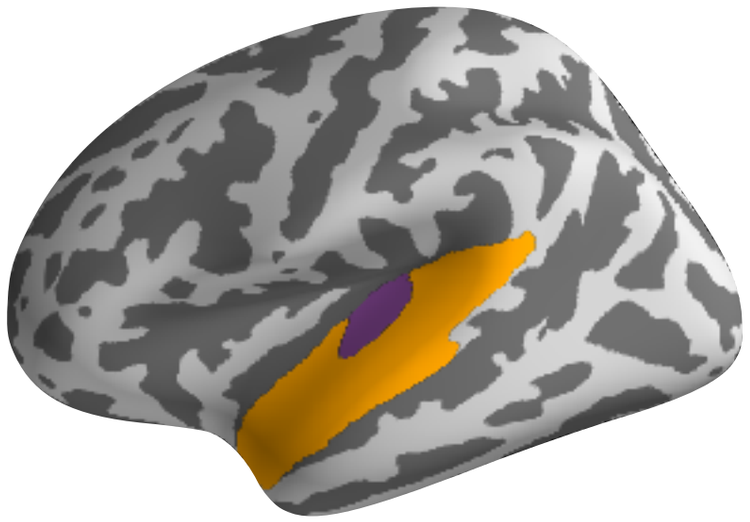
Laura Gwilliams

6th March 2018

Laura Gwilliams | Chang Lab | UCSF

Motivation

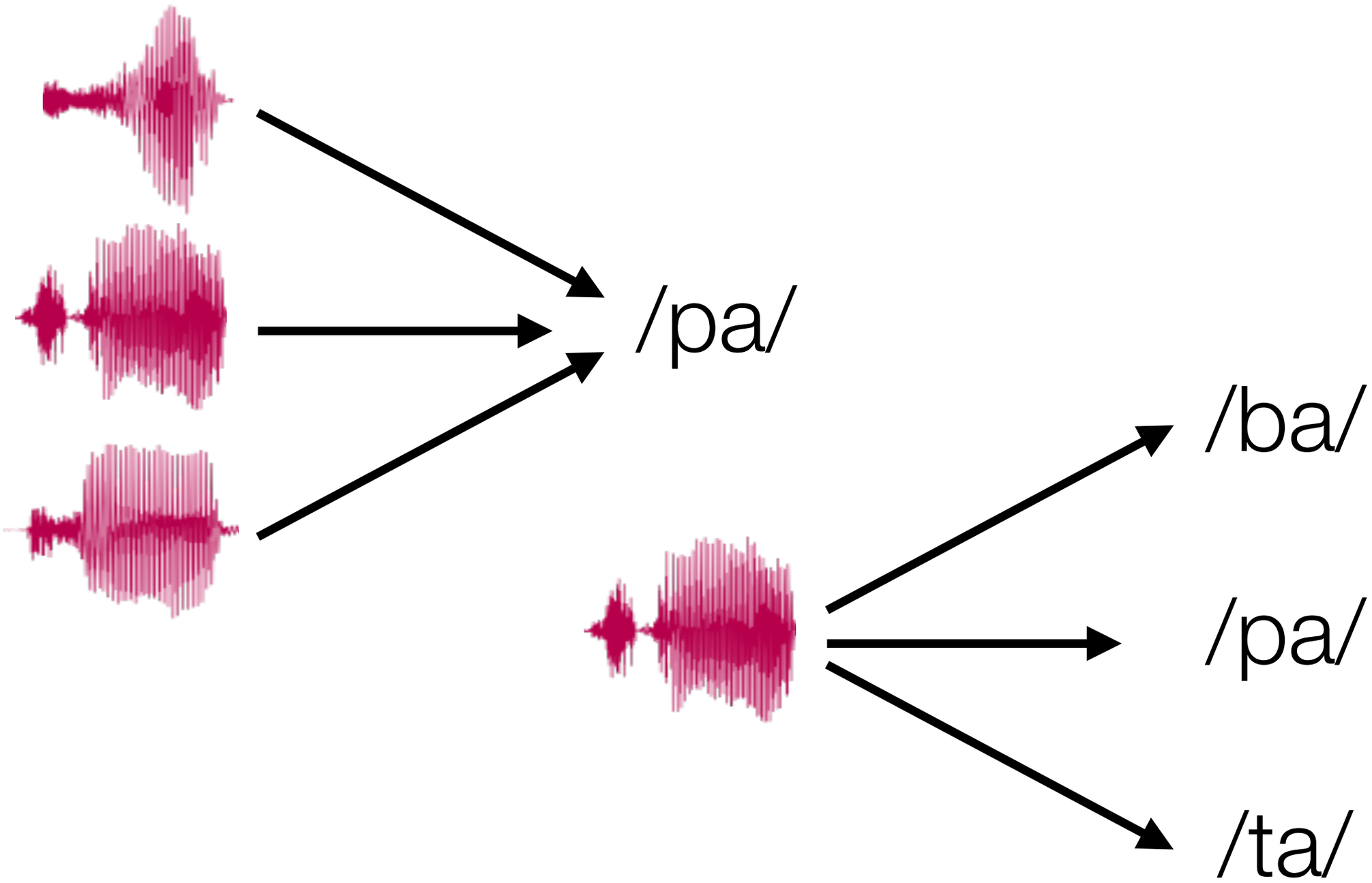
acoustics
(continuous)



percept
(categorical)

/pa/

Lack of invariance problem



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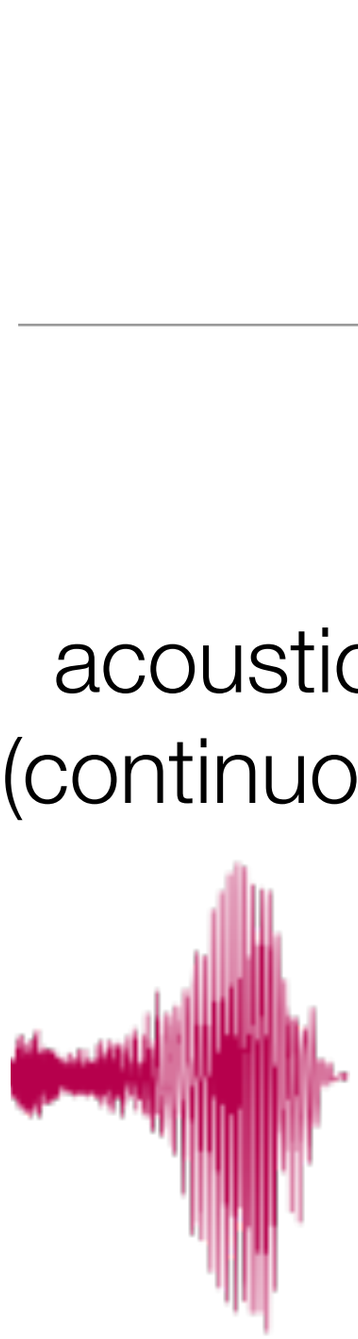

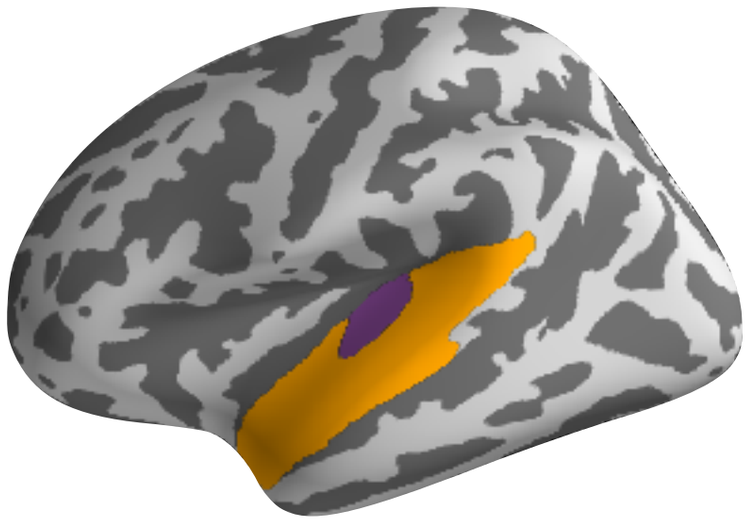

percept
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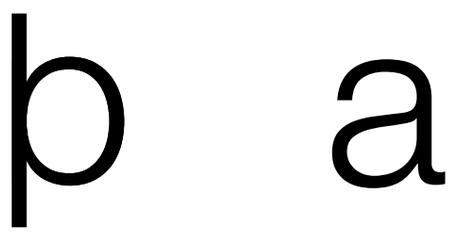
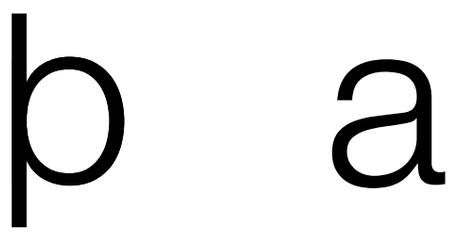
/pa/

Roadmap



Roadmap

- Completed projects
  - **Bottom-up processes**: Transforming acoustic signal into discrete phonological categories



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  - Testing re-activation processes in **natural speech**

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Bottom-up processing of phonemes

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- Phonetic features are processes ~100 ms after onset in superior temporal gyrus (Simos et al., 1998; Ackermann et al., 1999; Obleser et al., 2003; Papanicolaou et al., 2003; Obleser et al., 2004; Mesgarani et al., 2014; Di Liberto et al., 2015…)

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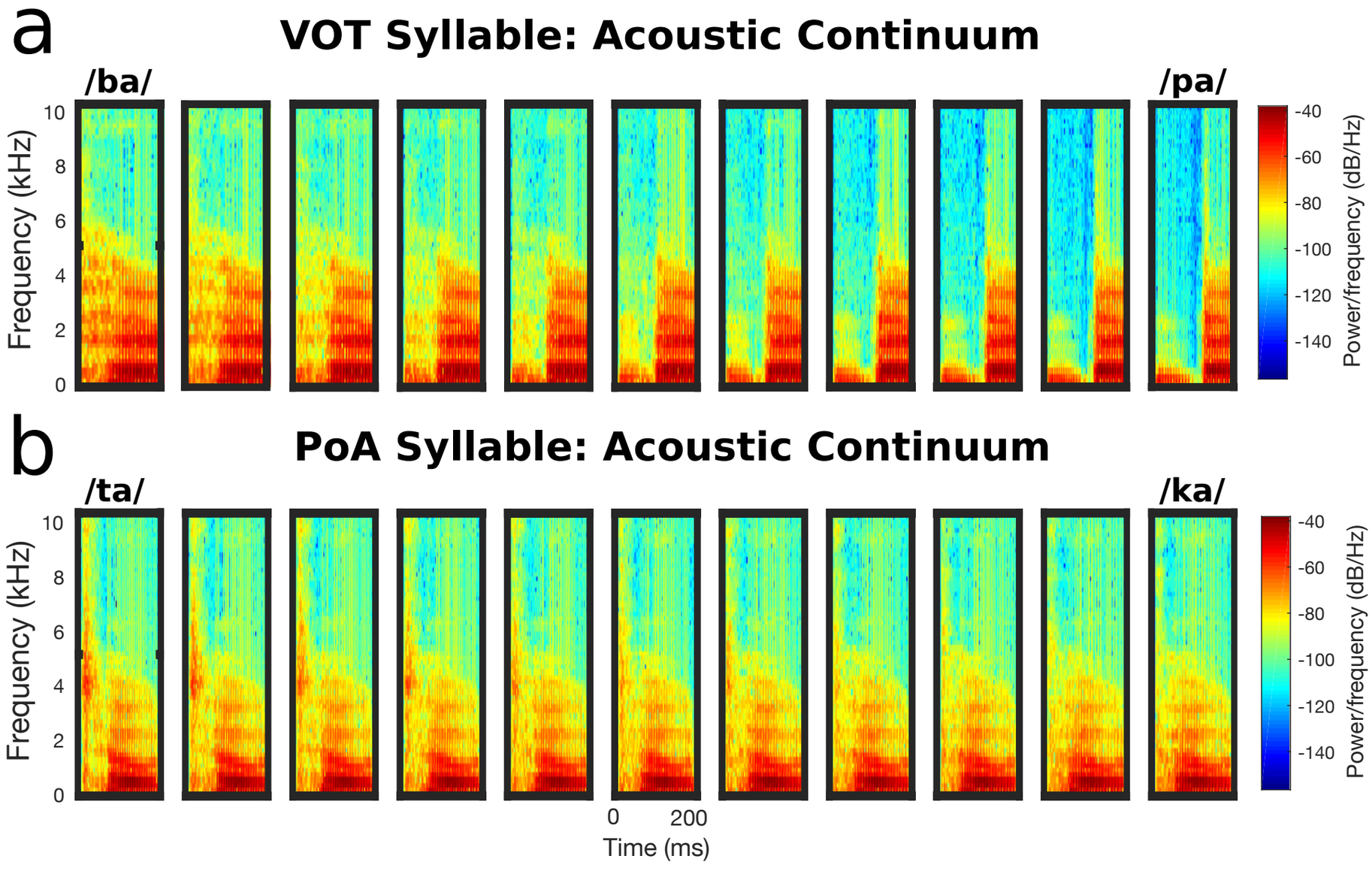
- This processing stage appears to be **categorically** modulated (Chang et al., 2010)

Neutralising ambiguity

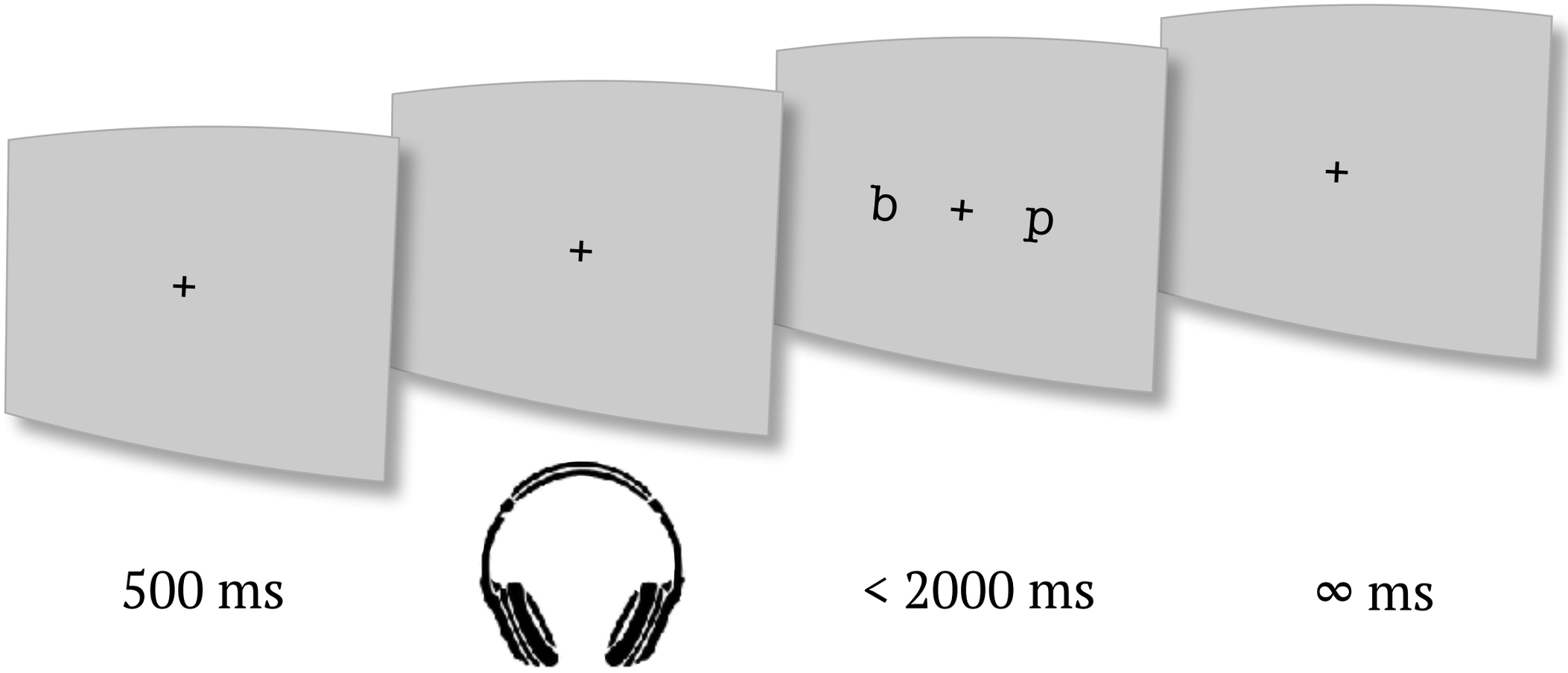
At what stage of processing is phonological **ambiguity** alleviated?

Materials



- VOT (31 pairs) {p-b, t-d, k-g} and POA (22 pairs) {t-k, p-t}

Design

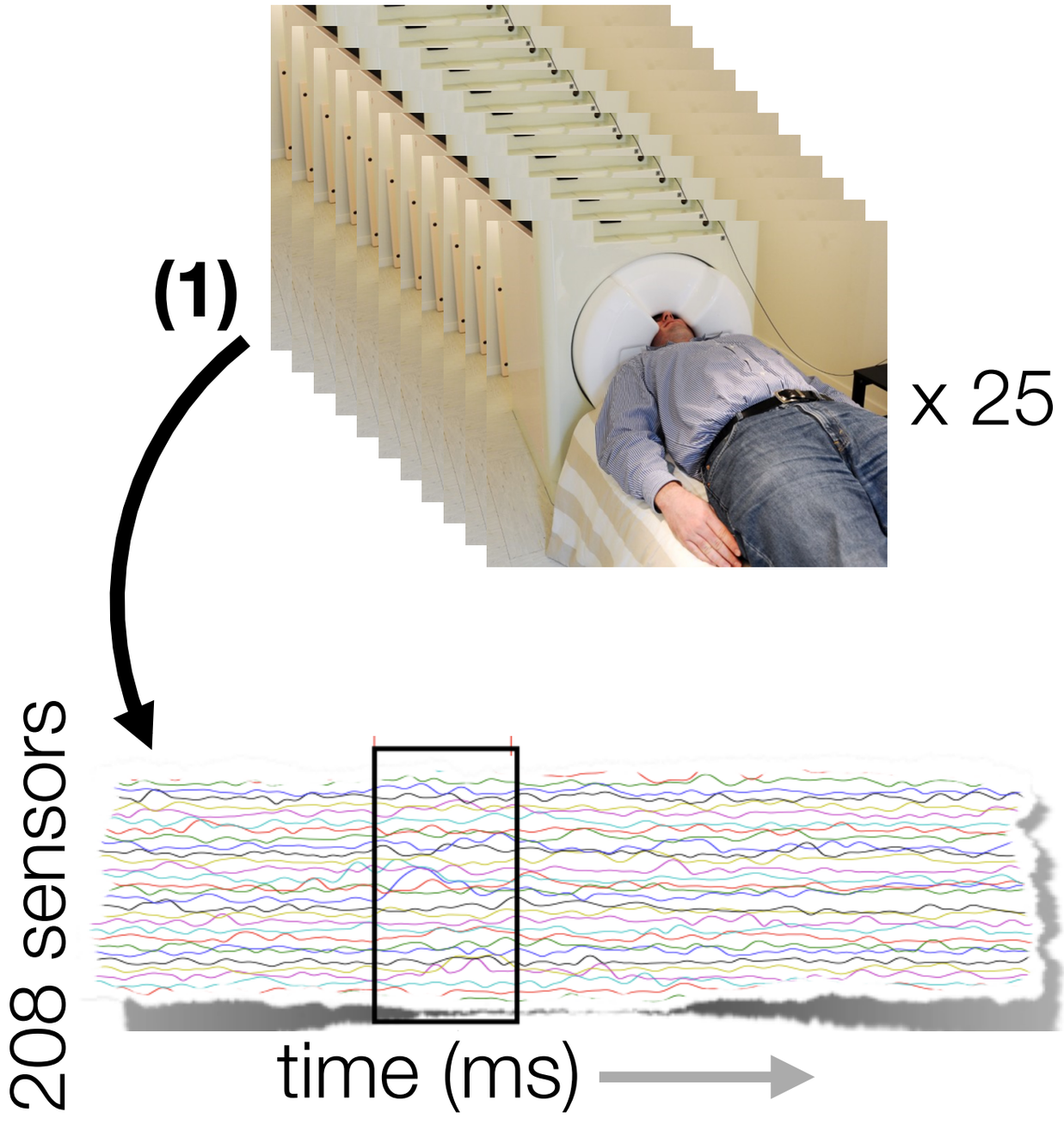


Procedure & Analysis

Procedure & Analysis

x 25

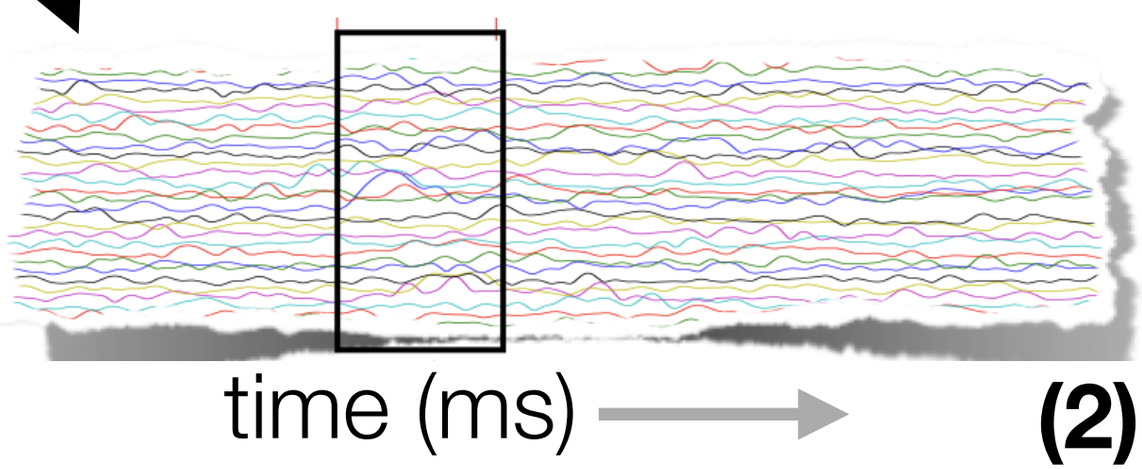
Procedure & Analysis



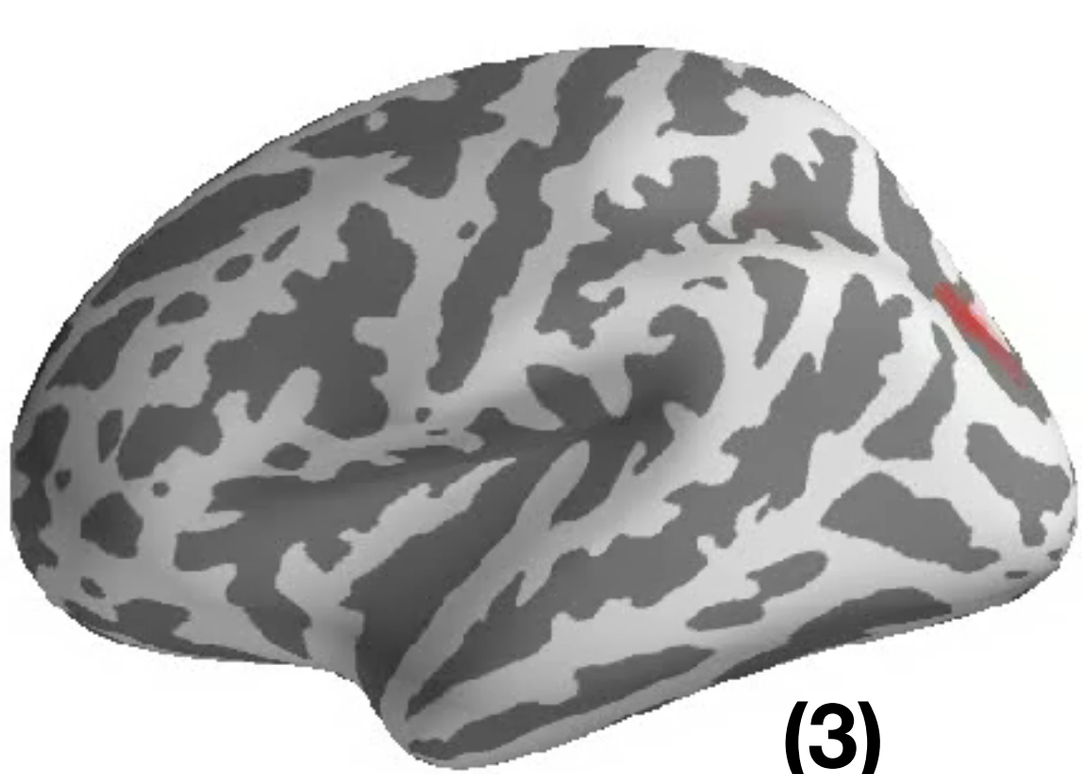
Procedure & Analysis

(1)

x 25



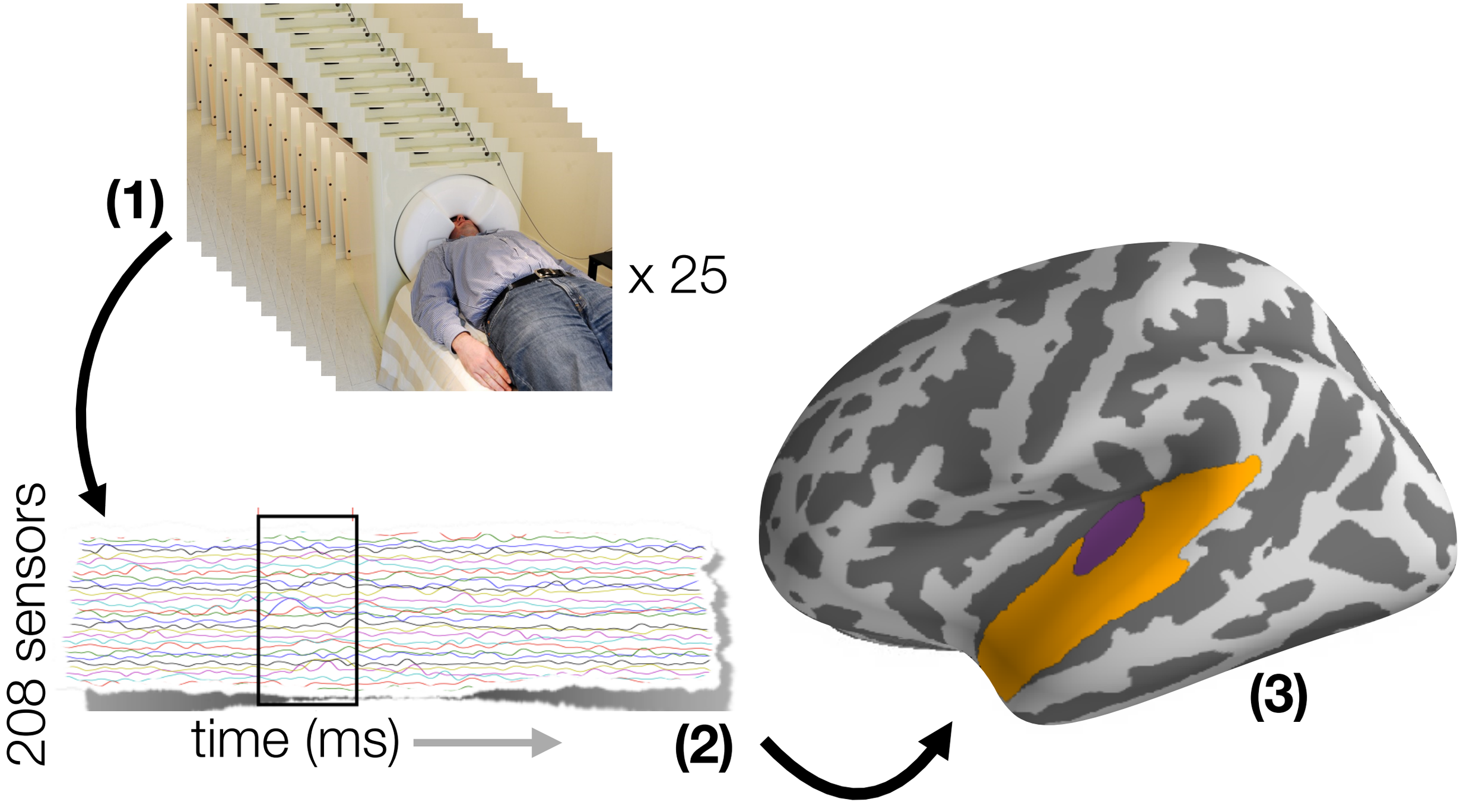
(2)



(3)

-100 ms

Procedure & Analysis



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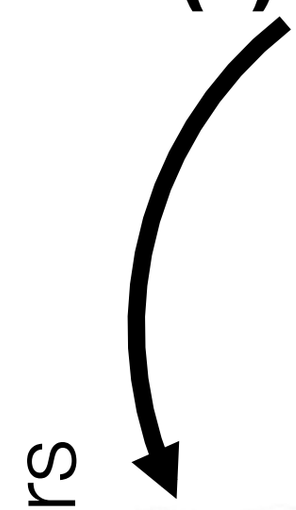
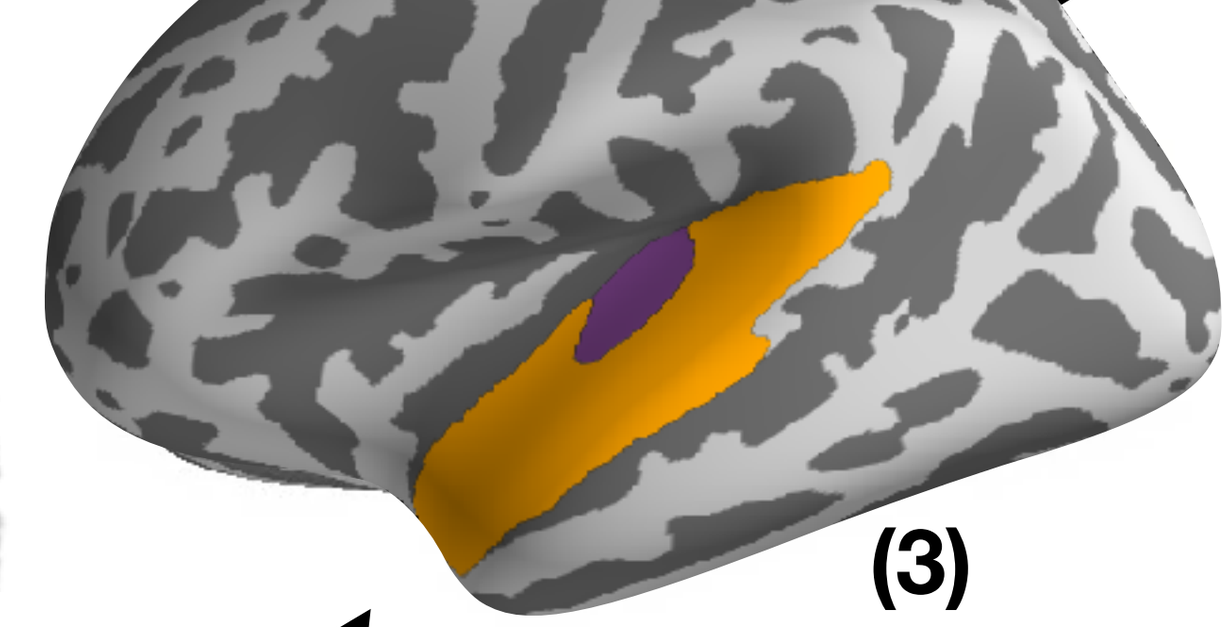
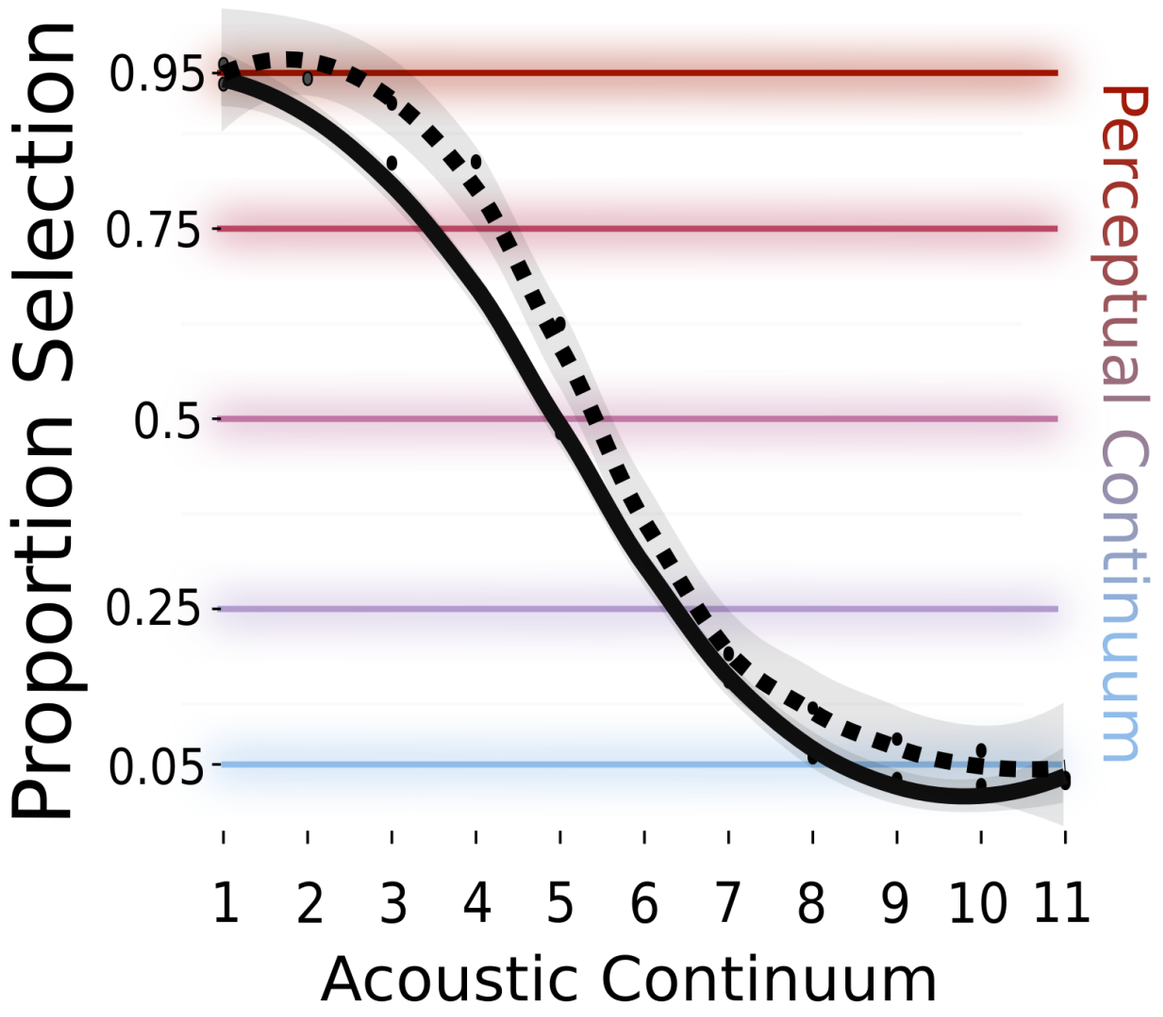


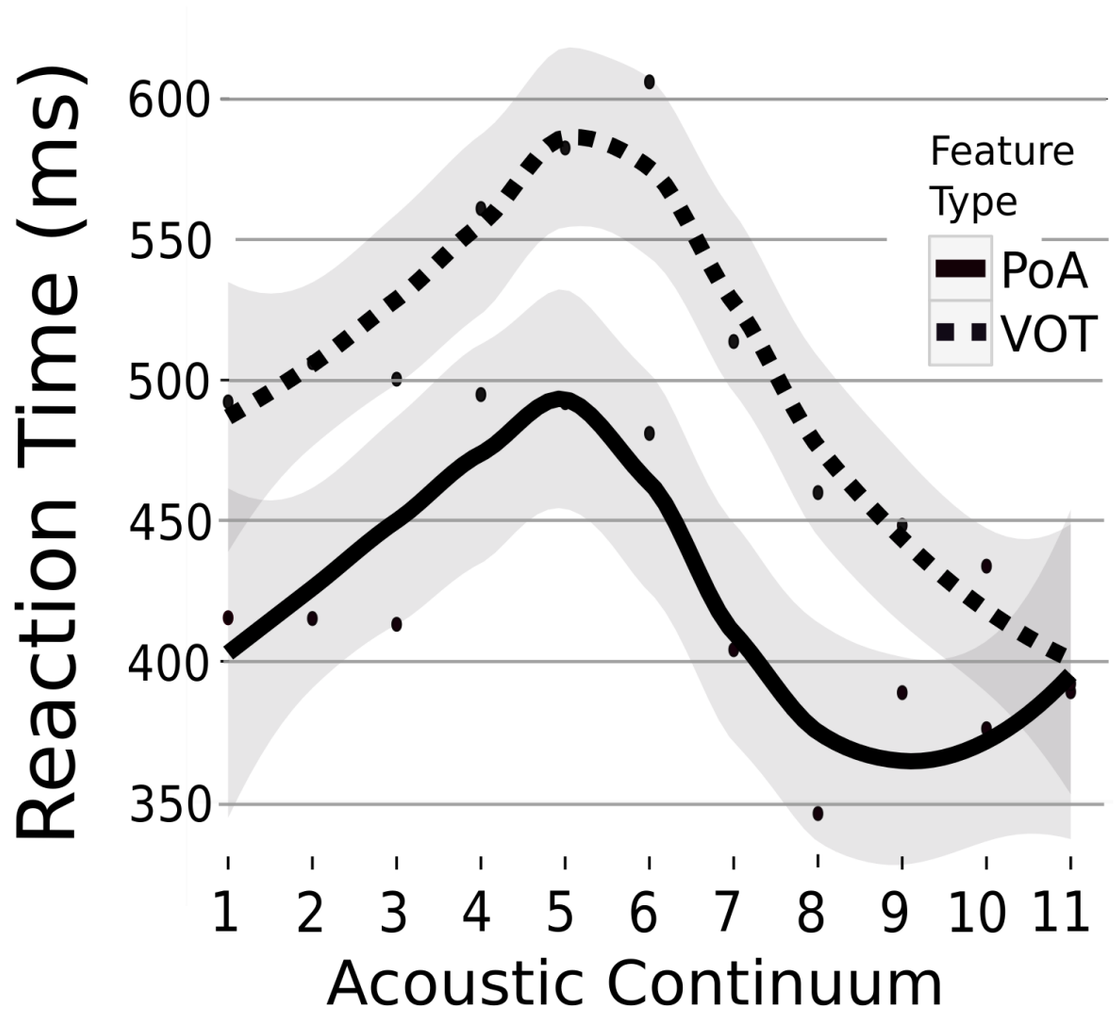


- Multiple regression at each ms and vertex
- Spatio-temporal cluster test on beta coefficients

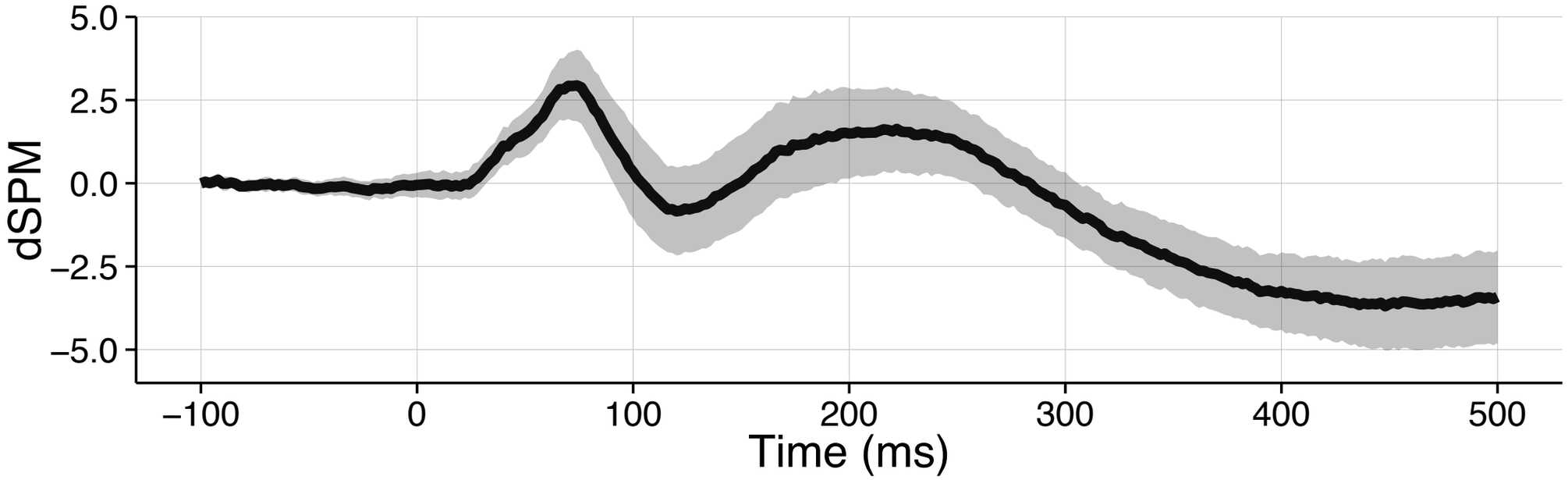
(for more info see Gwilliams, Lewis & Marantz, 2016)

Behaviour


Proportion Selection
0.95
0.75
0.5
0.25
0.05
Perceptual Continuum
1 2 3 4 5 6 7 8 9 10 11
Acoustic Continuum


Reaction Time (ms)
600
550
500
450
400
350
Feature Type
PoA
VOT
1 2 3 4 5 6 7 8 9 10 11
Acoustic Continuum

Neutralising ambiguity



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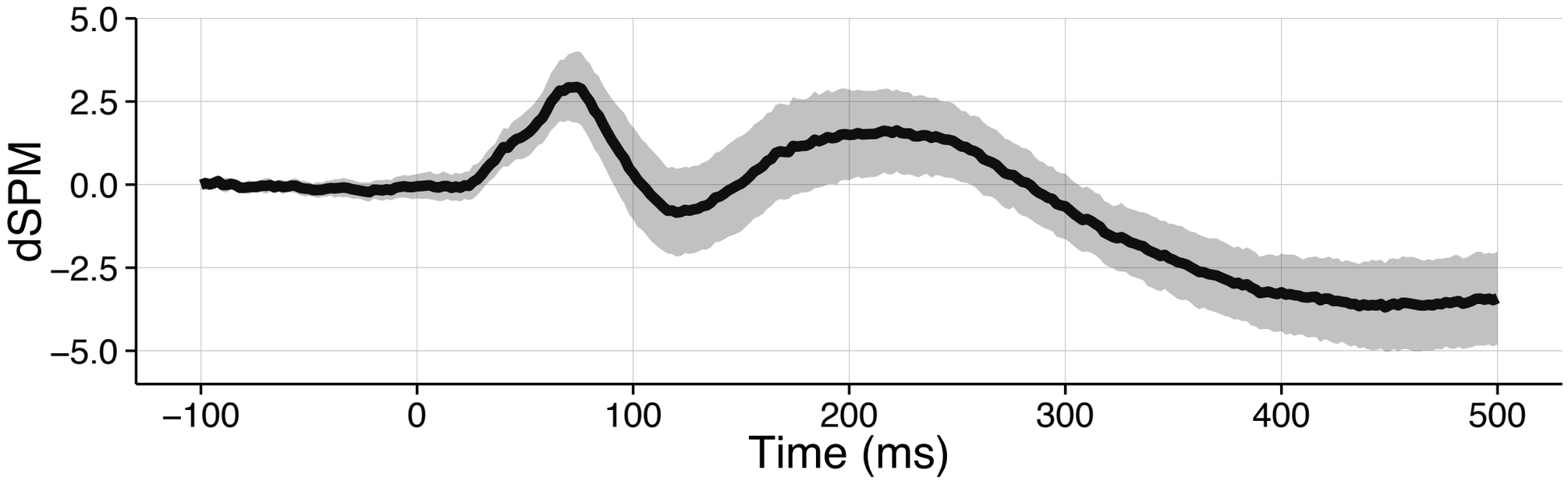
At what stage of processing is phonological **ambiguity** alleviated?



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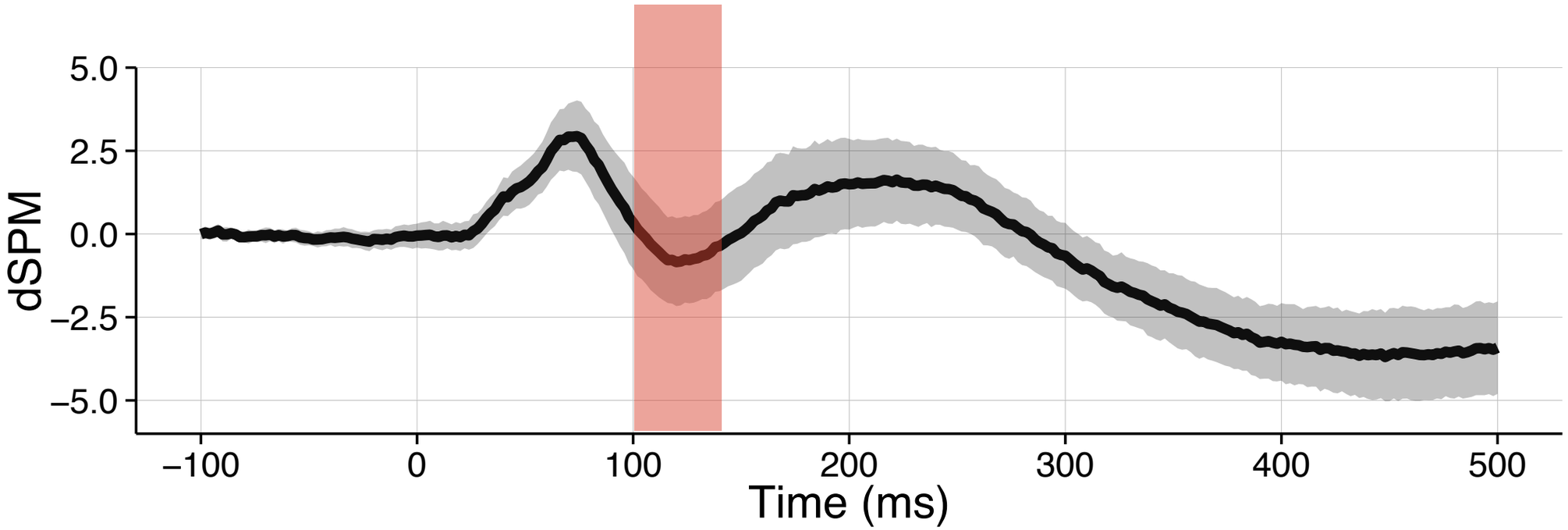

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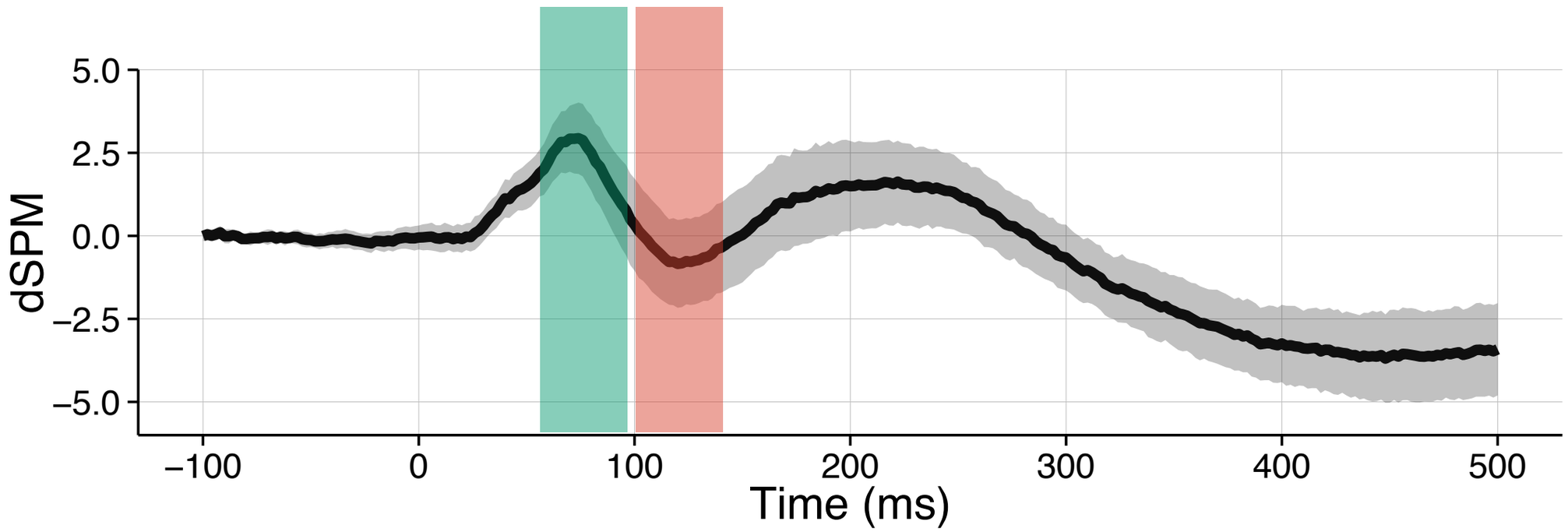

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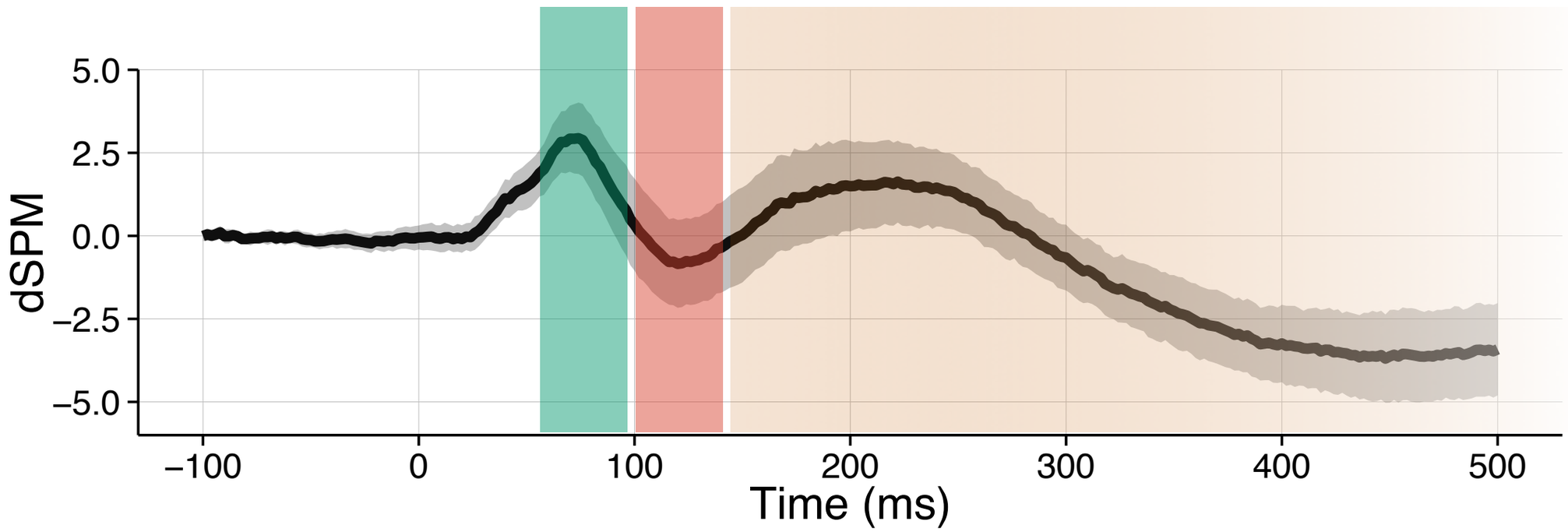
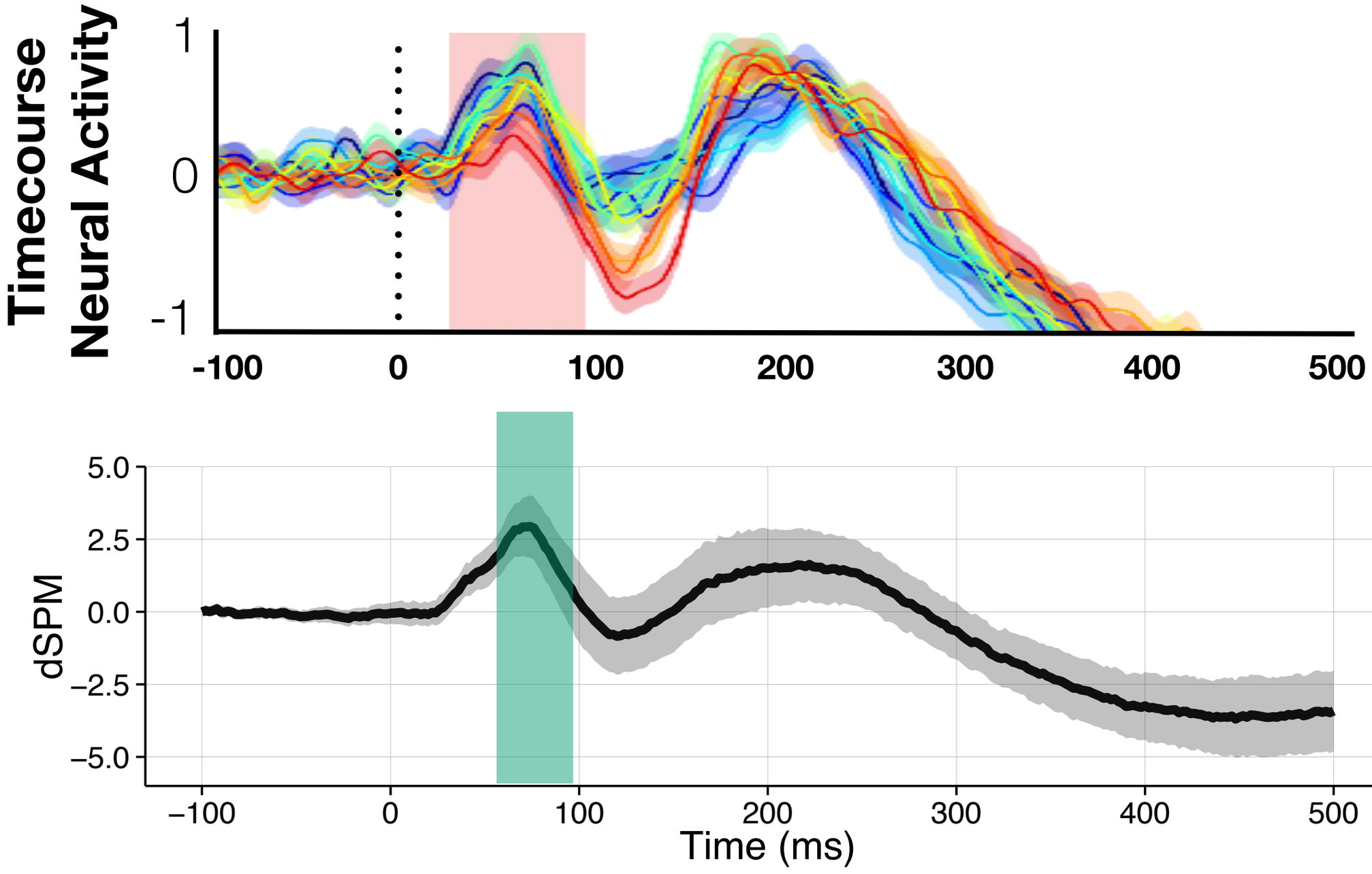


Early ambiguity responses in Heschl's gyrus



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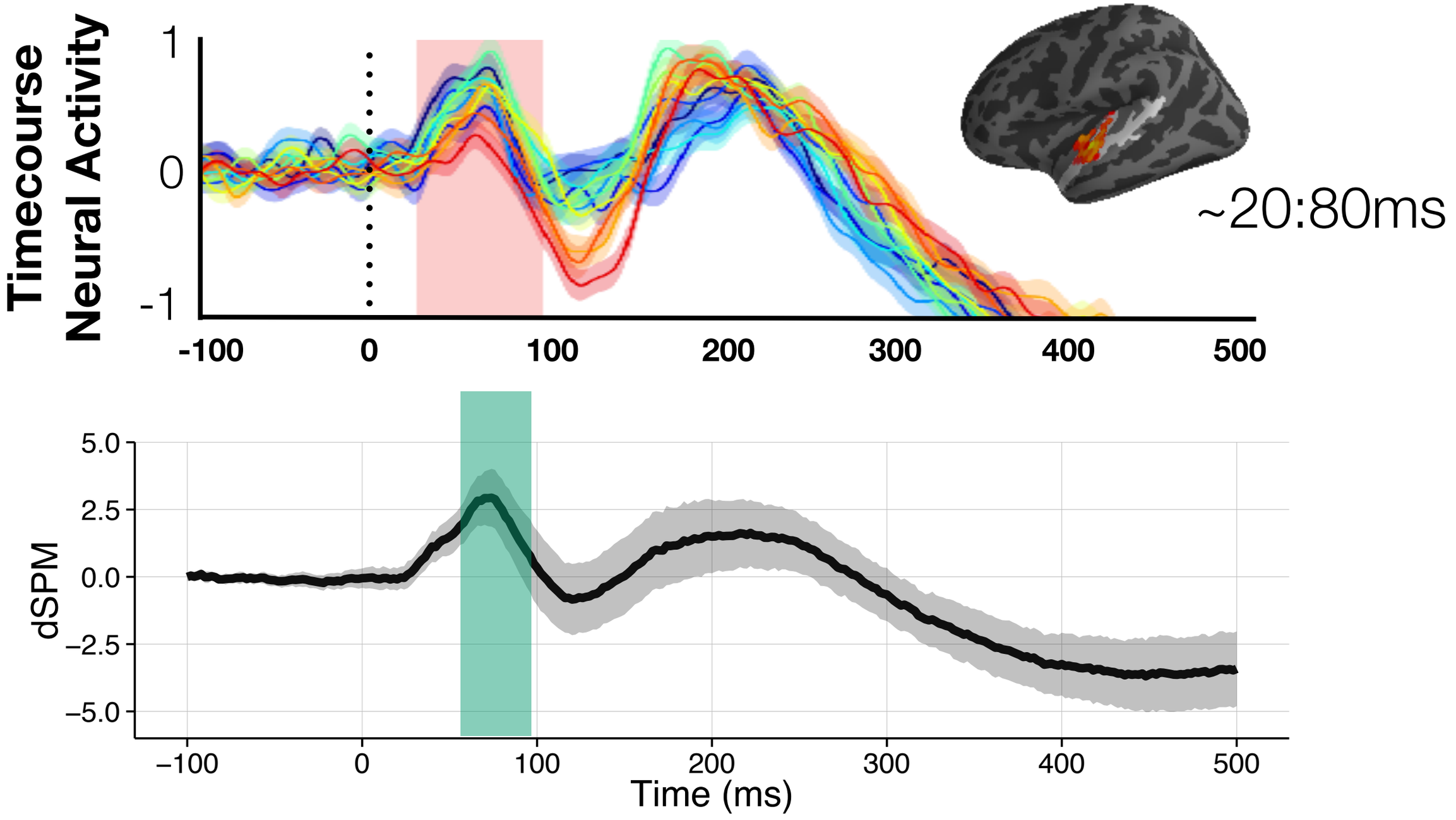

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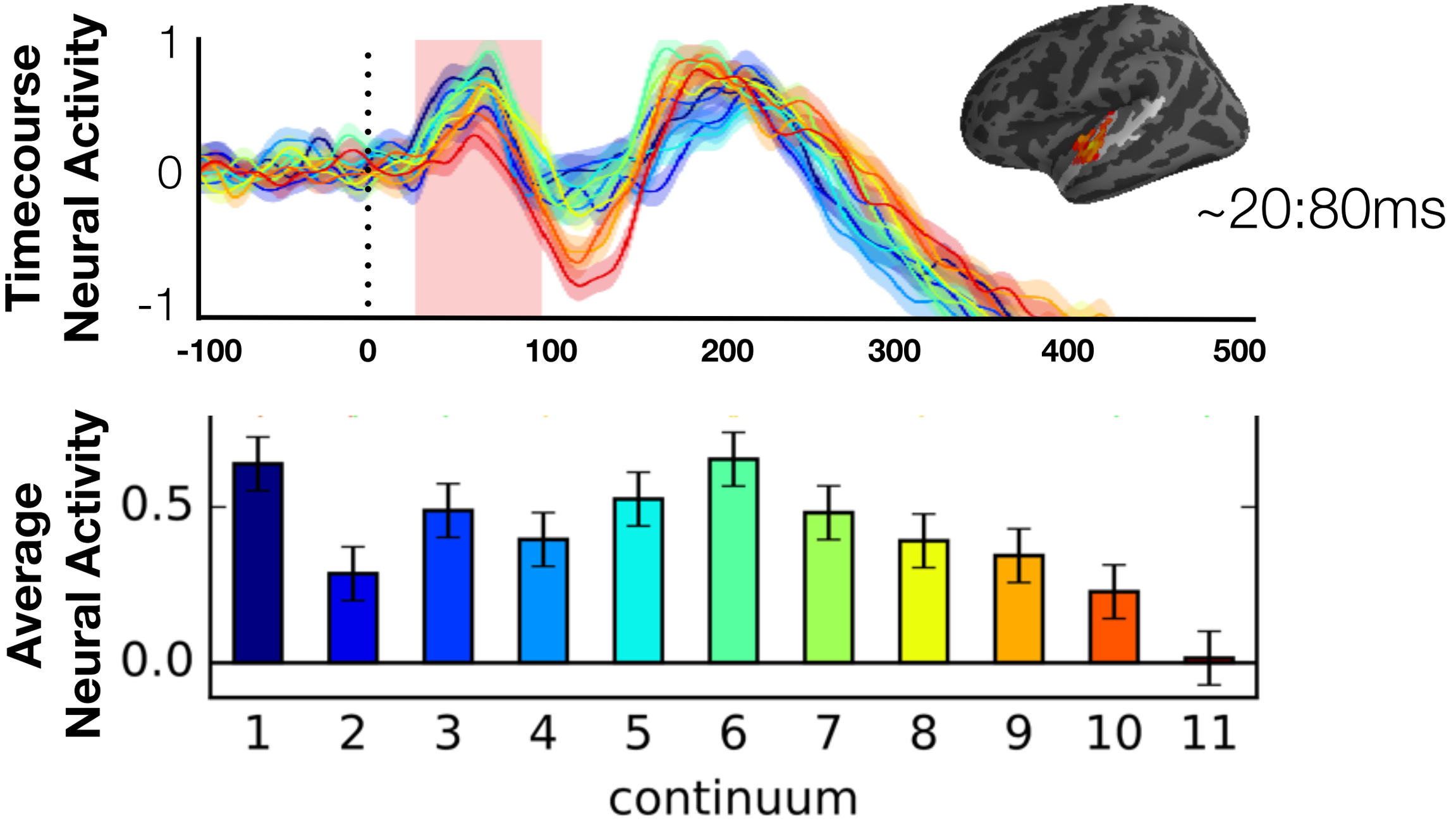
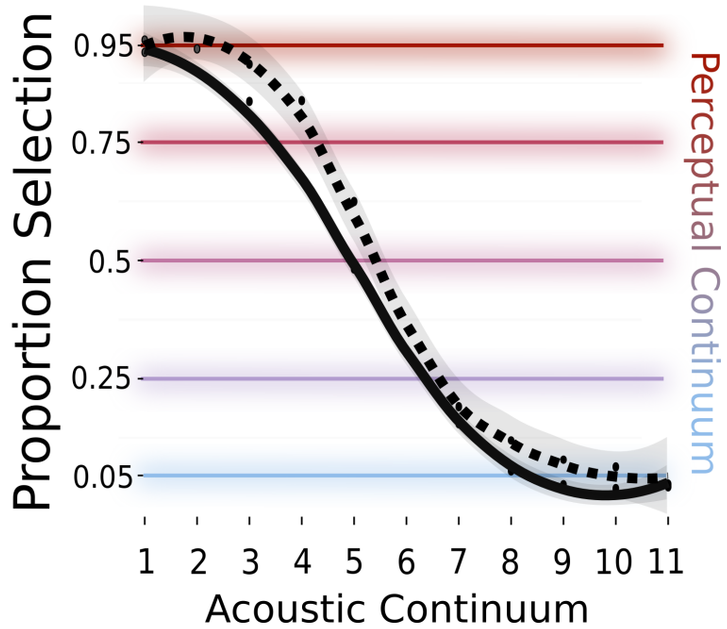


Is ambiguity correlated with acoustic properties?



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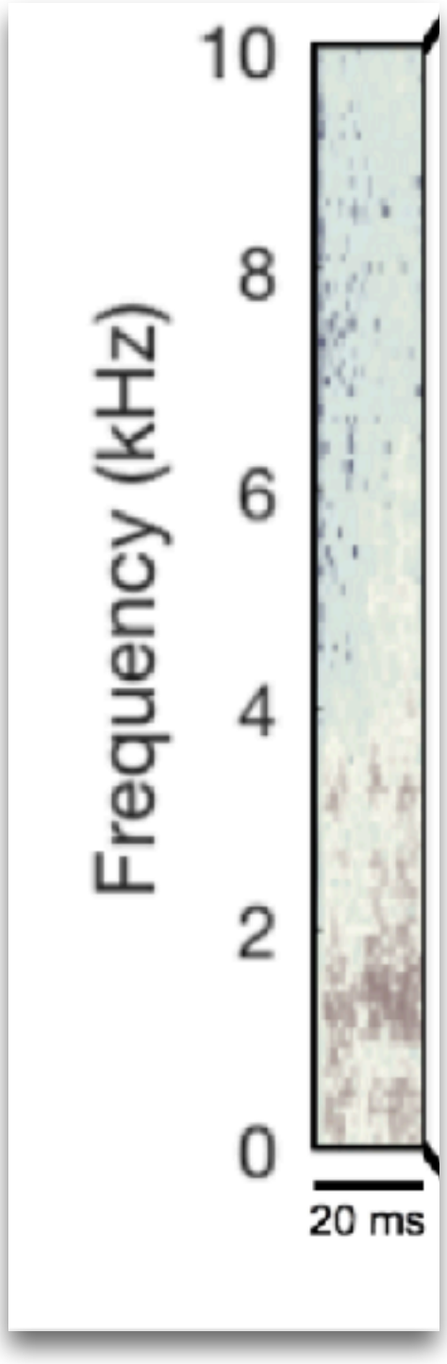

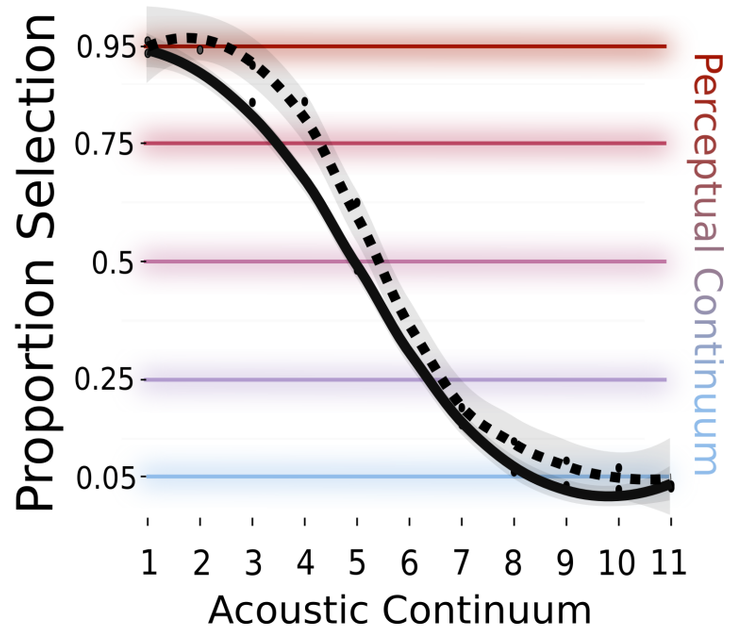

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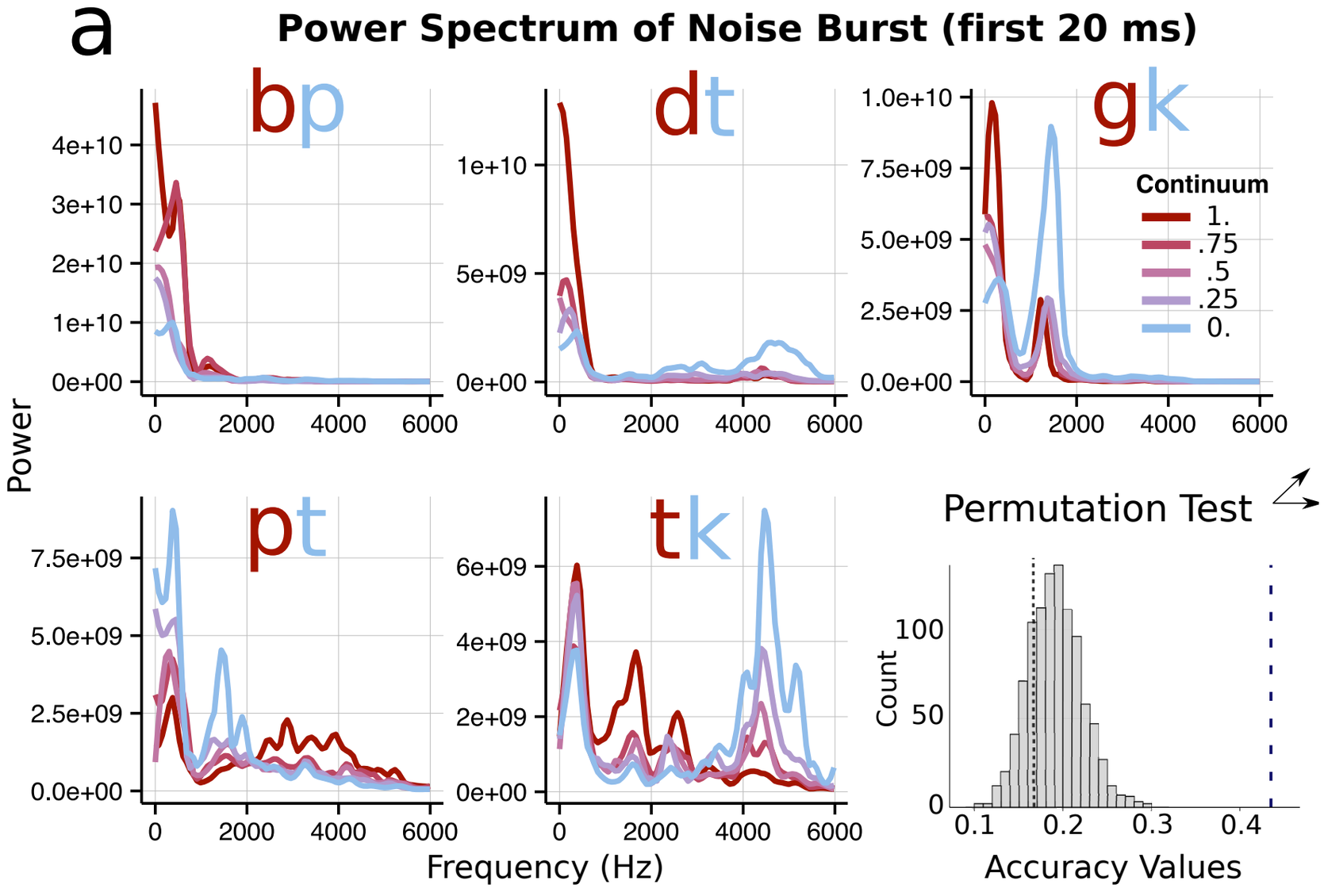

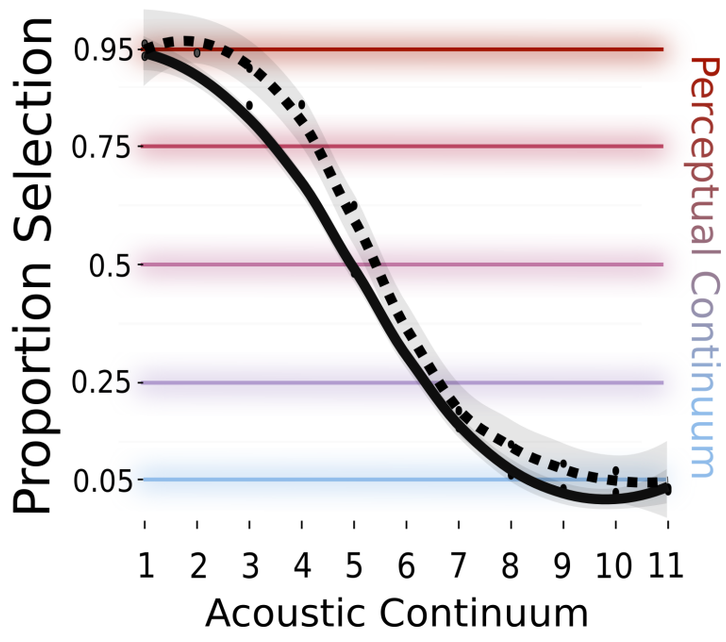

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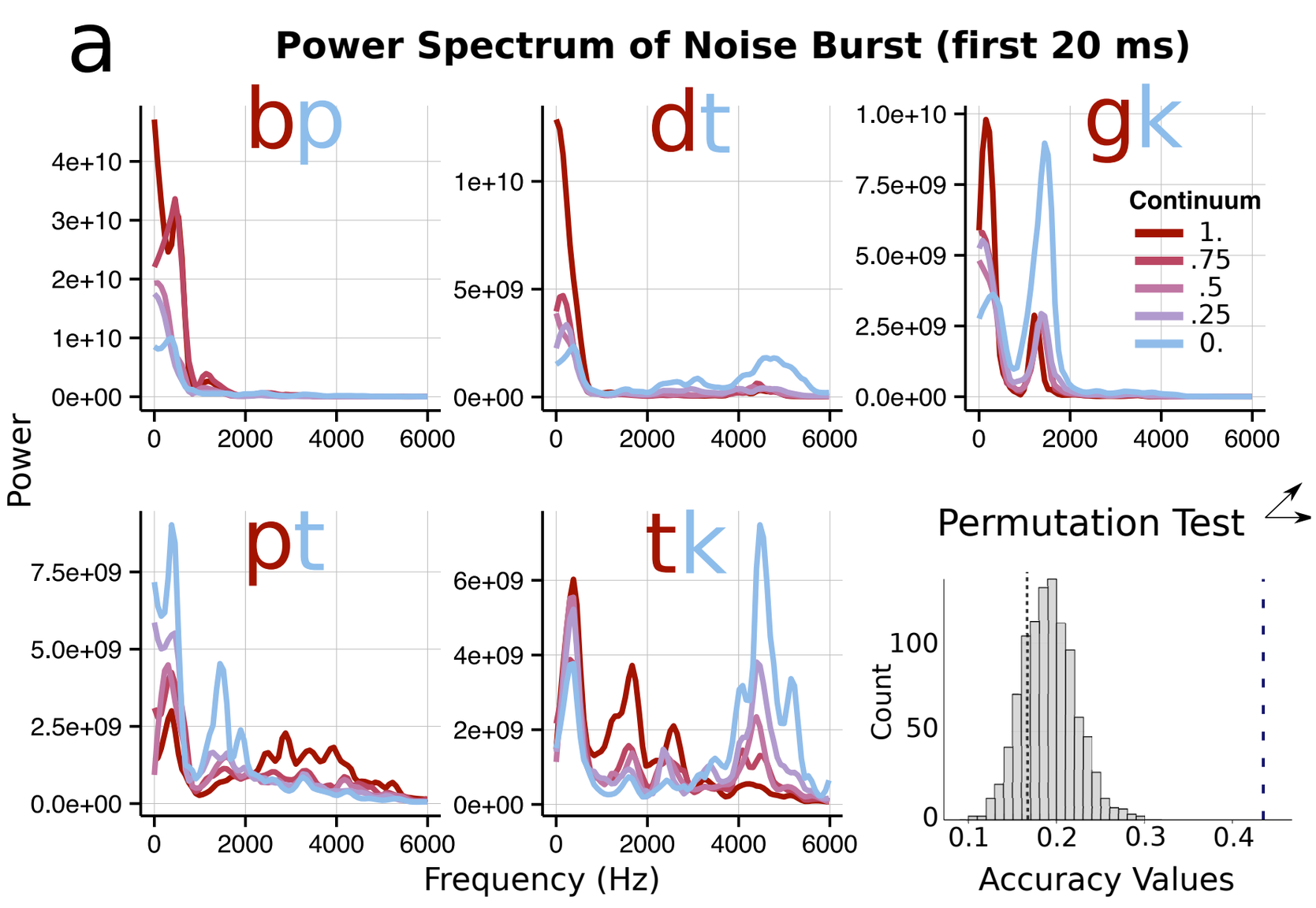

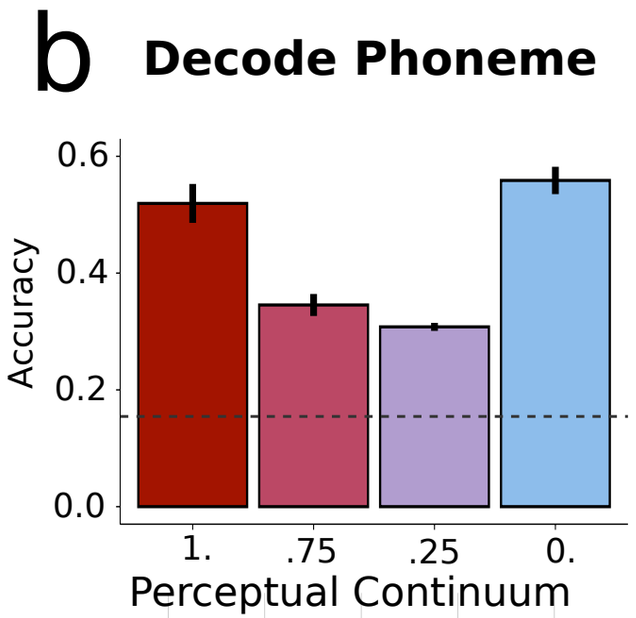

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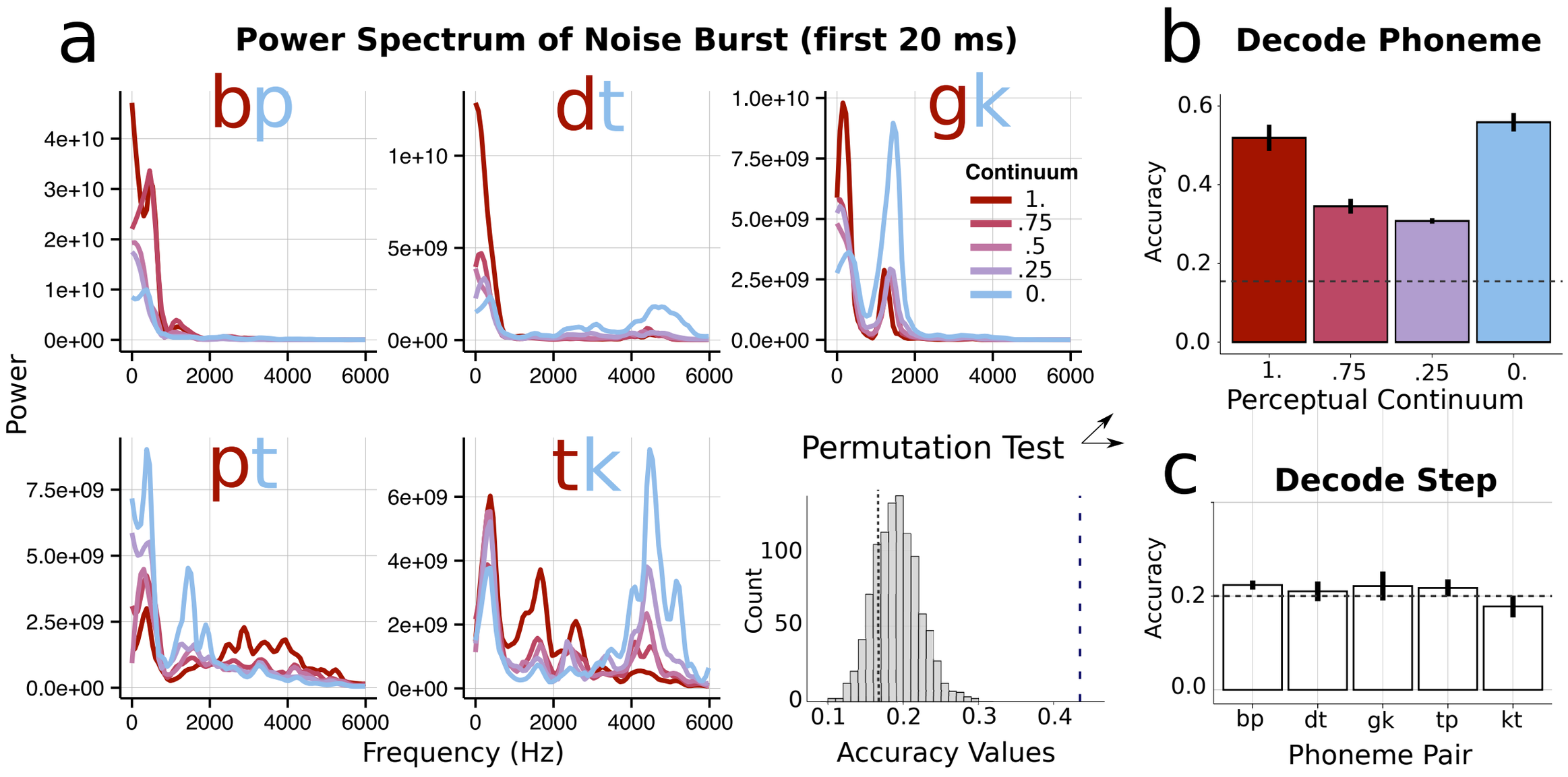

Replicating the categorical trajectory using MEG

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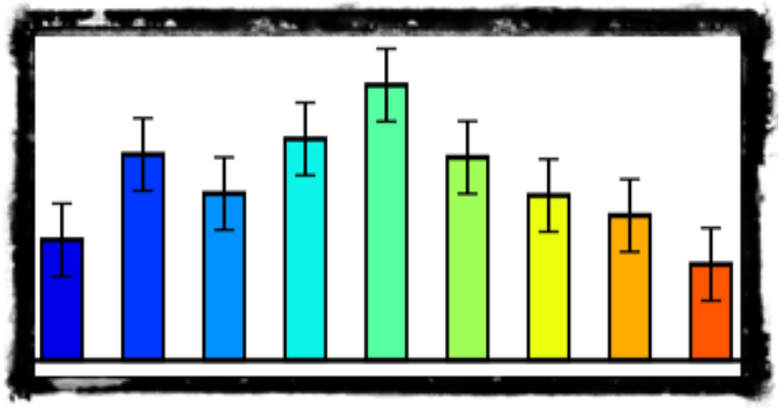
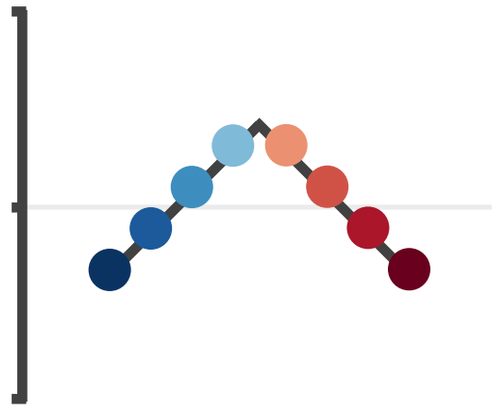


~20:80ms
ambiguity



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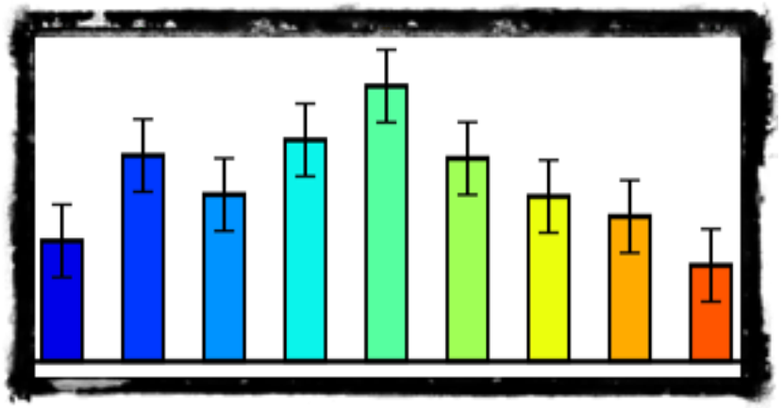

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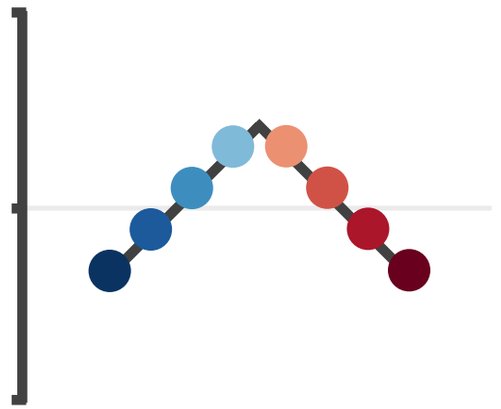
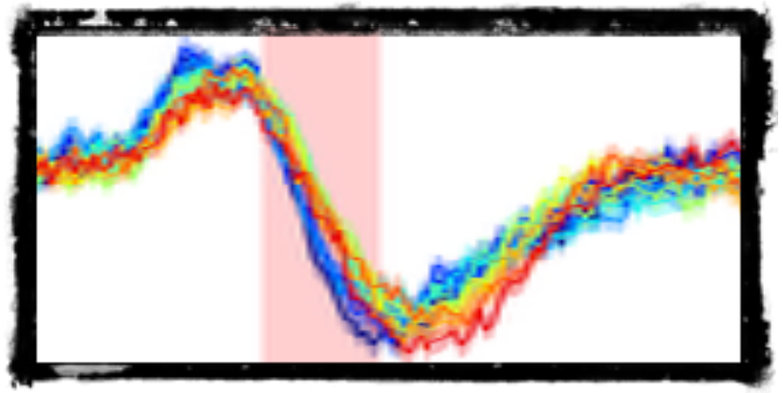
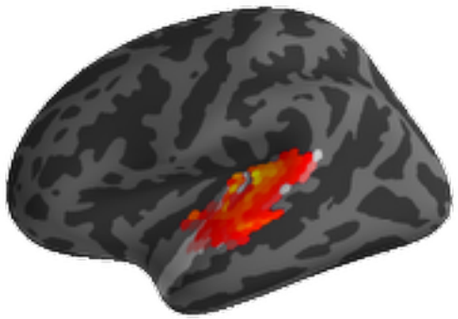
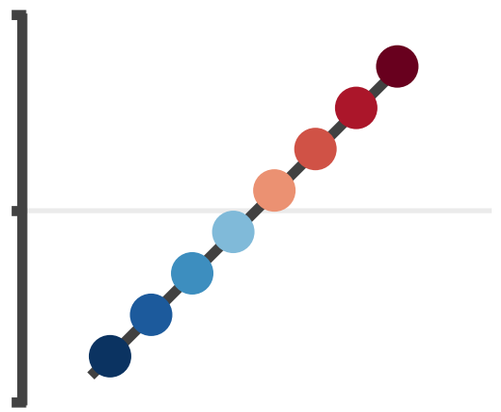






~80:150ms
linear



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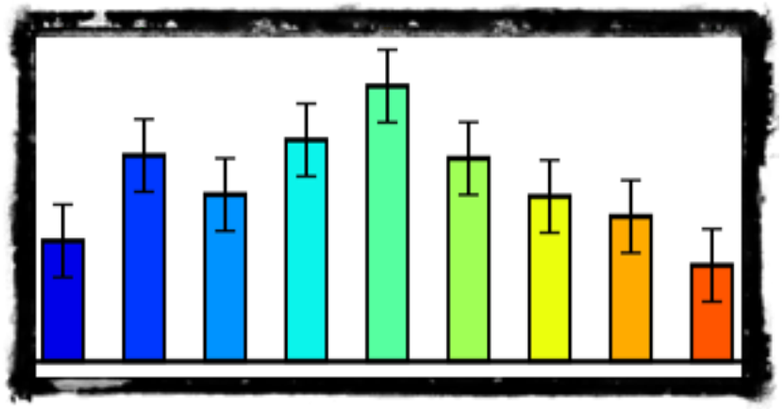
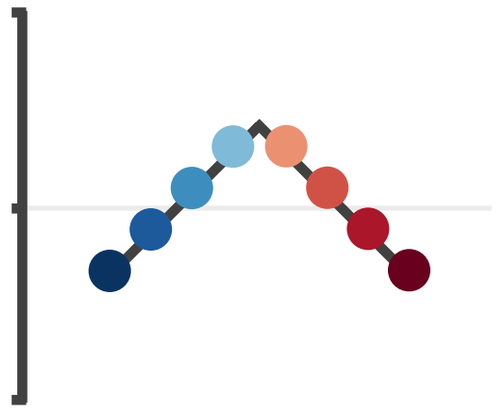
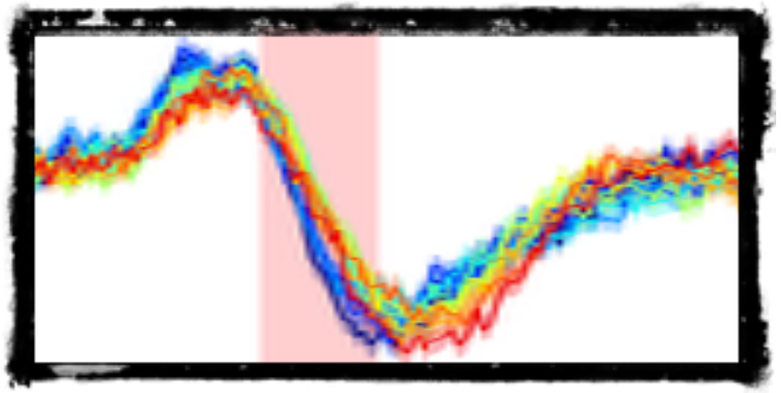


~20:80ms
ambiguity





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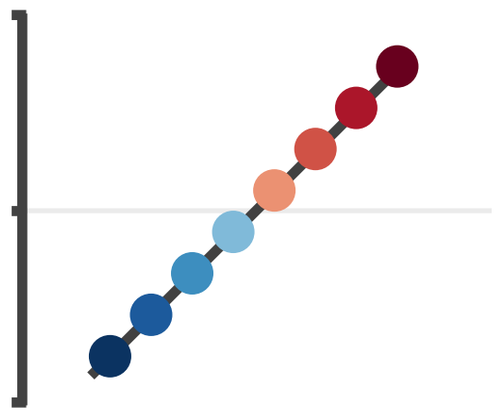
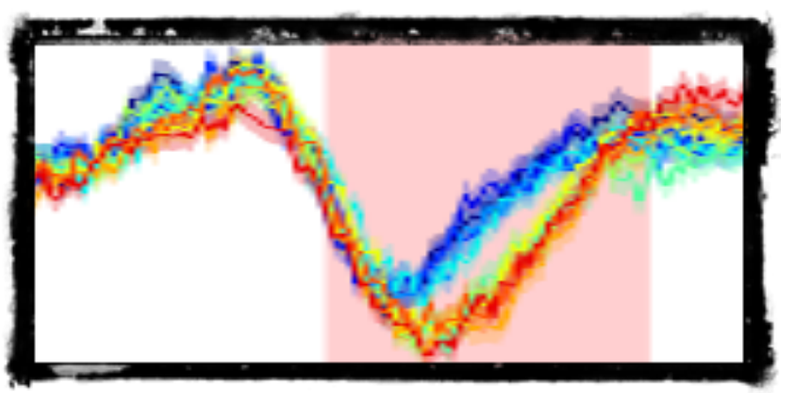
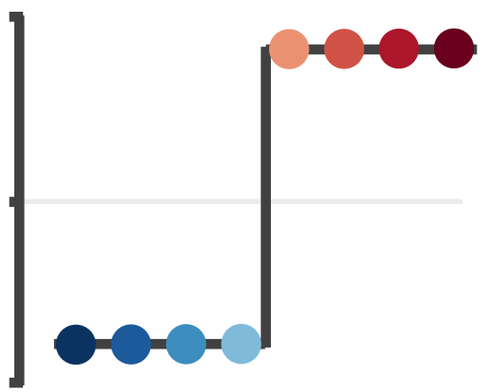


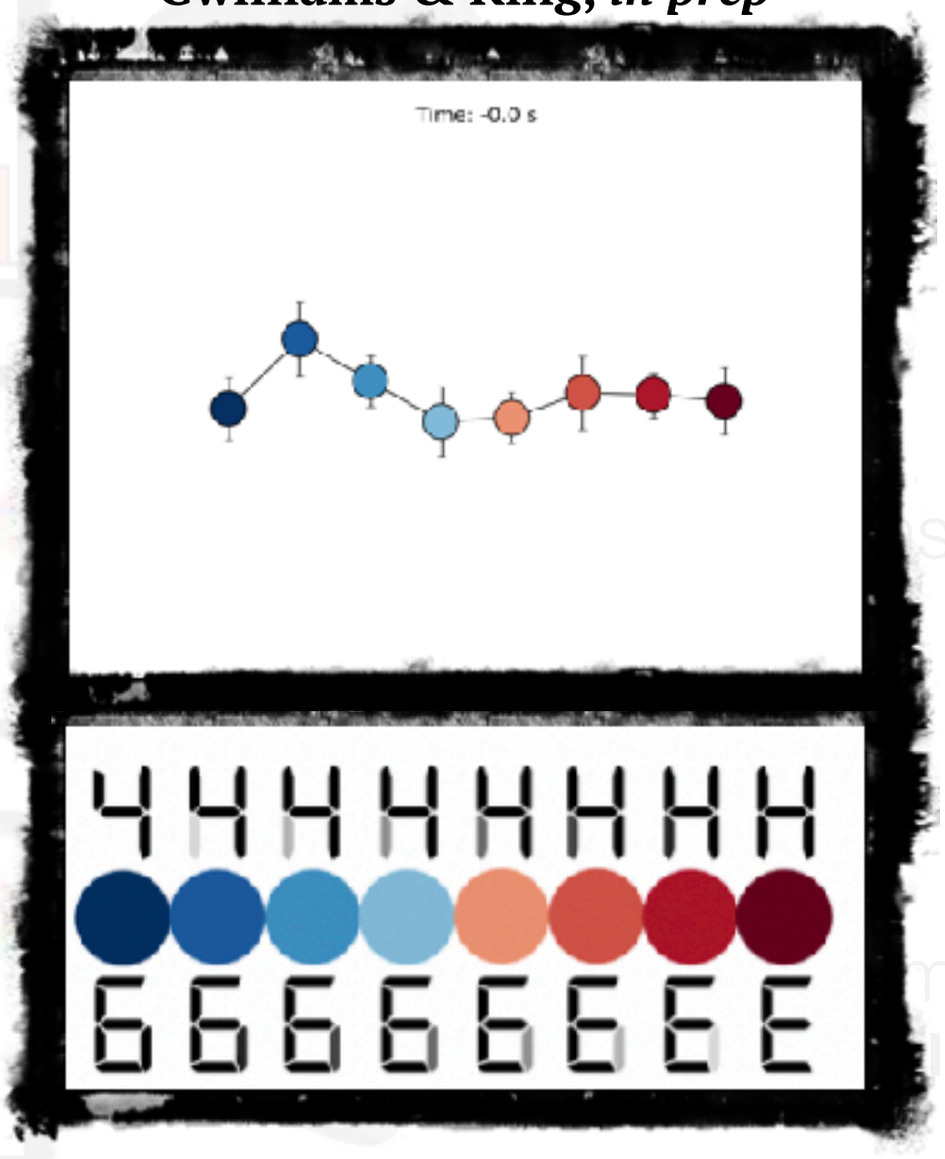


~100:200ms
categorical



Interesting links in a different domain

Gwilliams & King, *in prep*



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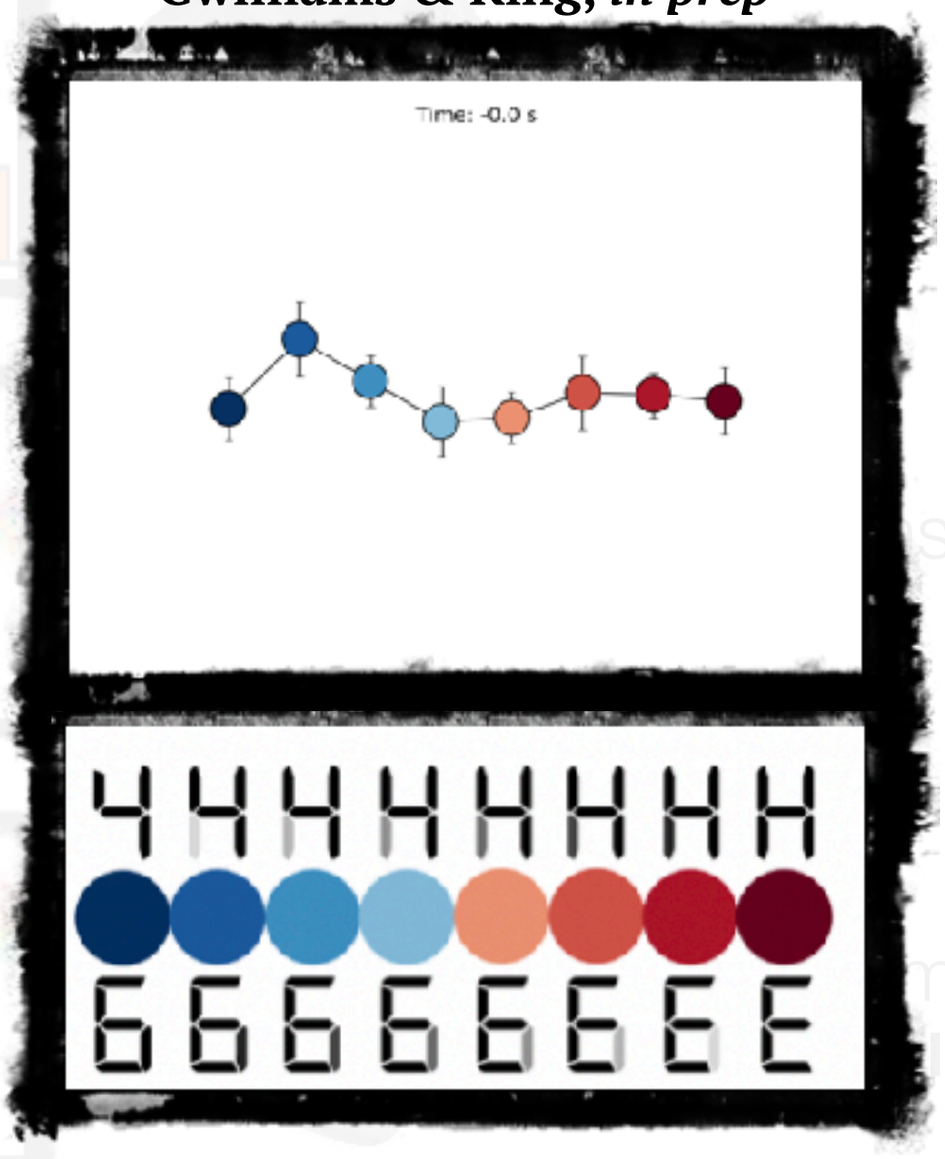
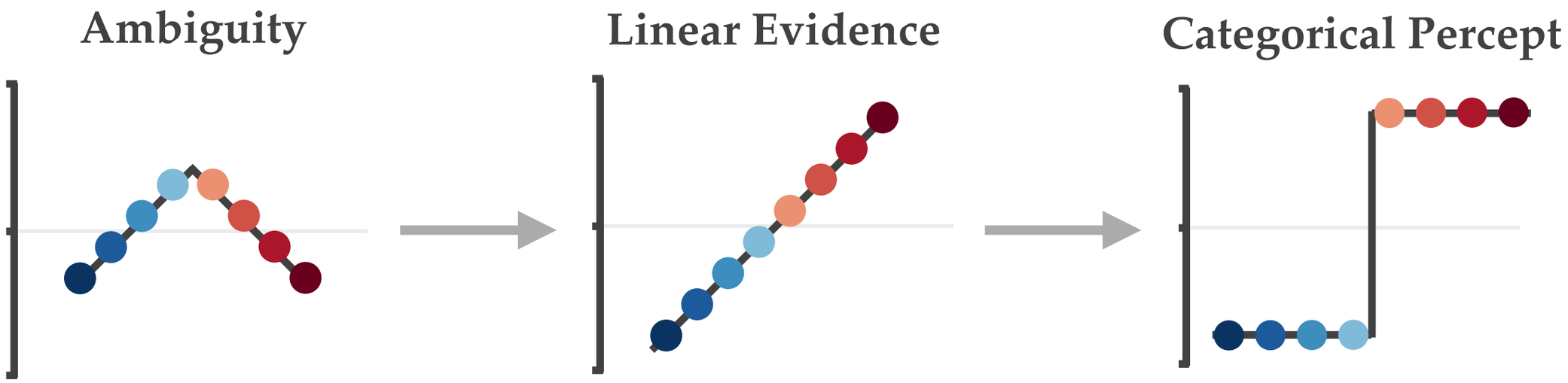
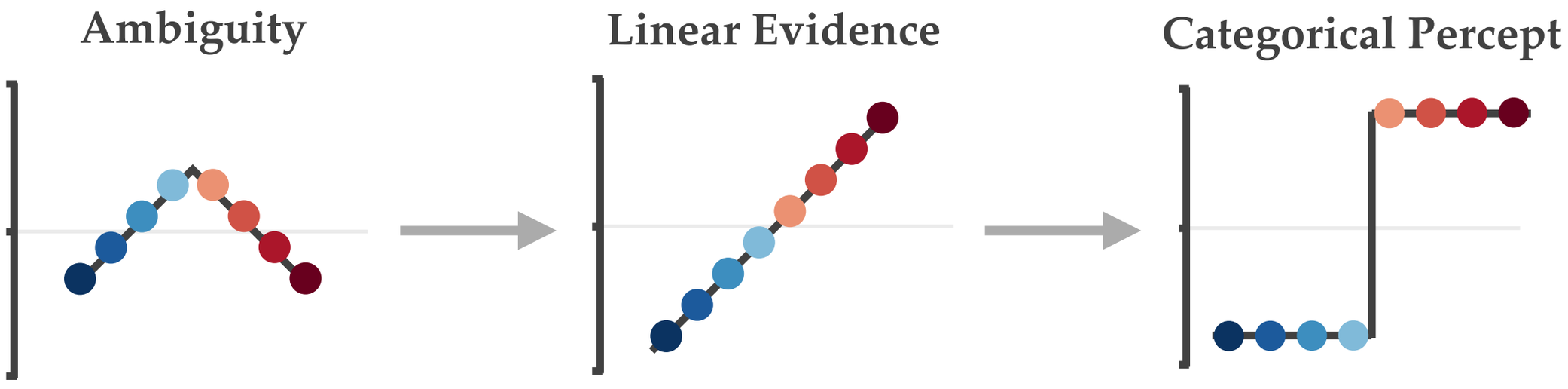


Experiment 1 Conclusions

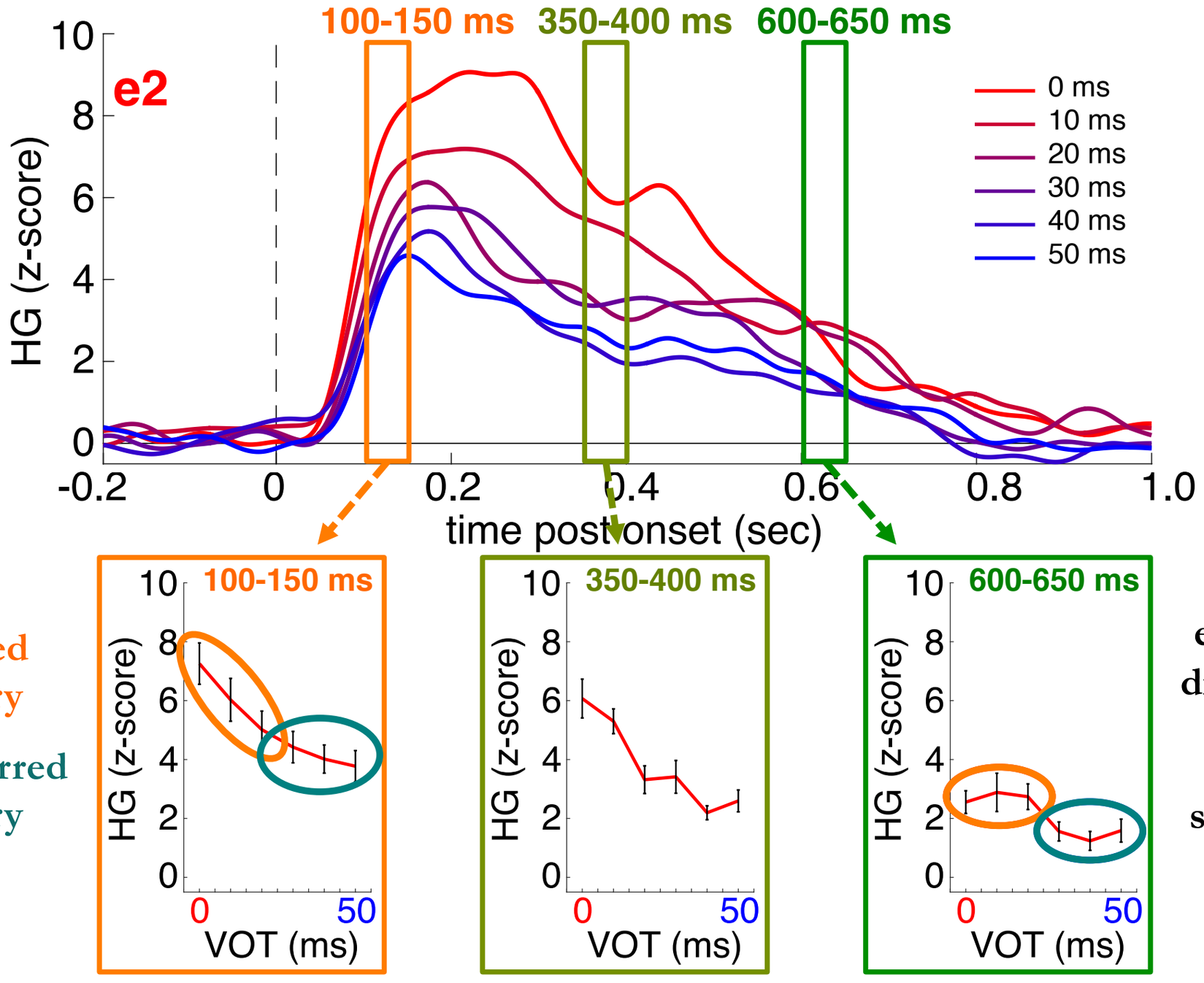


Experiment 1 Conclusions

- Very **early sensitivity to phonological boundaries** in left Heschl's gyrus — occurs *before* categorisation (speech specific?)
- Responses shift from being modulated **linearly** to being modulated **categorically** (domain general?)



Representation of VOT becomes **categorical** over time



Fox, Sjerps, Leonard & Chang **(thanks Neal for the slide!)**

Roadmap

- Completed projects
  - **Bottom-up processes**: Transforming acoustic signal into discrete phonological categories
  - **Top-down processes**: Revising that categorisation based on subsequent context

Roadmap

- Completed projects
  - **Bottom-up processes**: Transforming acoustic signal into discrete phonological categories
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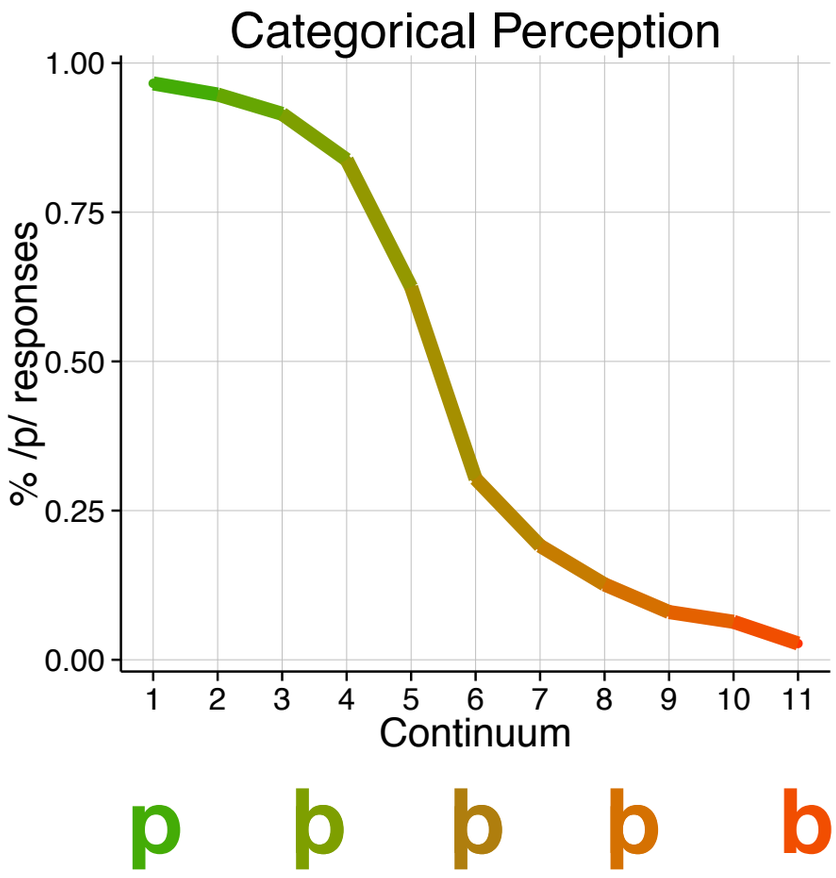
Top-down Influences on Perception

Top-down Influences on Perception

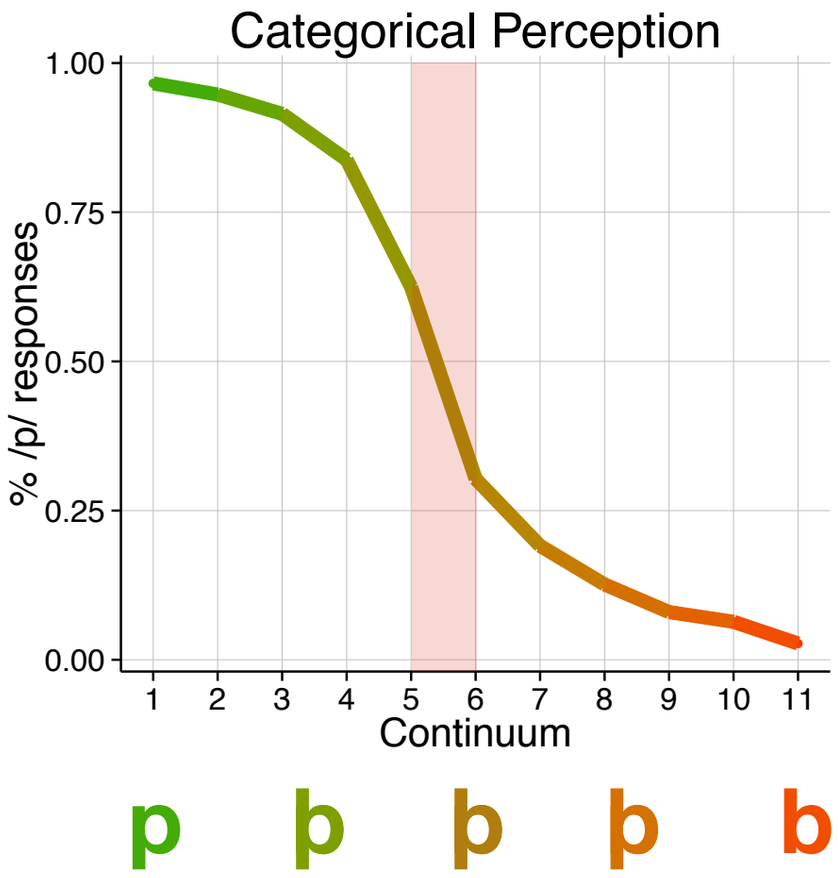
- Context occurring *after* an acoustic signal can be integrated to **update the perception of earlier sounds** (Bicknell et al., submitted; Connine et al., 1991; Samuel, 1981; Szostak & Pitt, 2013; Warren & Sherman, 1974)

Future Influences on Perception

Future Influences on Perception



Future Influences on Perception



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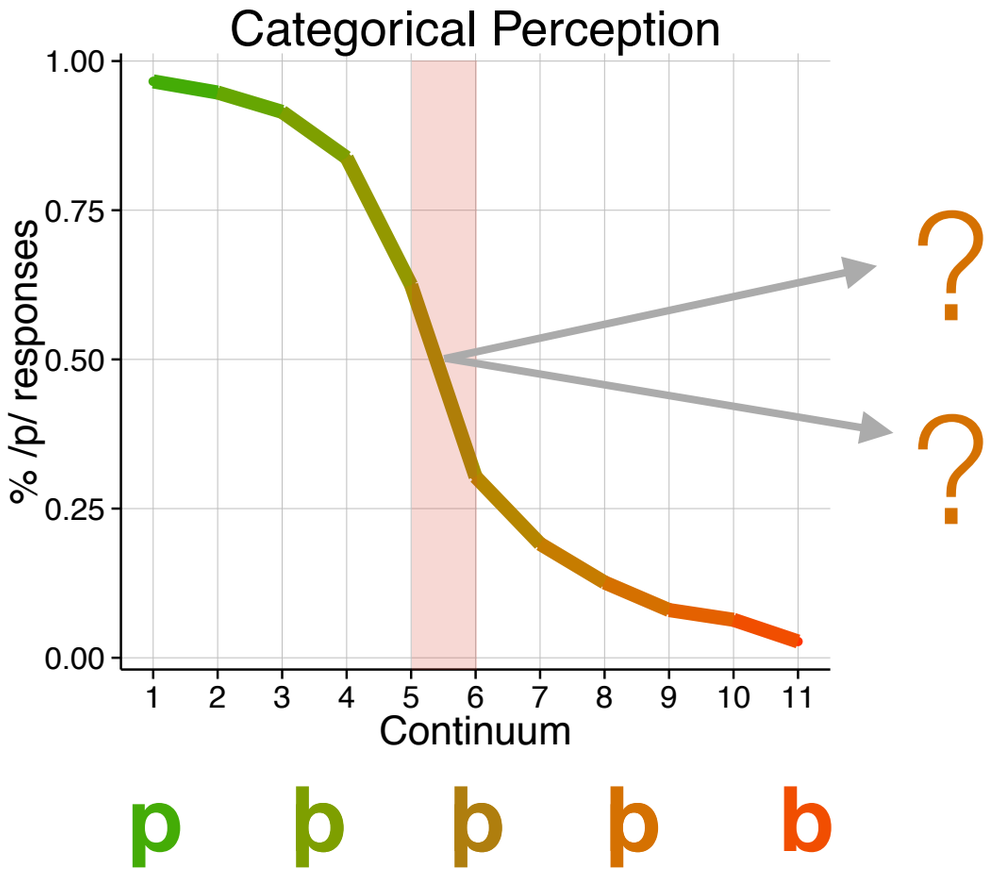

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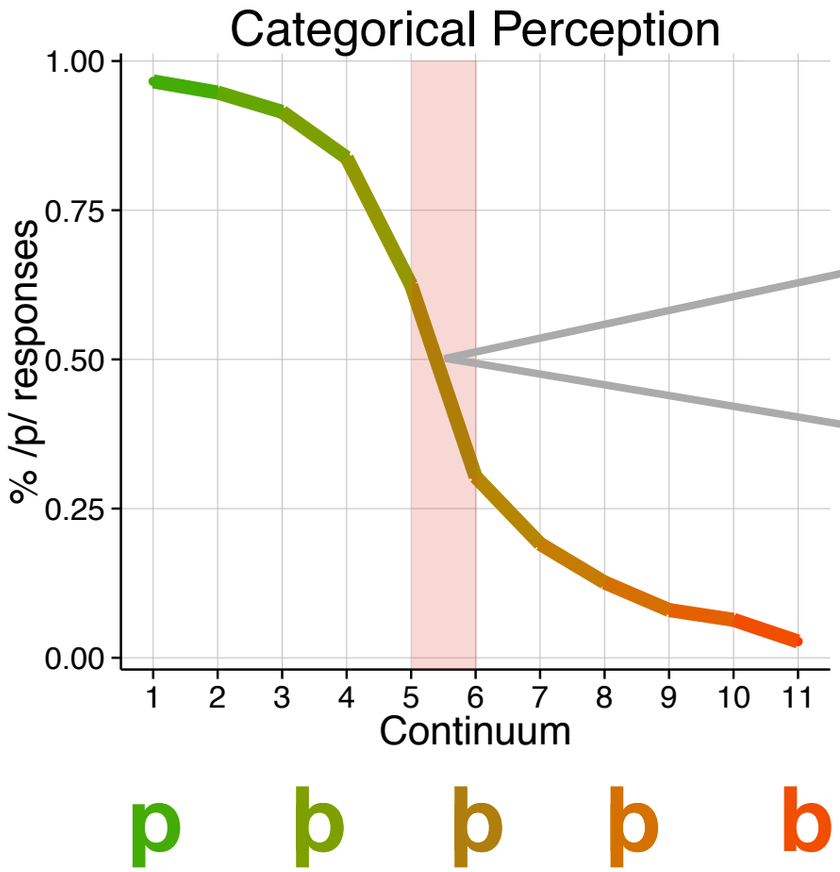

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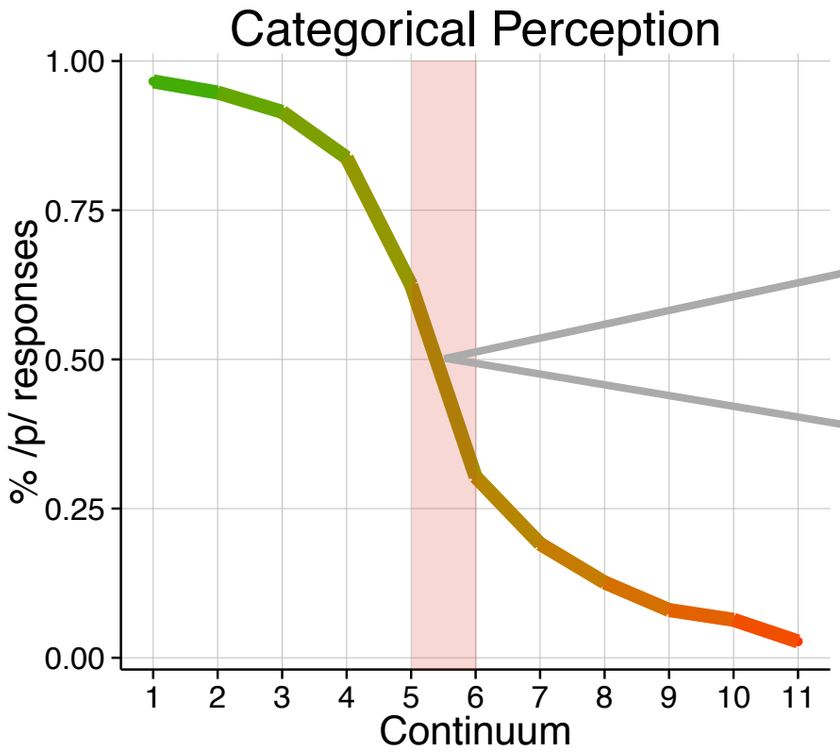
Future Influences on Perception



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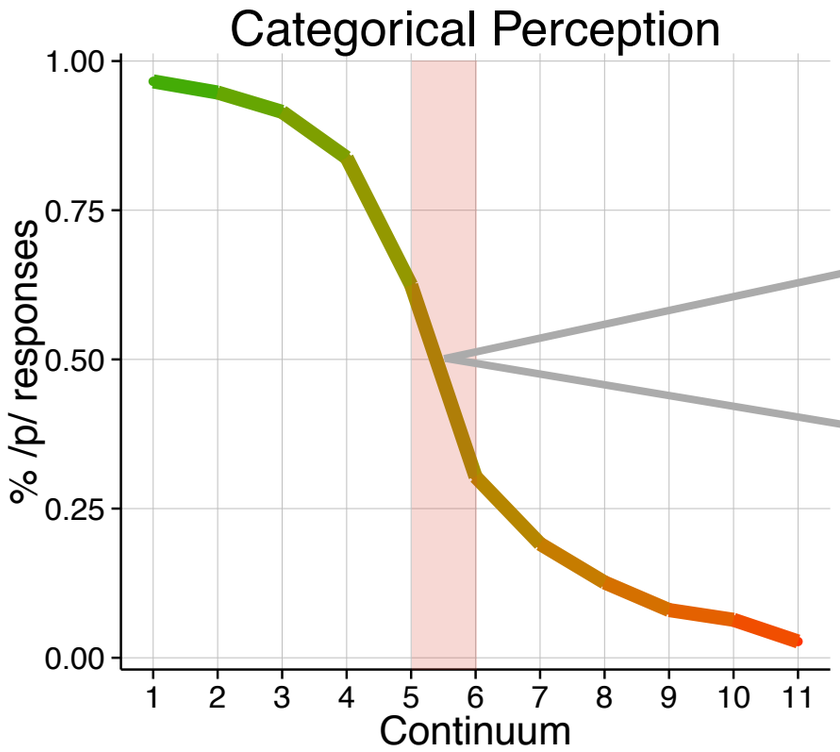
Future Influences on Perception



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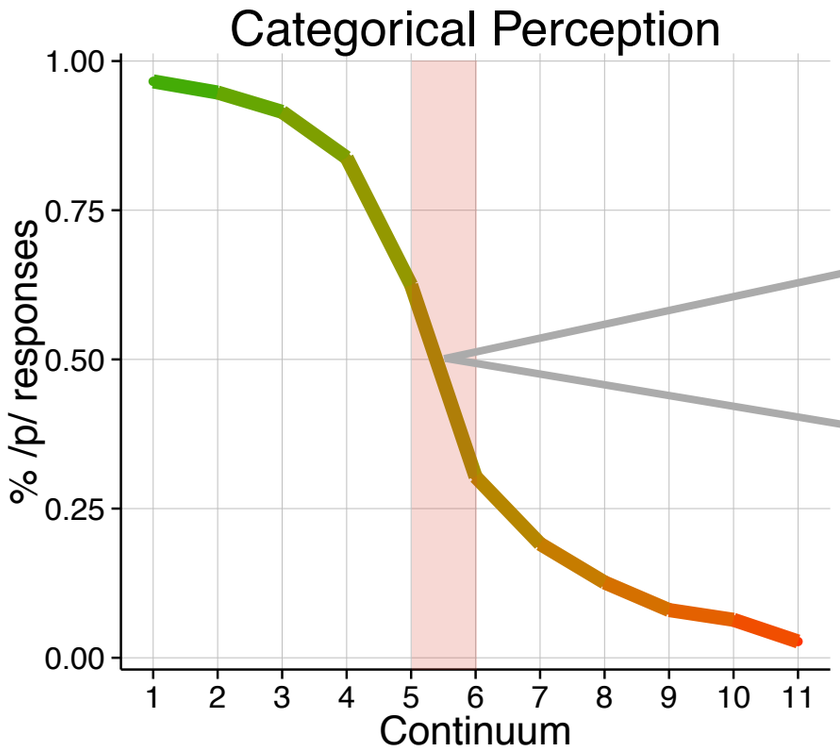
Future Influences on Perception



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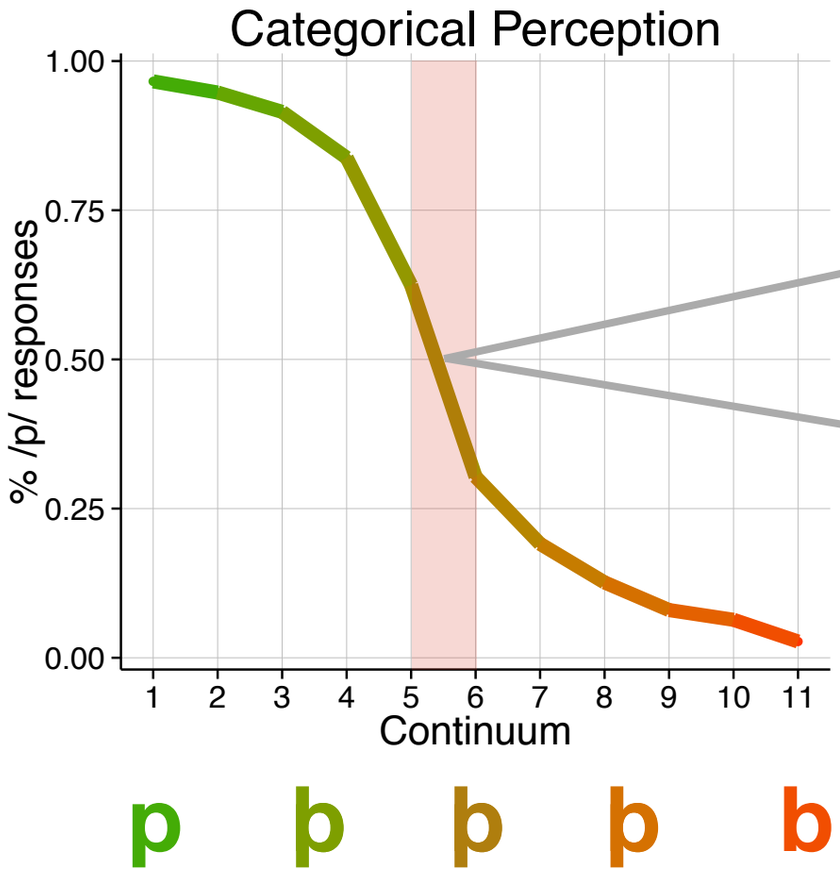
Future Influences on Perception



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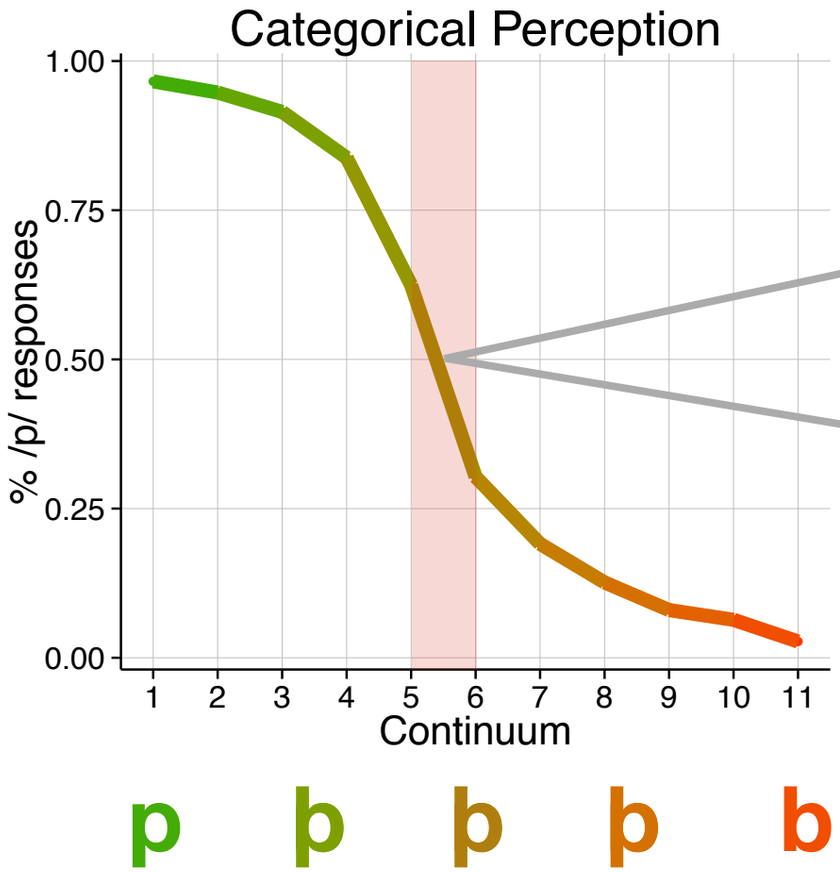
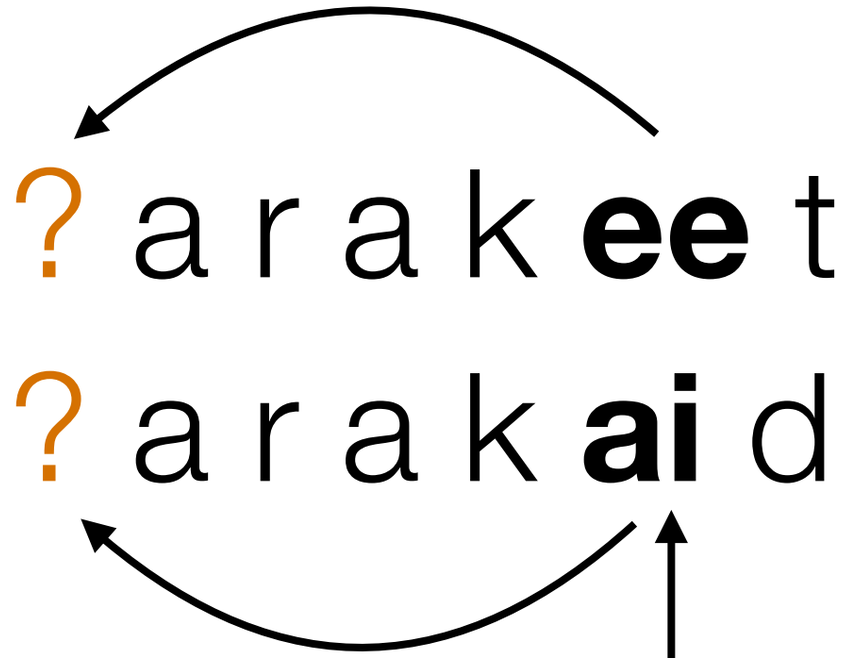
"**P**oint **o**f **D**isambiguation" (POD)

Future Influences on Perception





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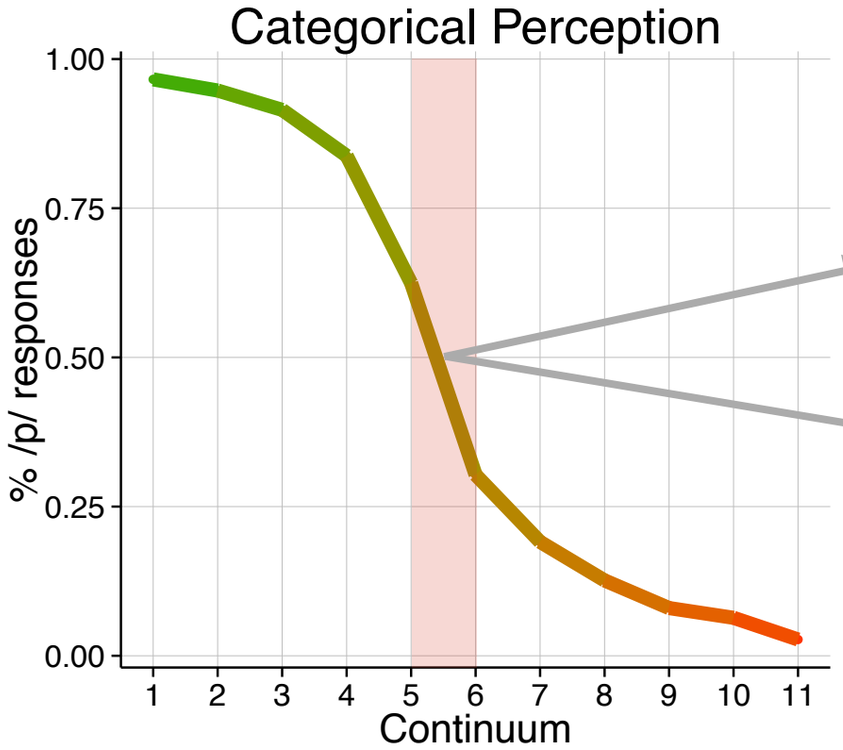

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(this is a parakeet)

(this is a barricade)

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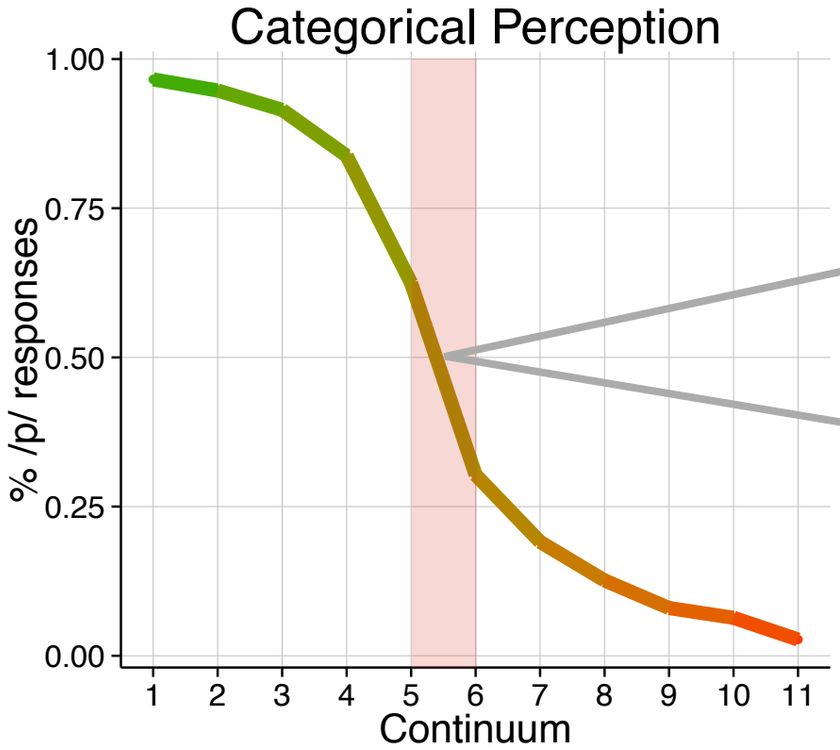
Future Influences on Perception



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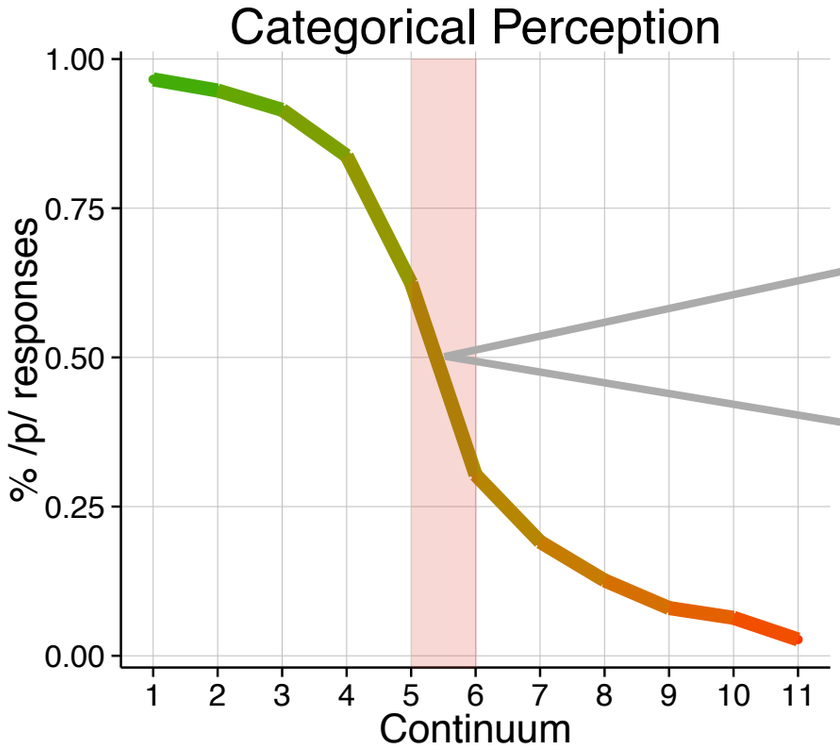

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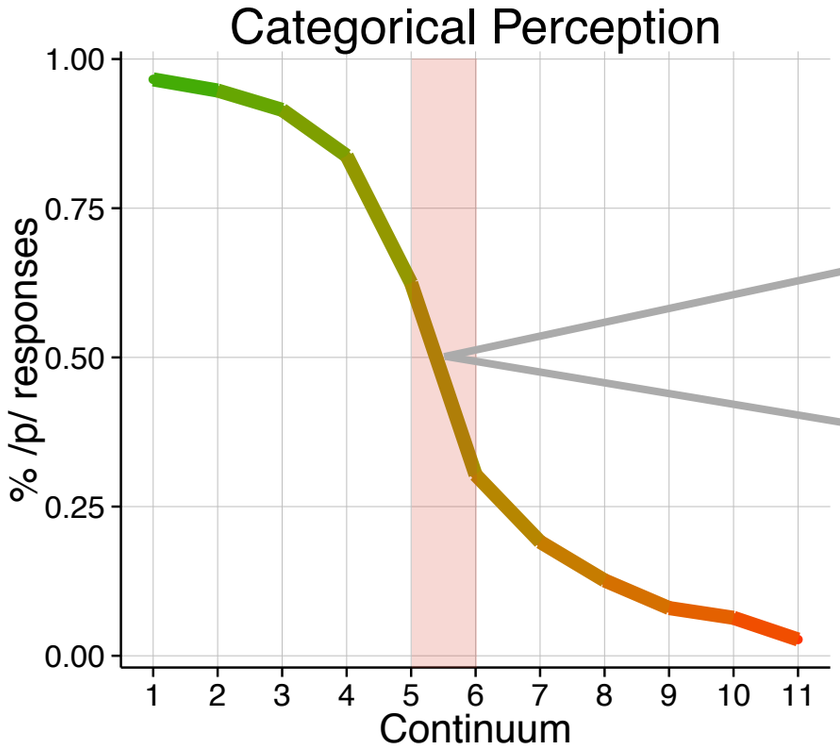

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Today's Questions

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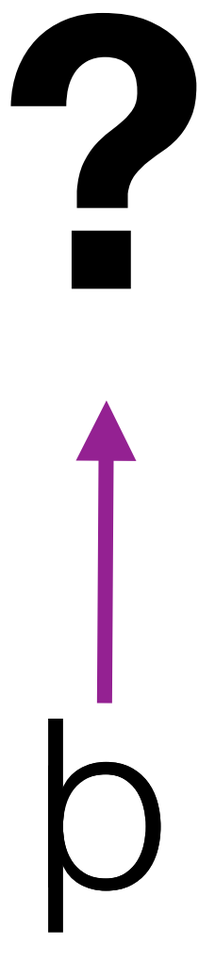
Today's Questions

How does the auditory cortex **respond** to phonological ambiguity?



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Today's Questions

How does the auditory cortex **respond** to phonological ambiguity?

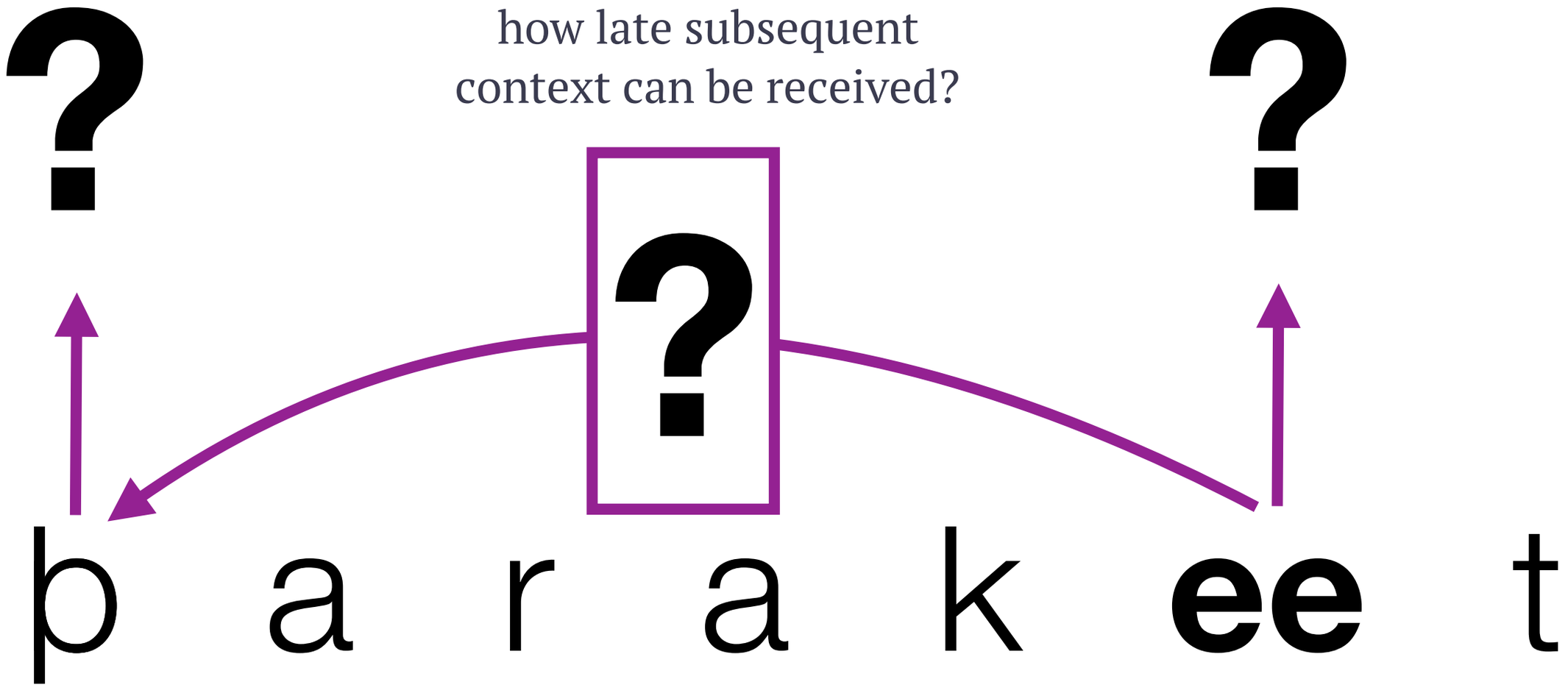
What are the neural signatures of ambiguity **resolution**?

Today's Questions

How does the auditory cortex **respond** to phonological ambiguity?

What is the **time-limit** on how late subsequent context can be received?

What are the neural signatures of ambiguity **resolution**?



Design & Materials

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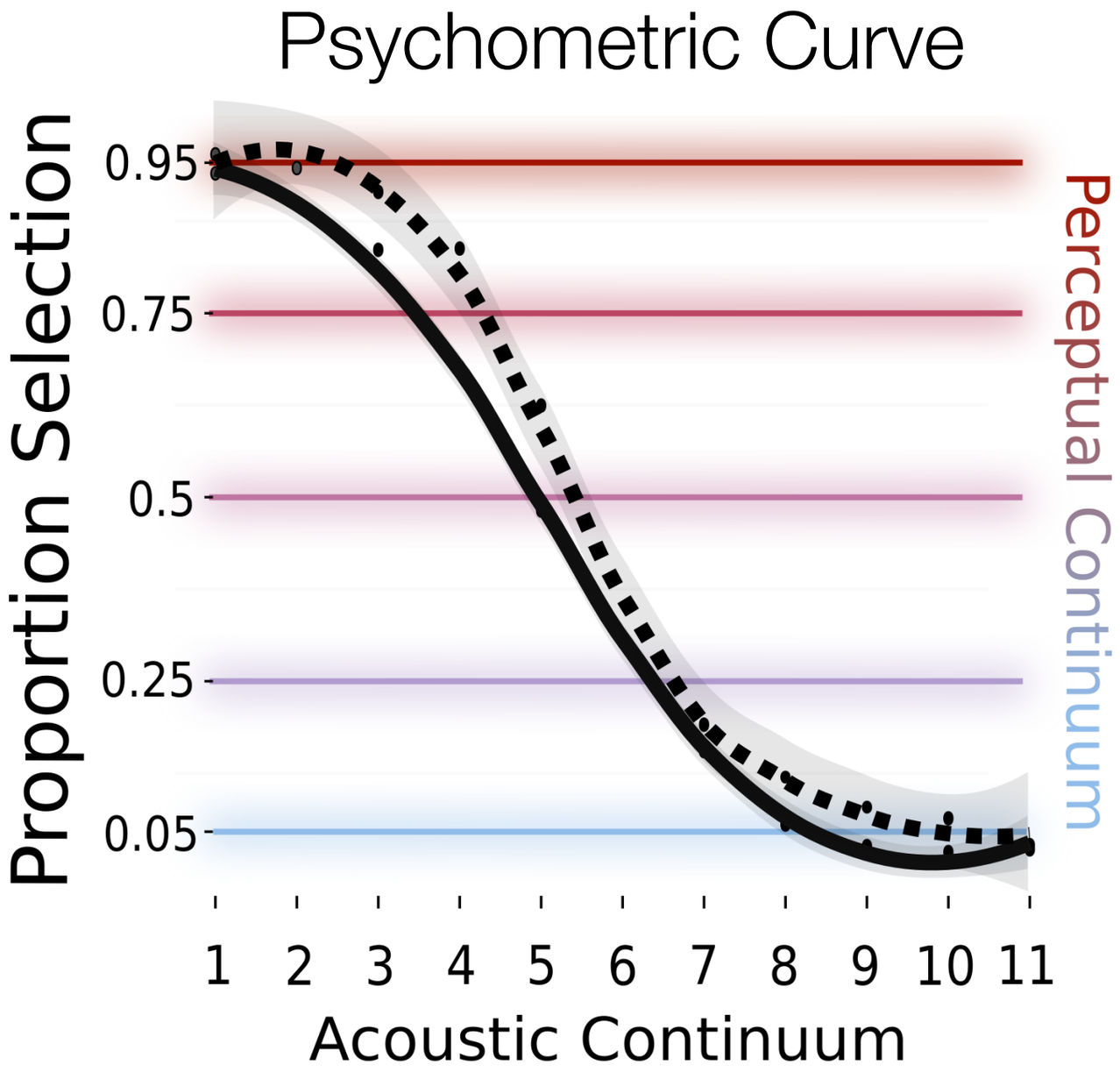
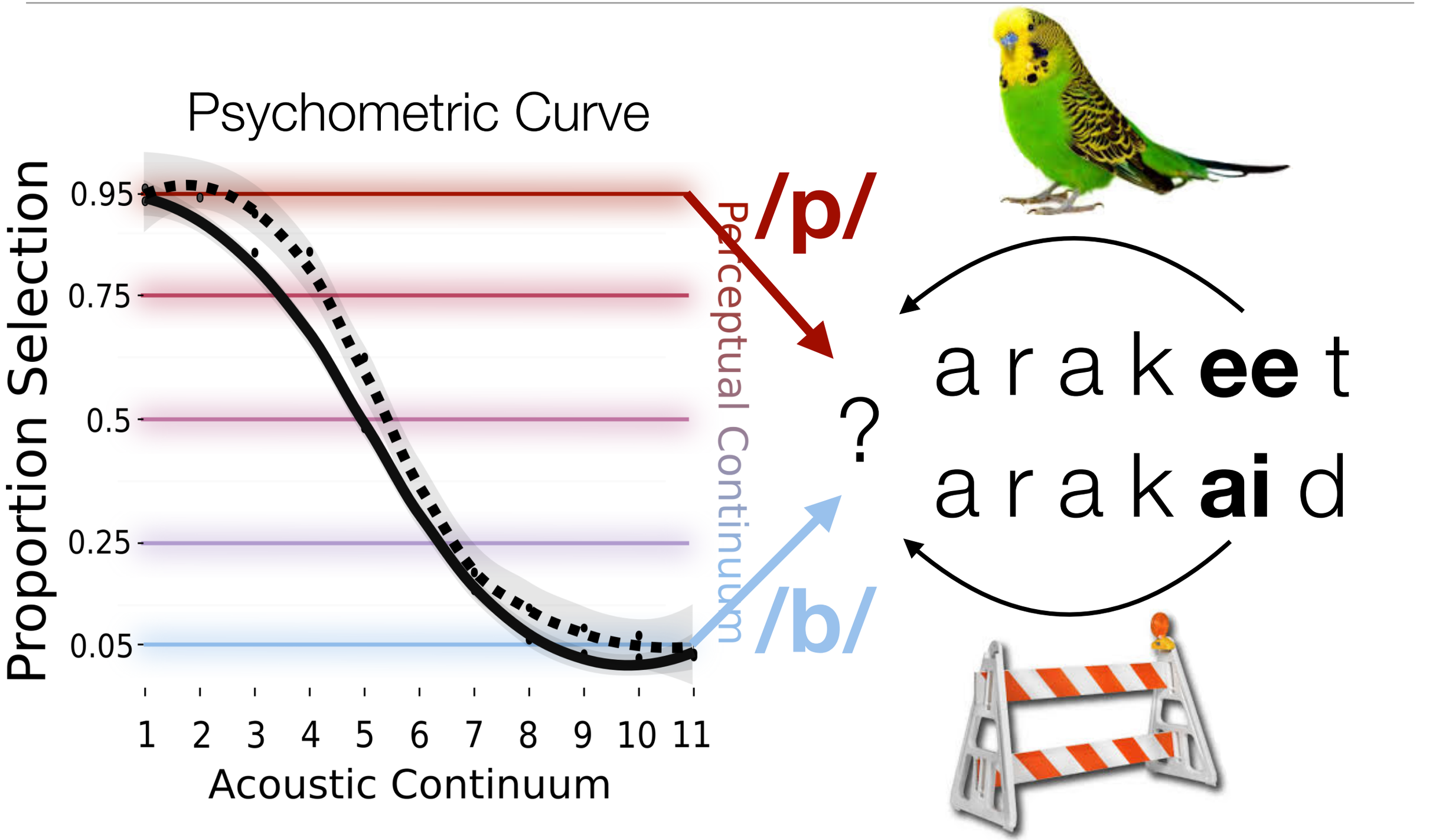
Design & Materials



Gwilliams et al., *under review*

Design & Materials



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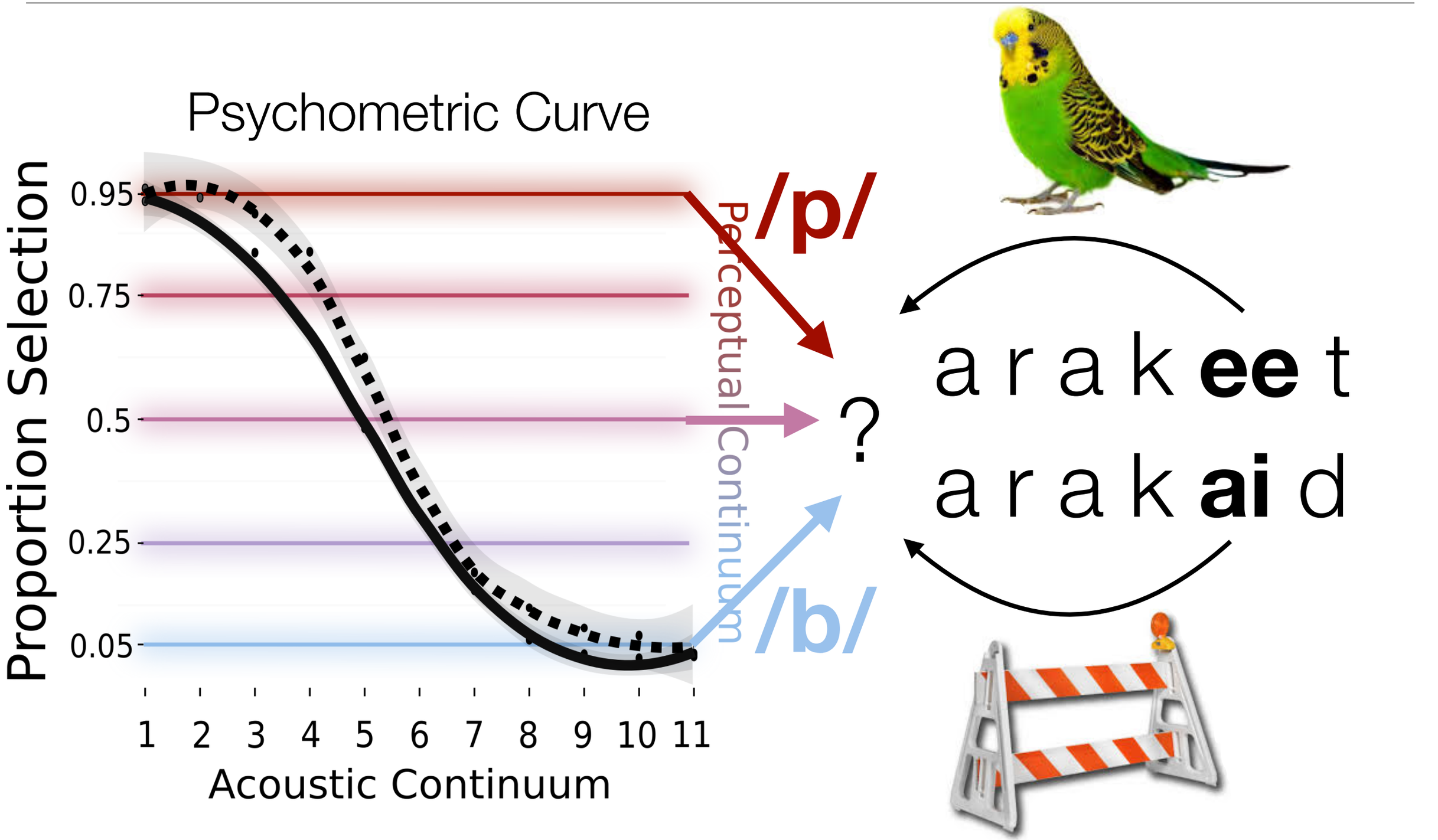

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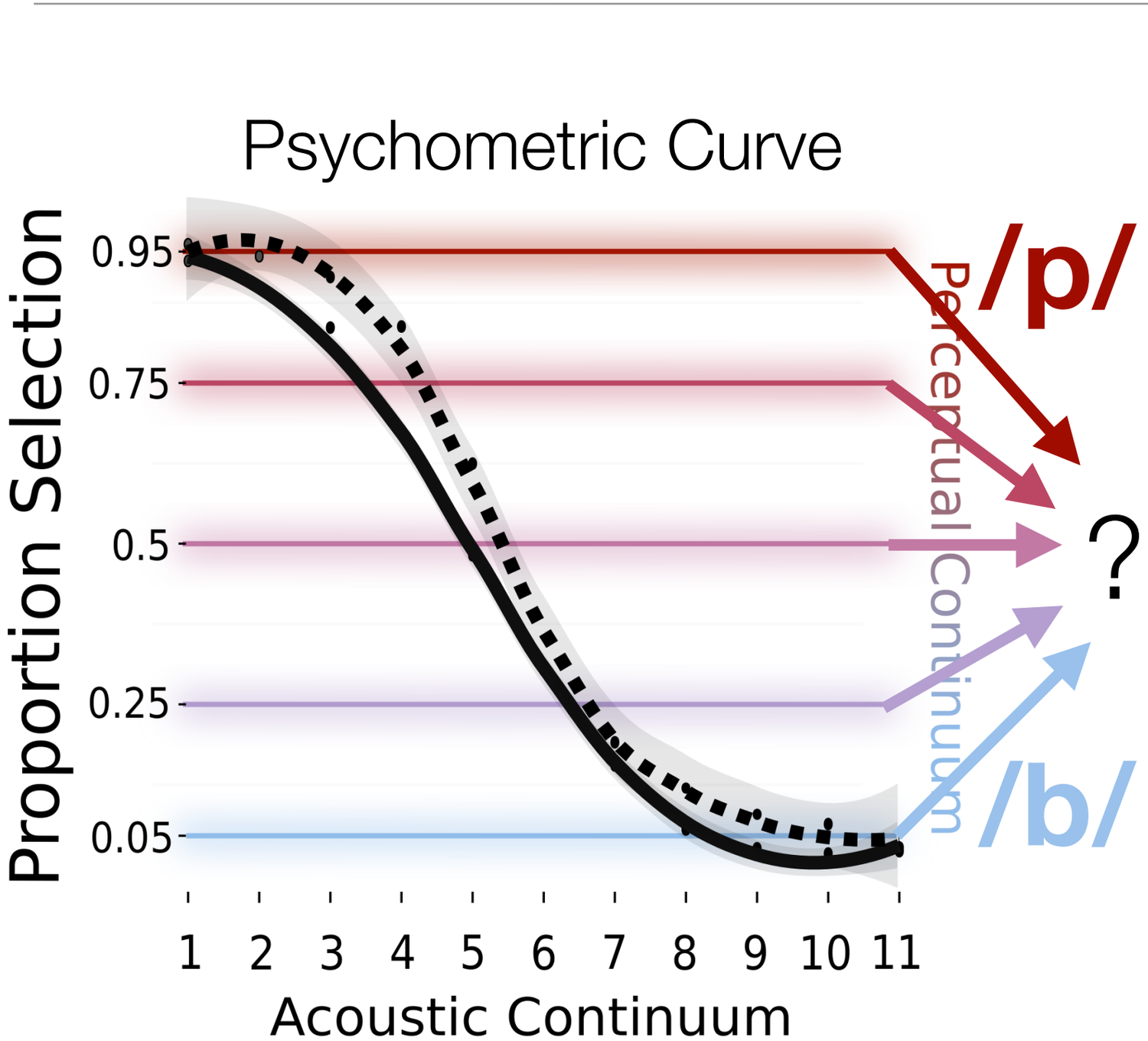

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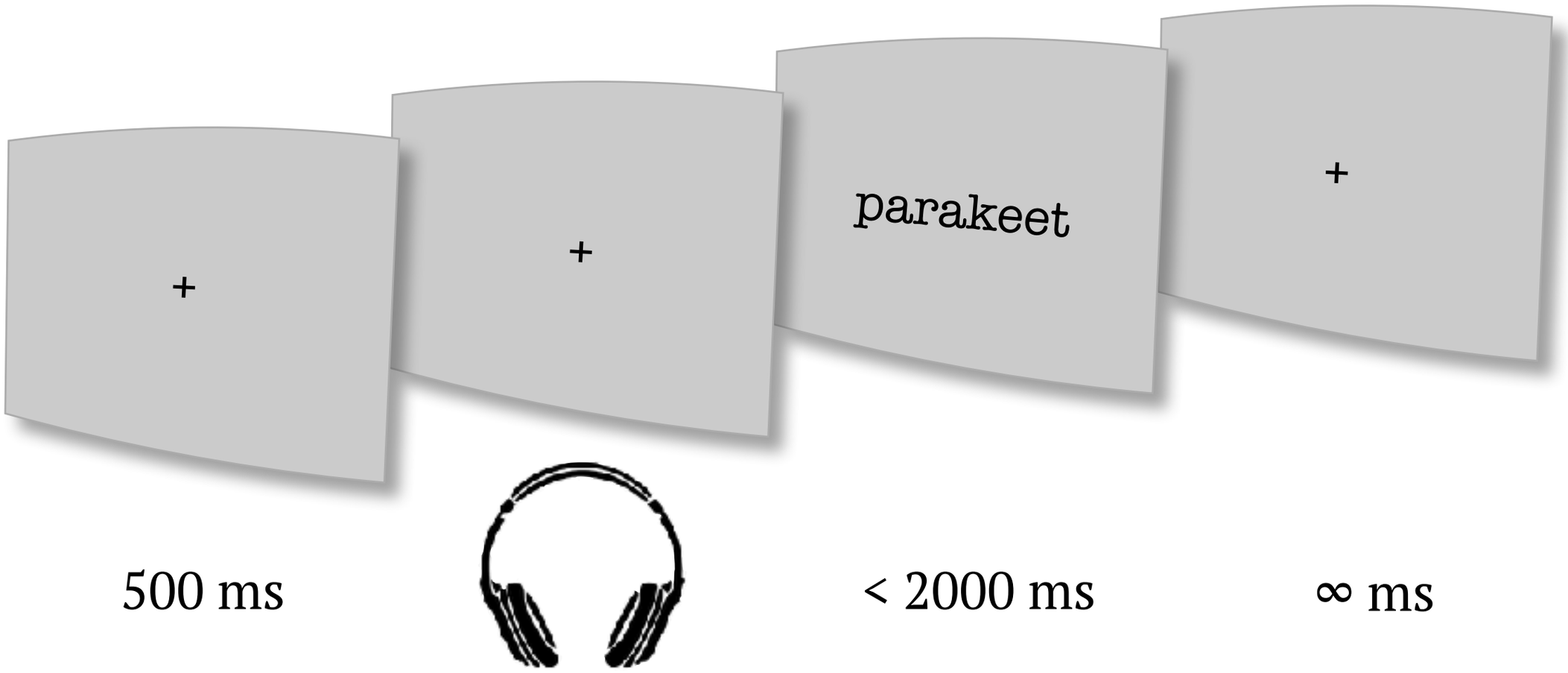


500 ms

< 2000 ms

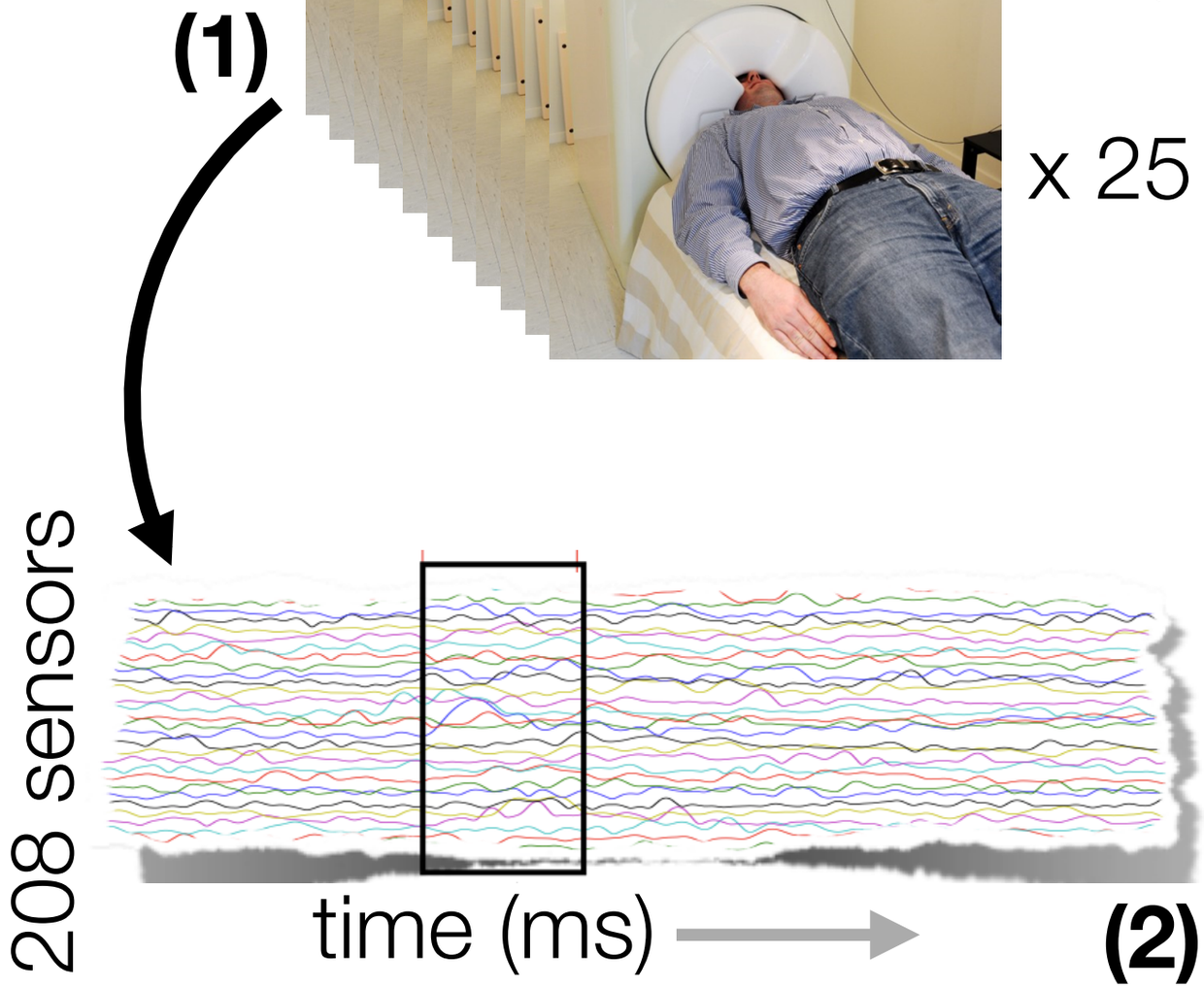
∞ ms

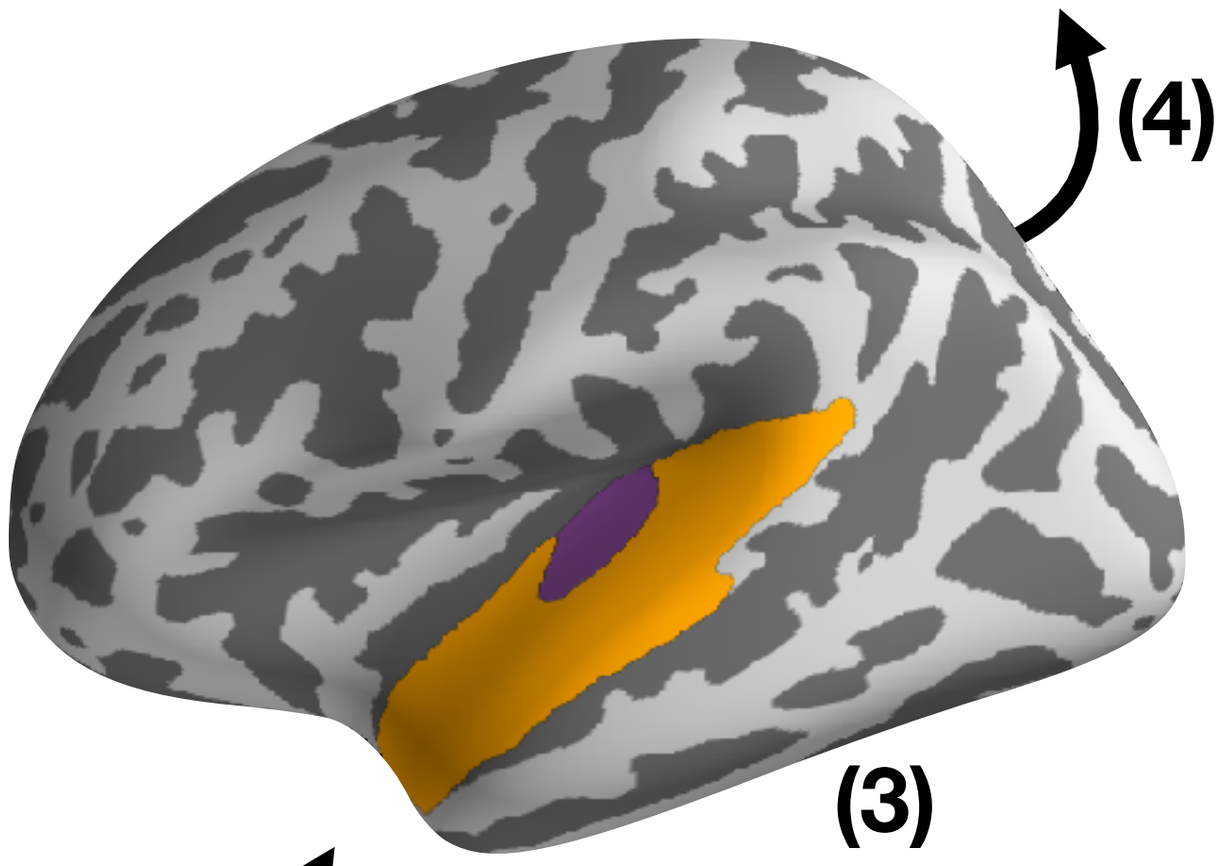
Procedure & Analysis

x 25

- Multiple regression at each ms and vertex
- Spatio-temporal cluster test on beta coefficients

(for more info see Gwilliams, Lewis & Marantz, 2016)





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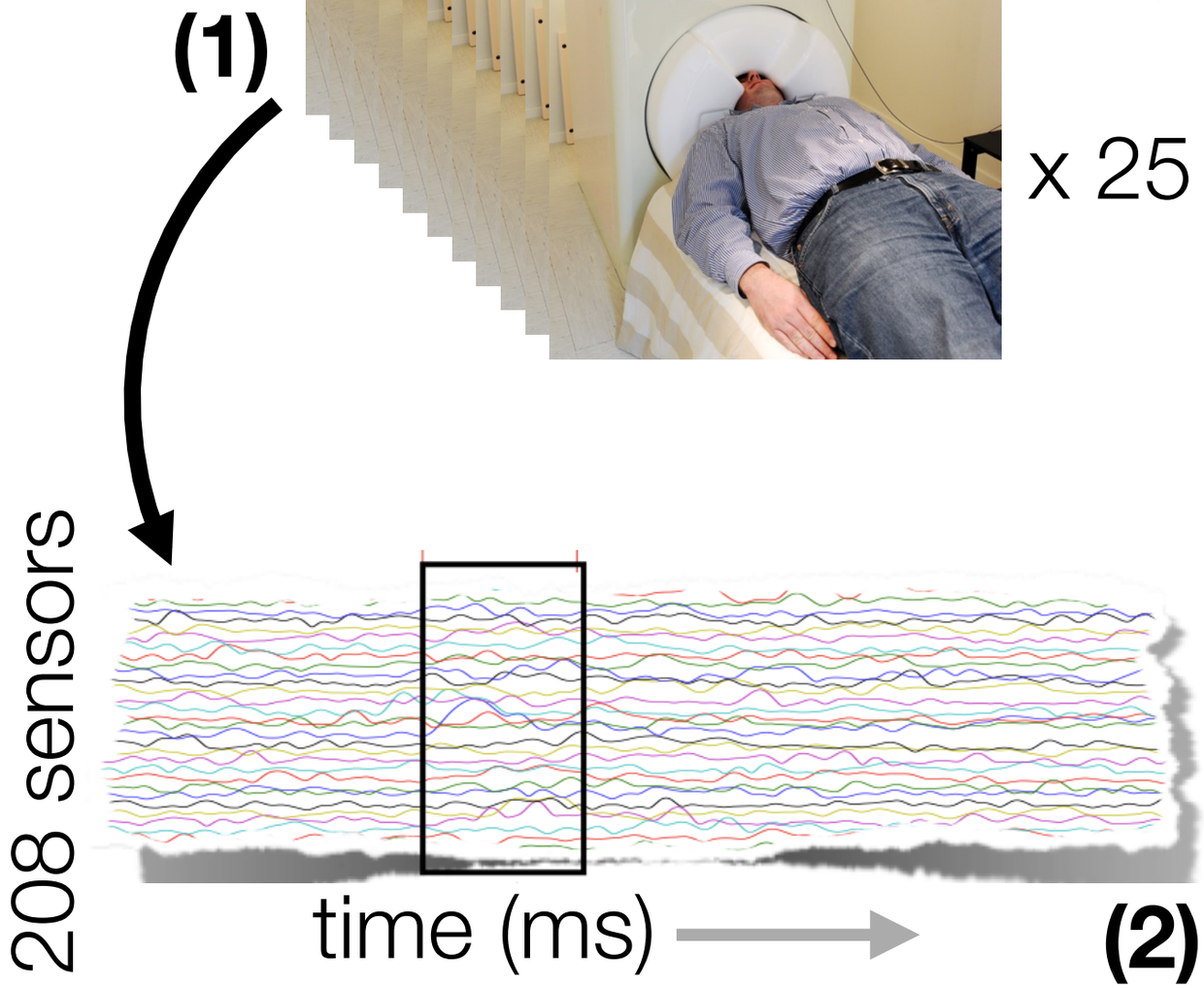

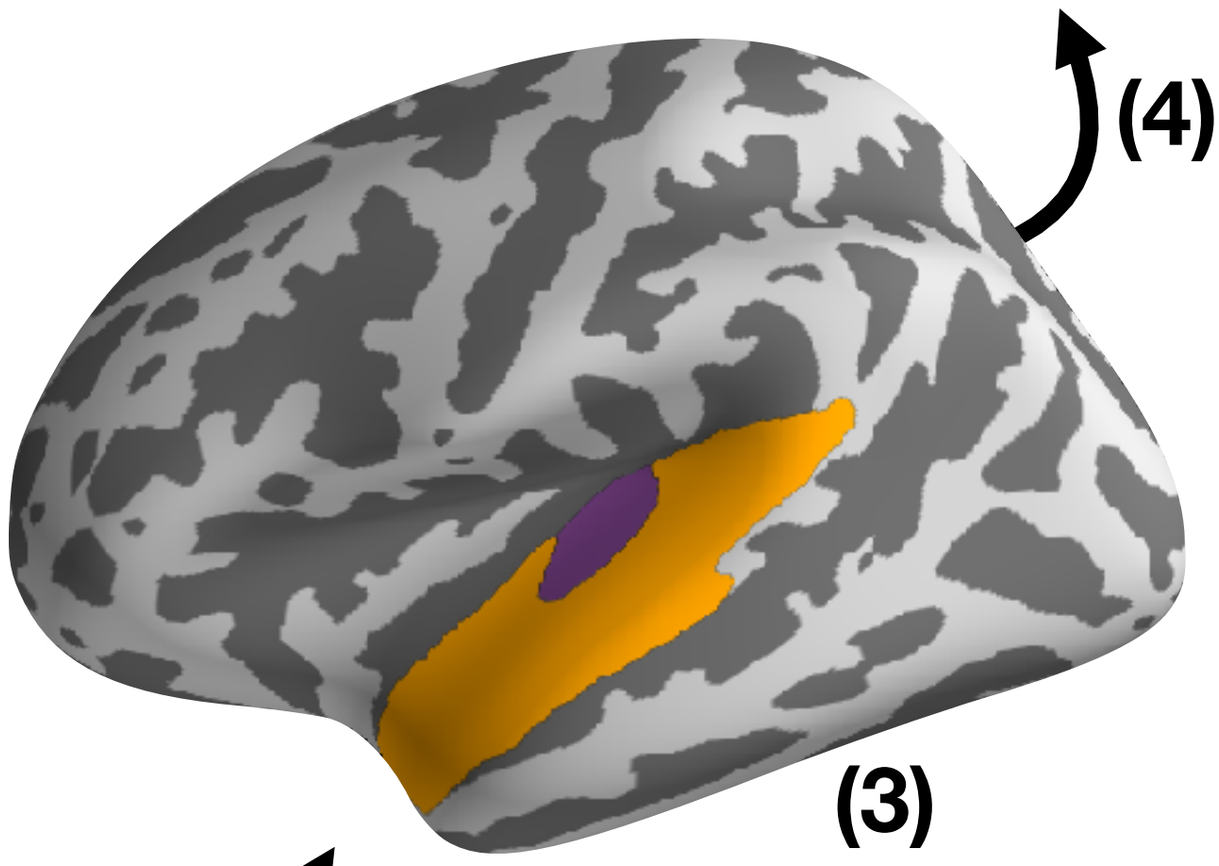

Today's Questions

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Today's Questions

How does the auditory cortex **respond** to phonological ambiguity?

p p p b b

Ambiguity at Onset

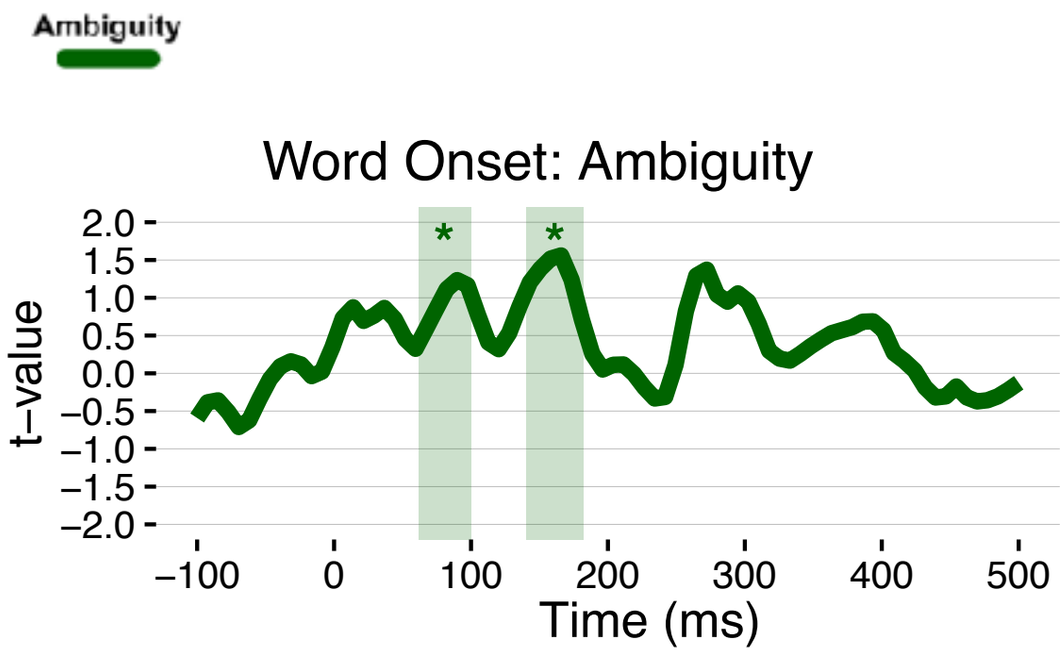
p p p b b

Ambiguity at Onset

Ambiguity

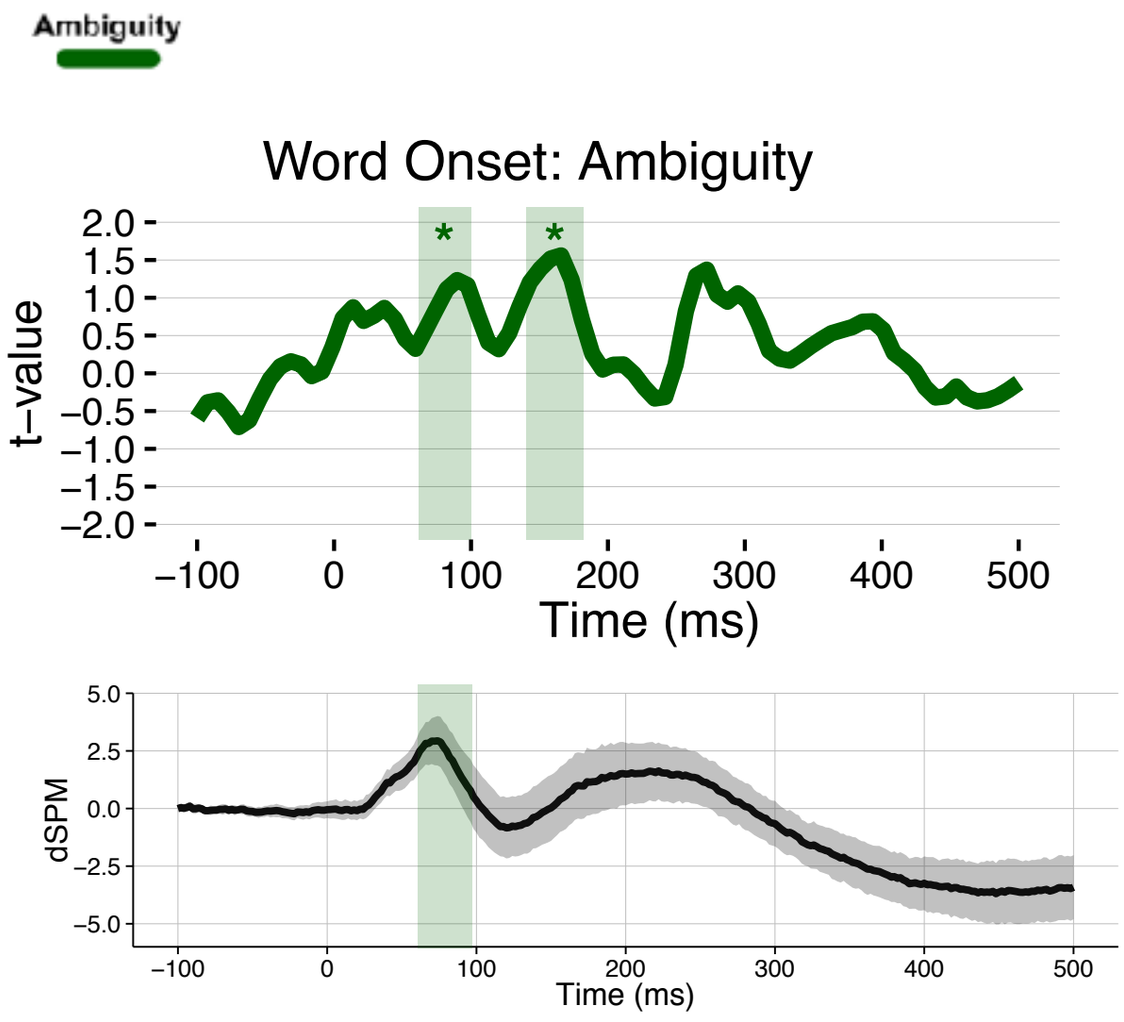
p p p b b

Ambiguity at Onset



p p p b b

Ambiguity at Onset



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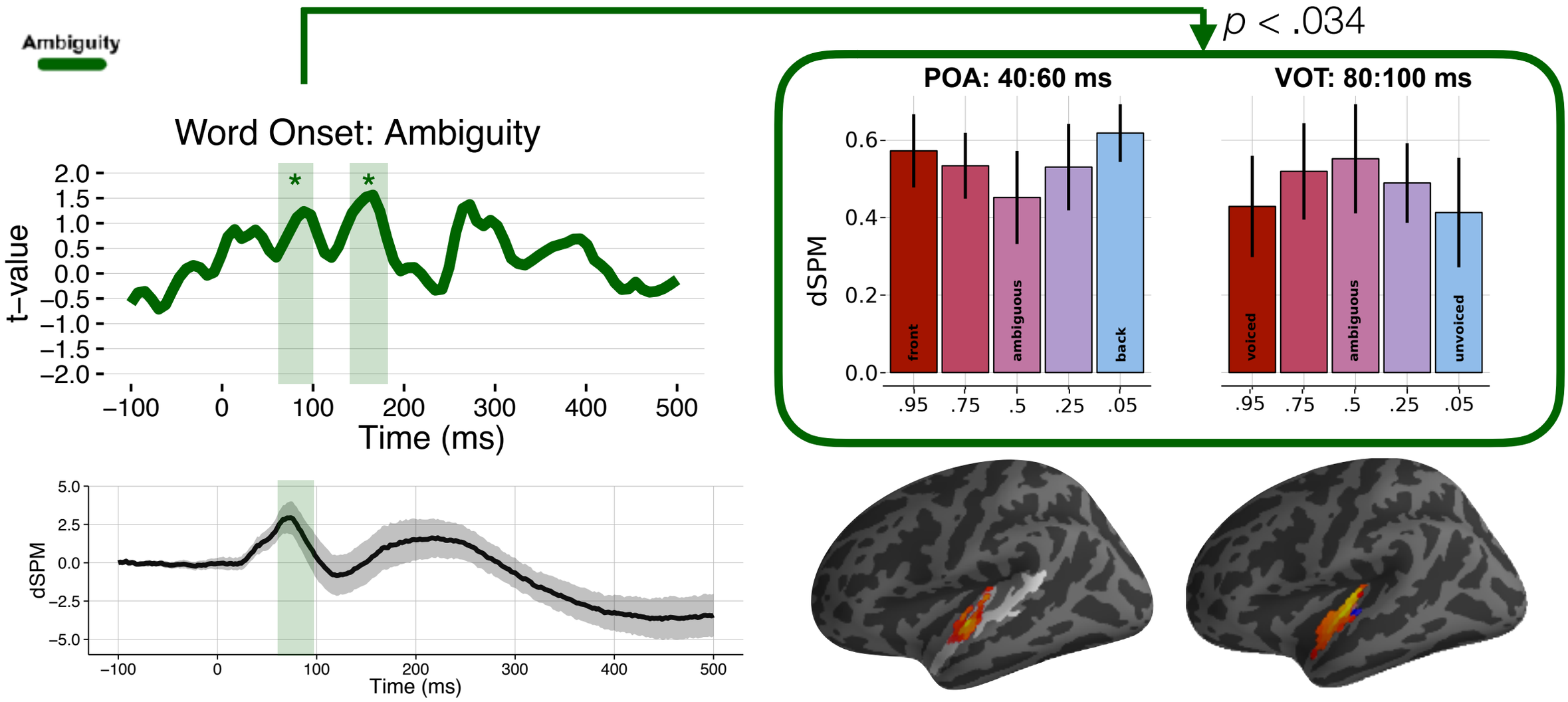

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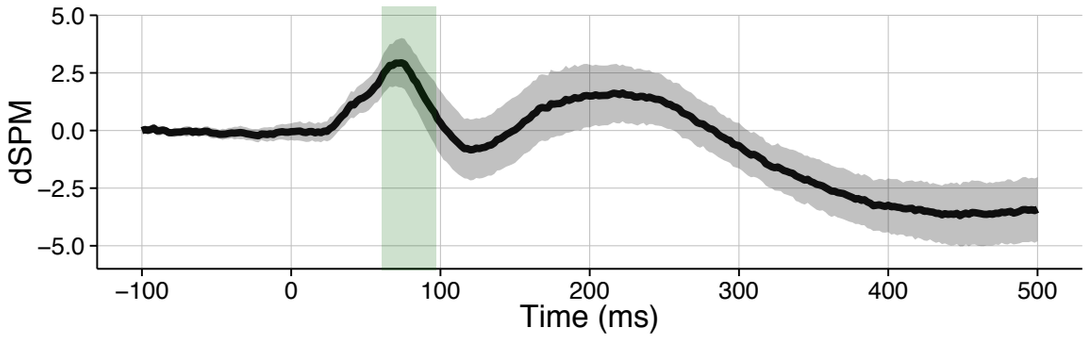
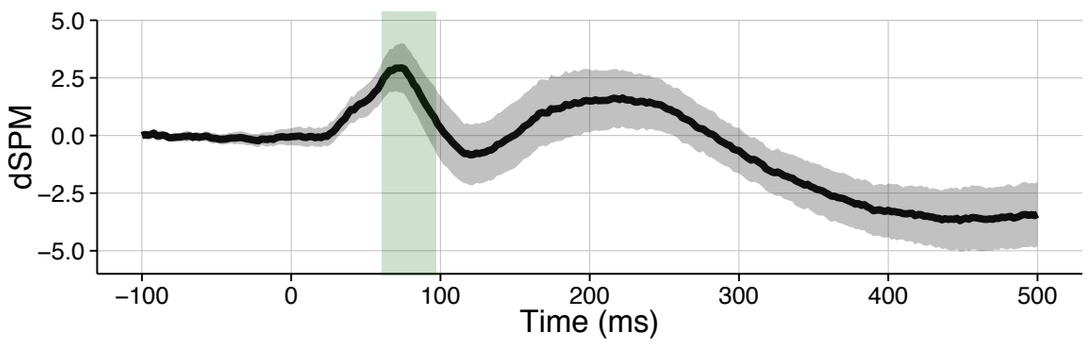


Ambiguity at Onset

POA

VOT



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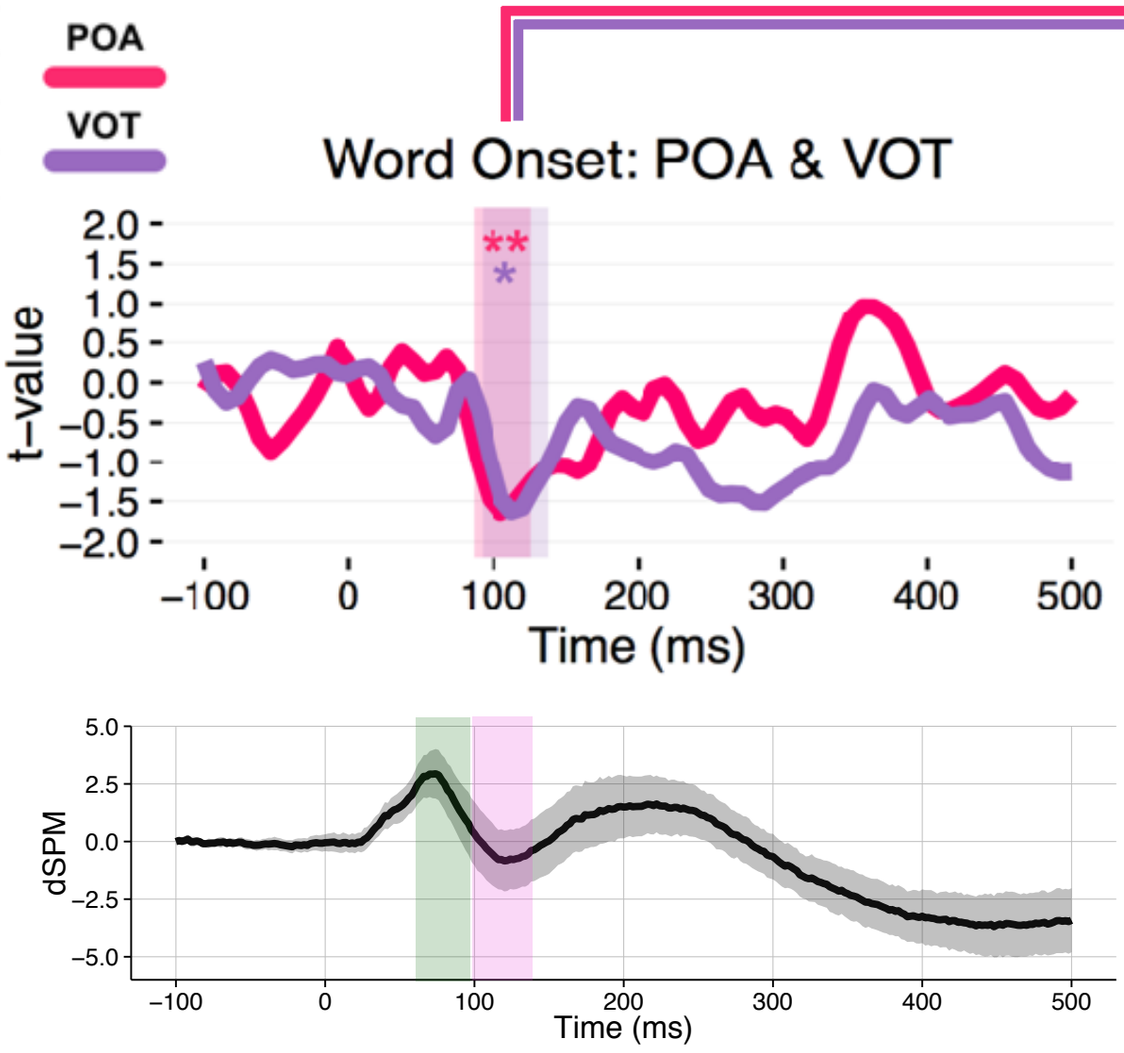

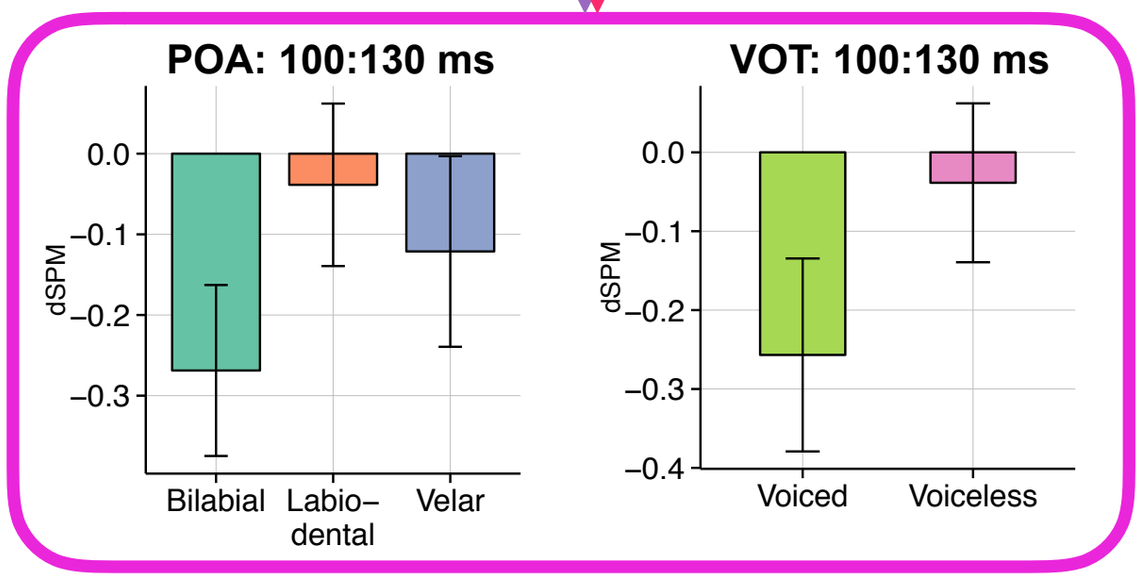

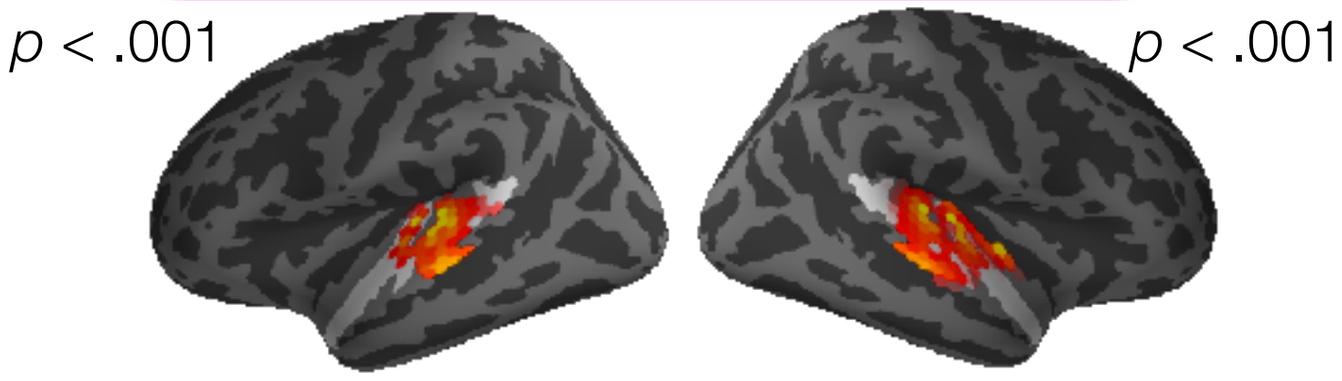

Interim Conclusion

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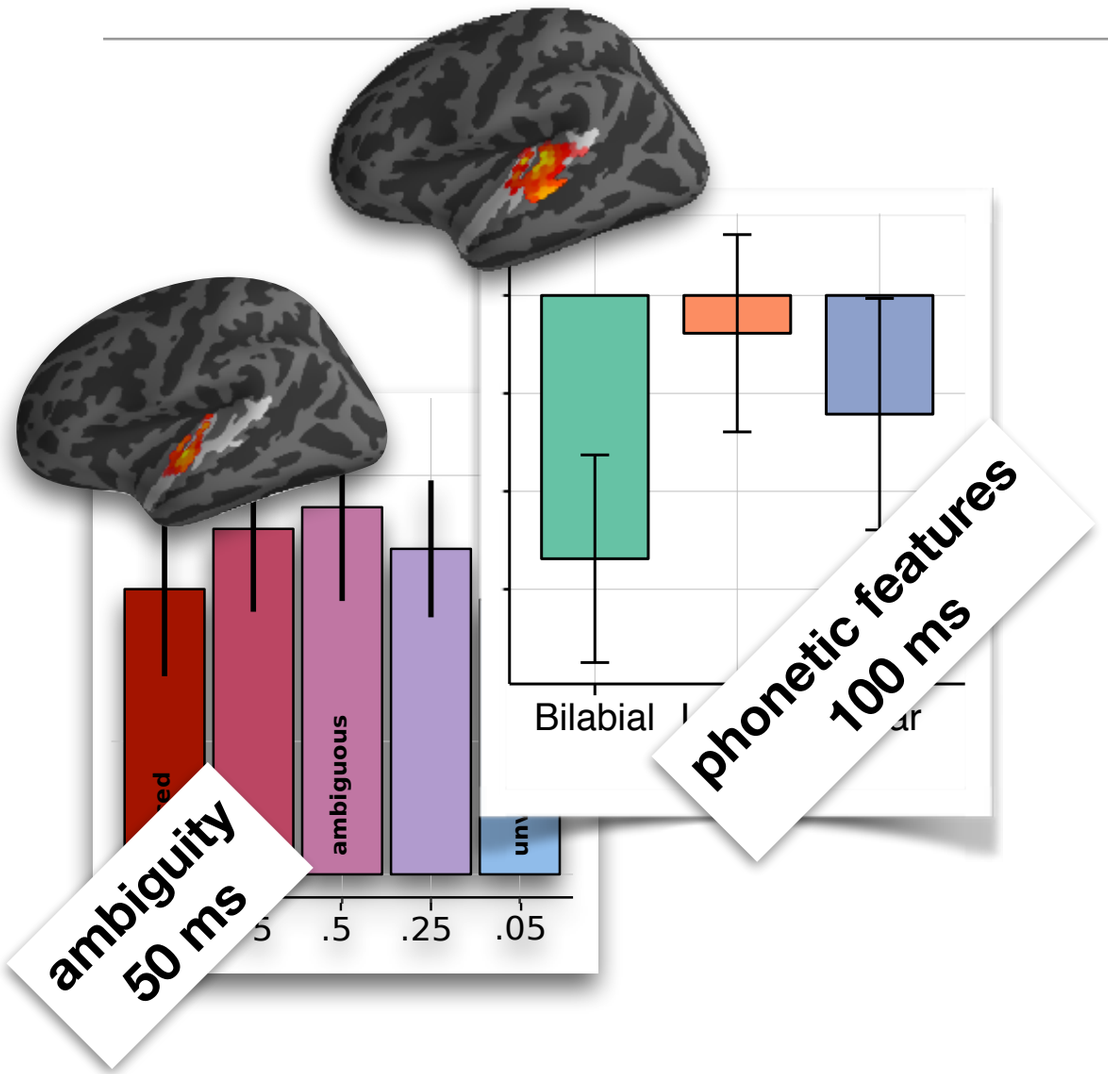
Interim Conclusion



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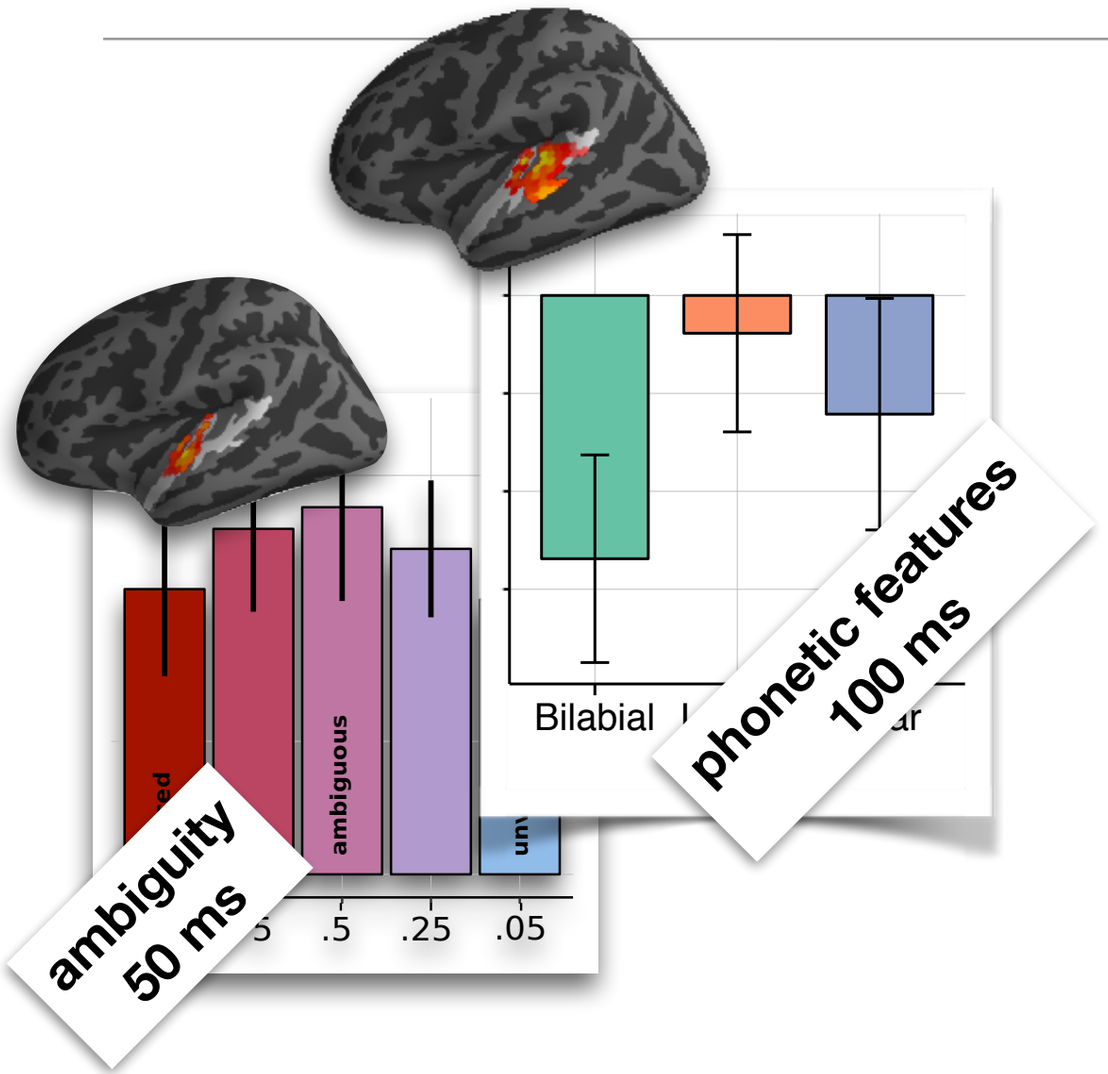

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Ambiguity at POD

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Ambiguity

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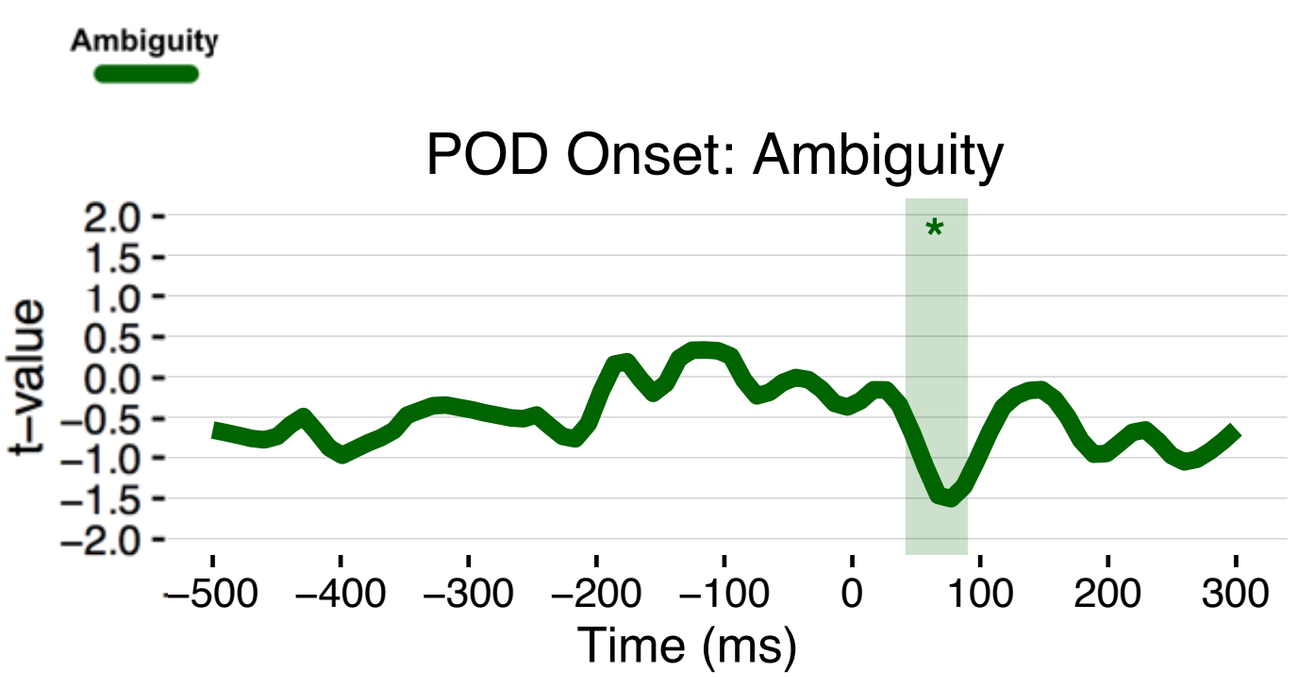

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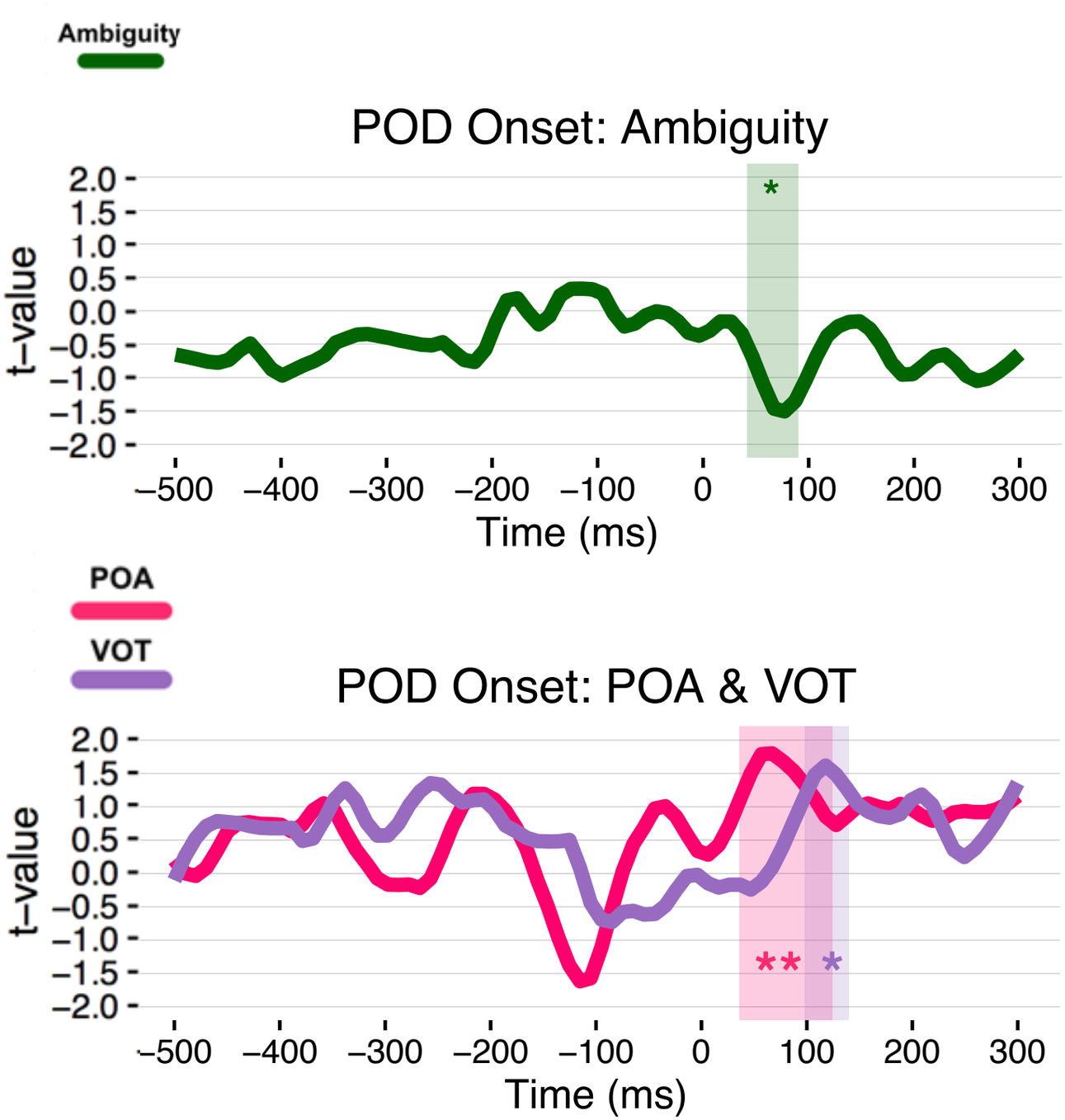

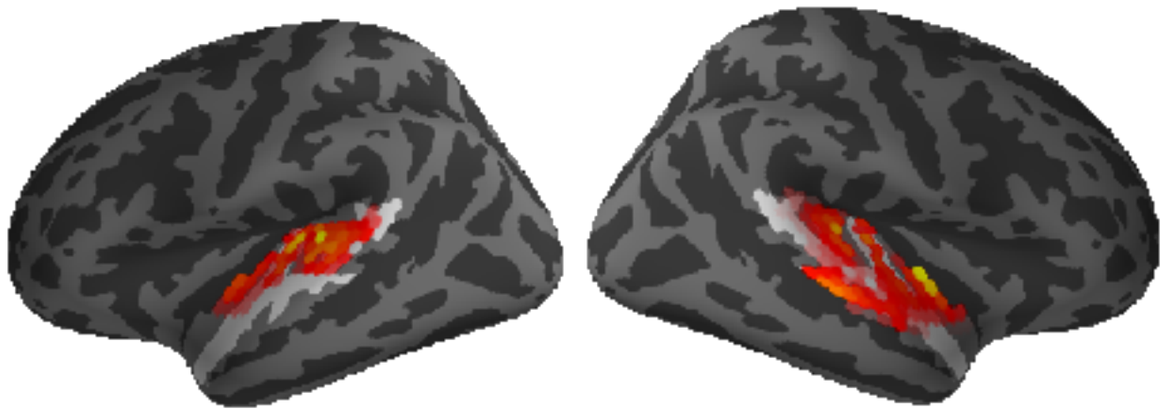

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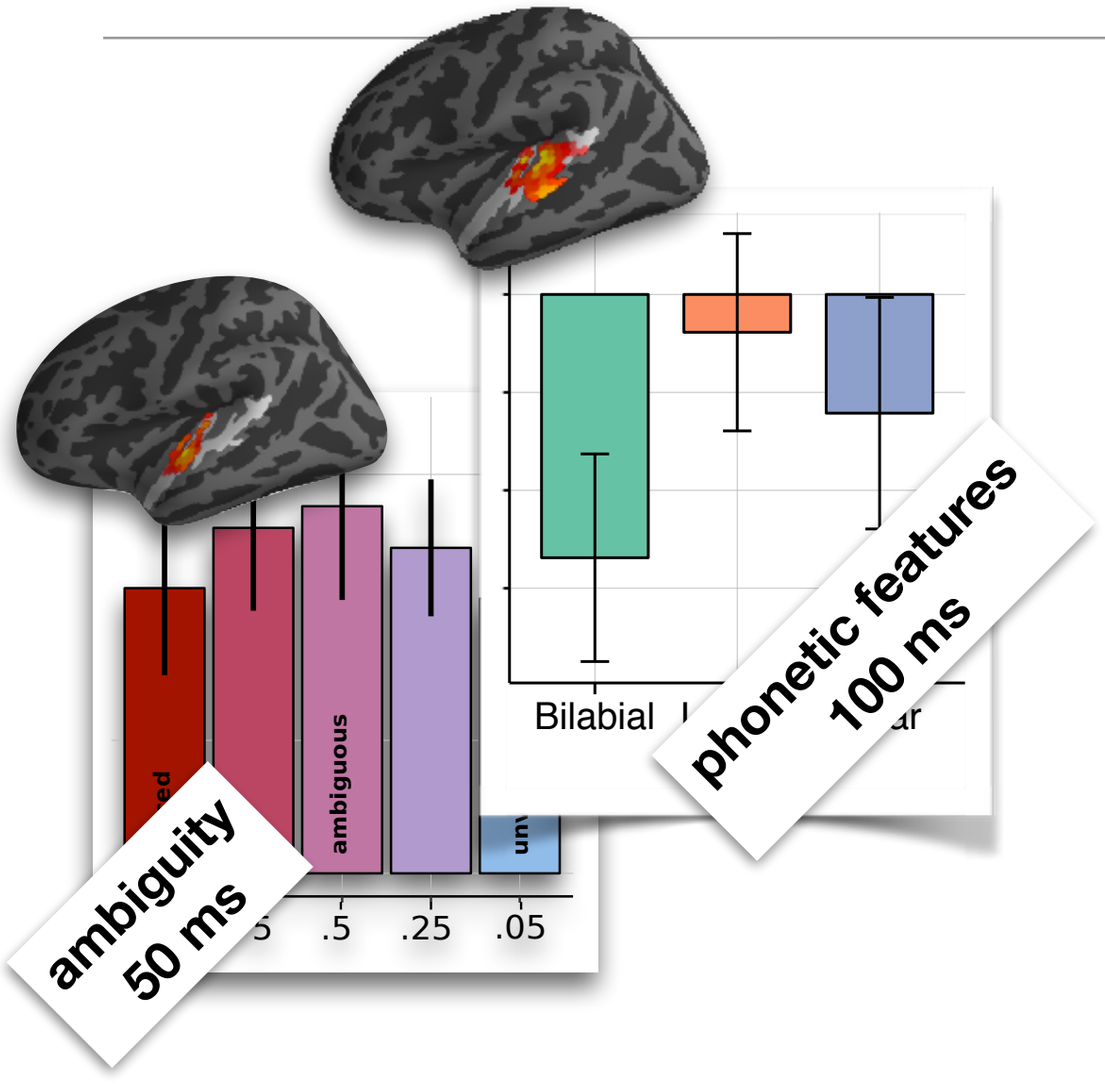

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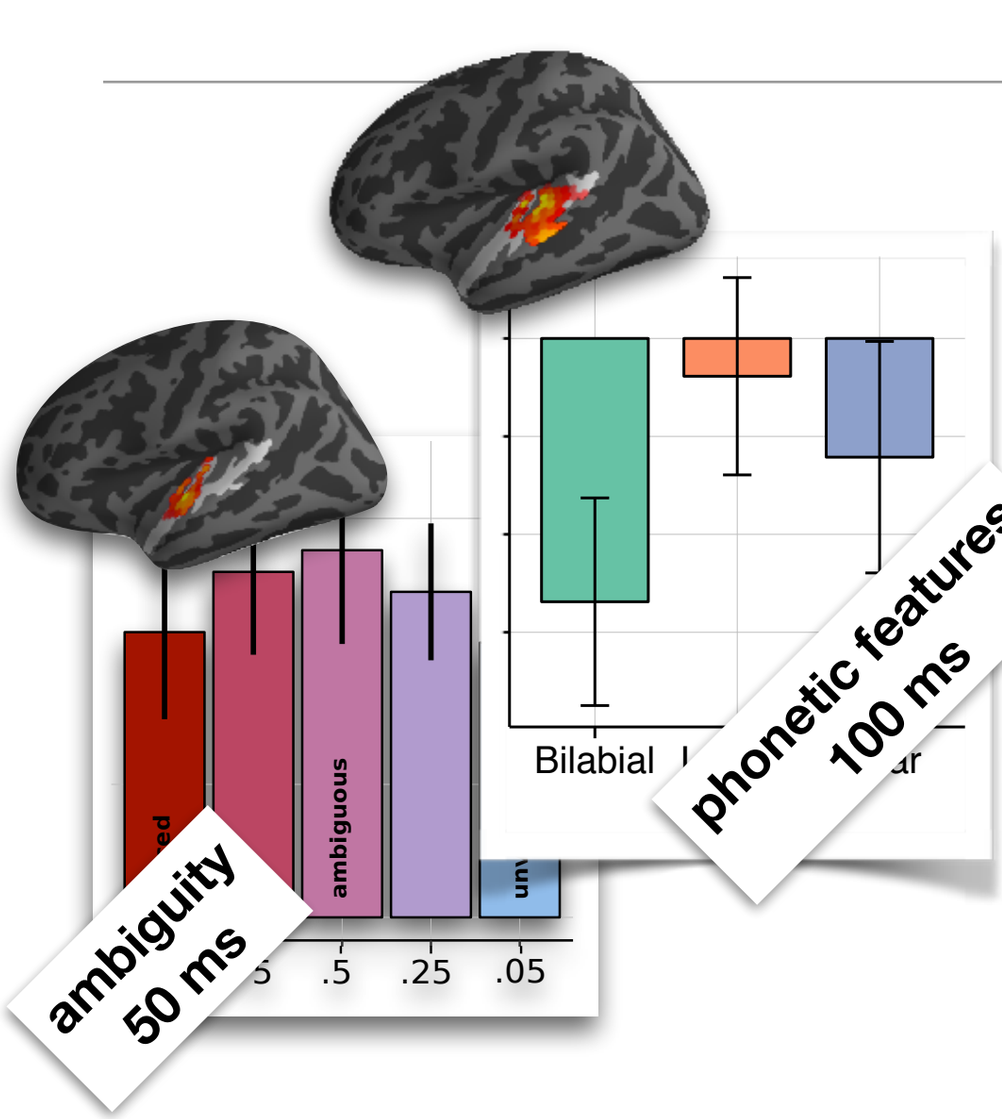

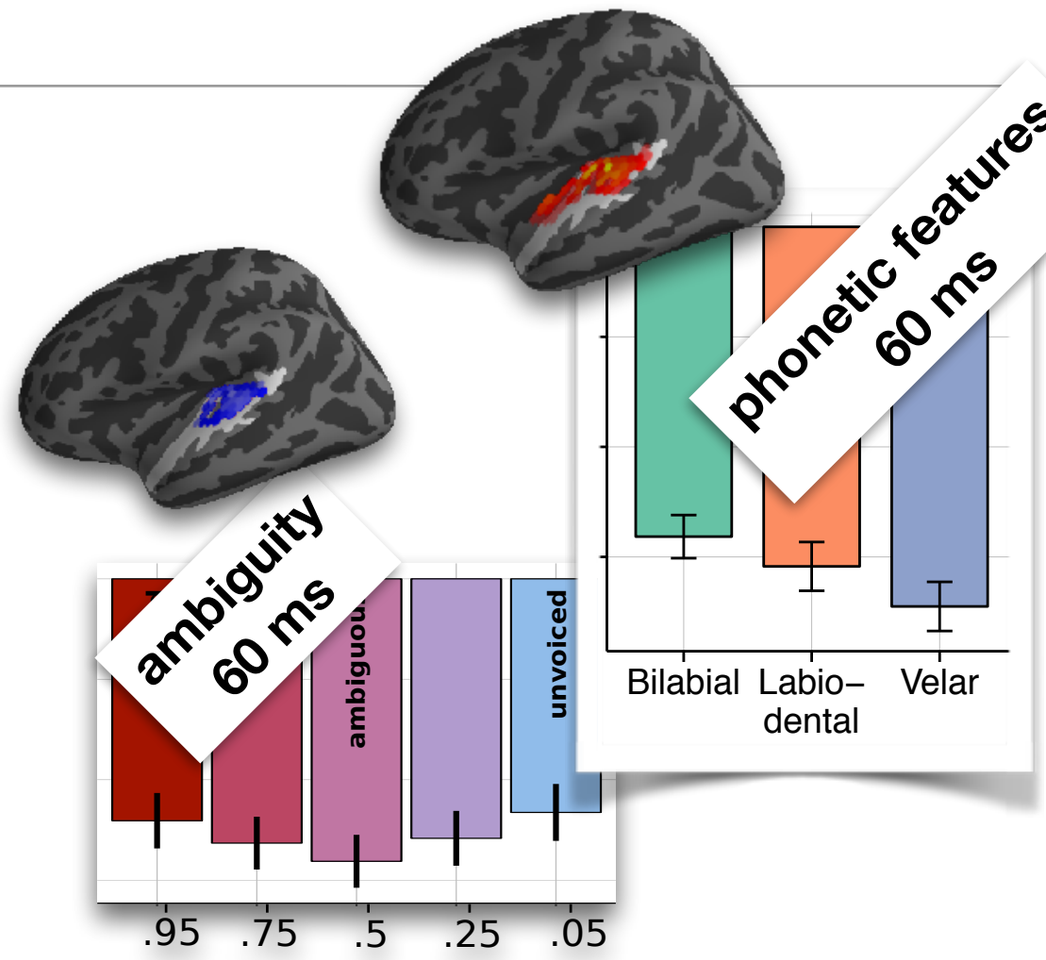

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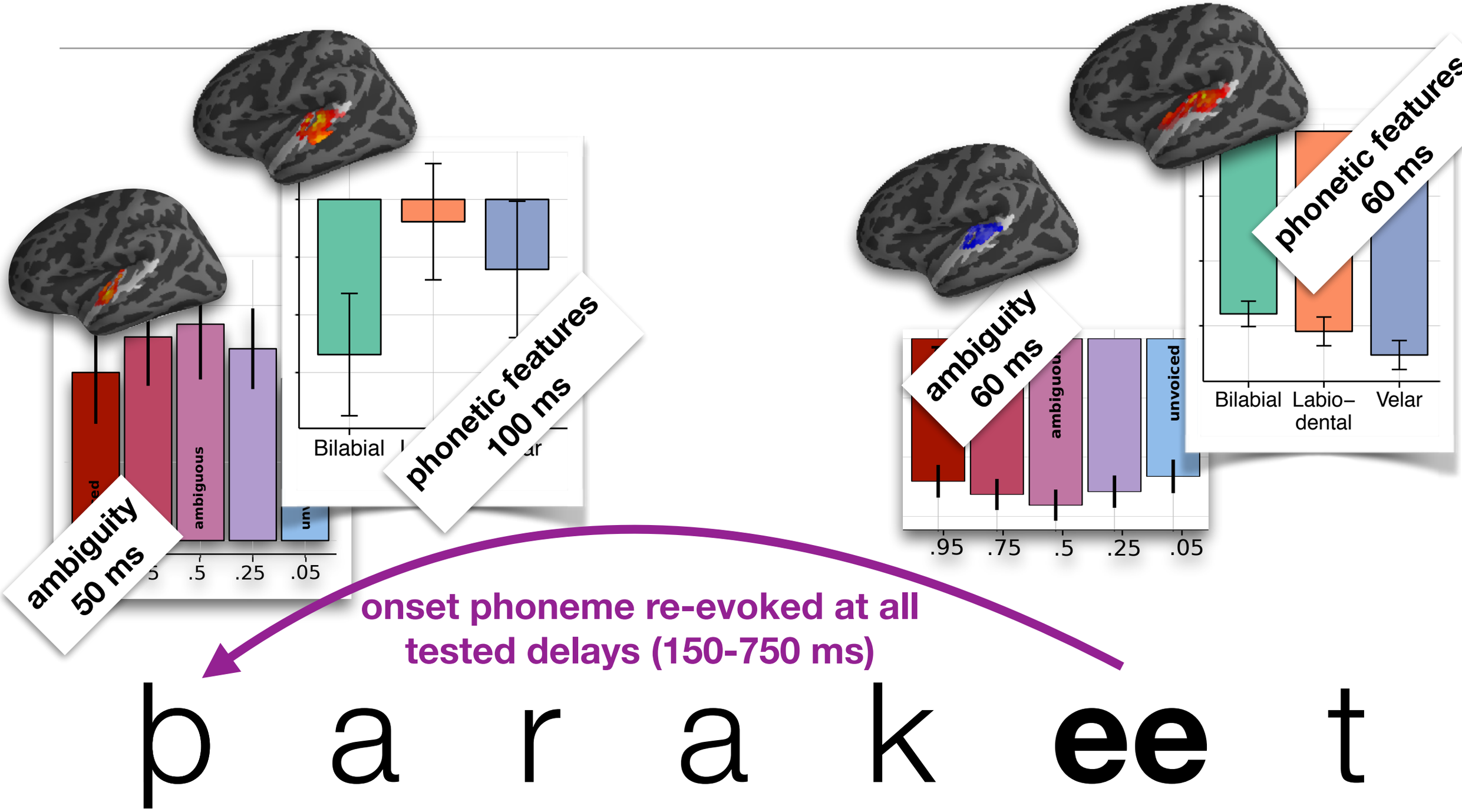

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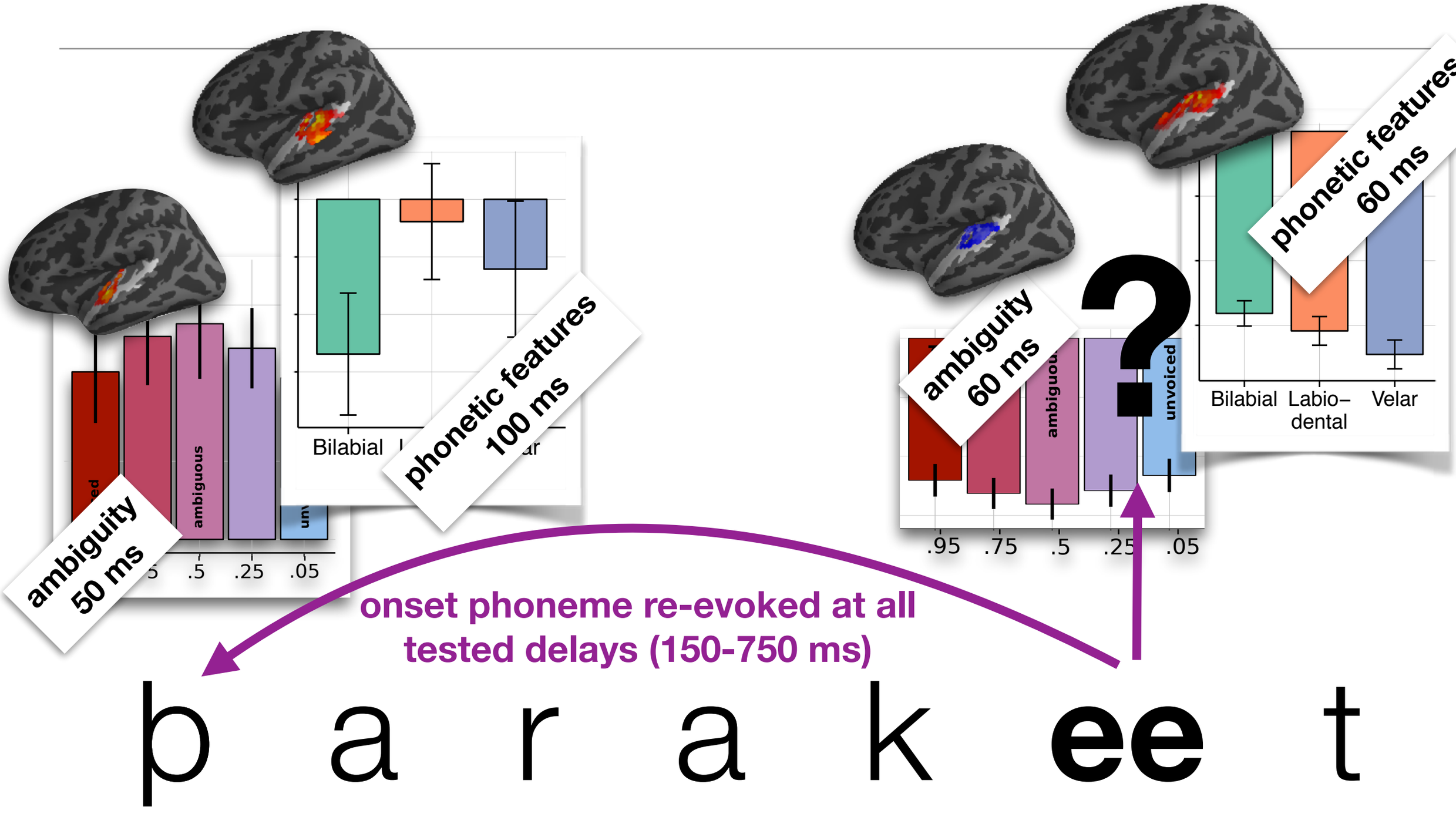

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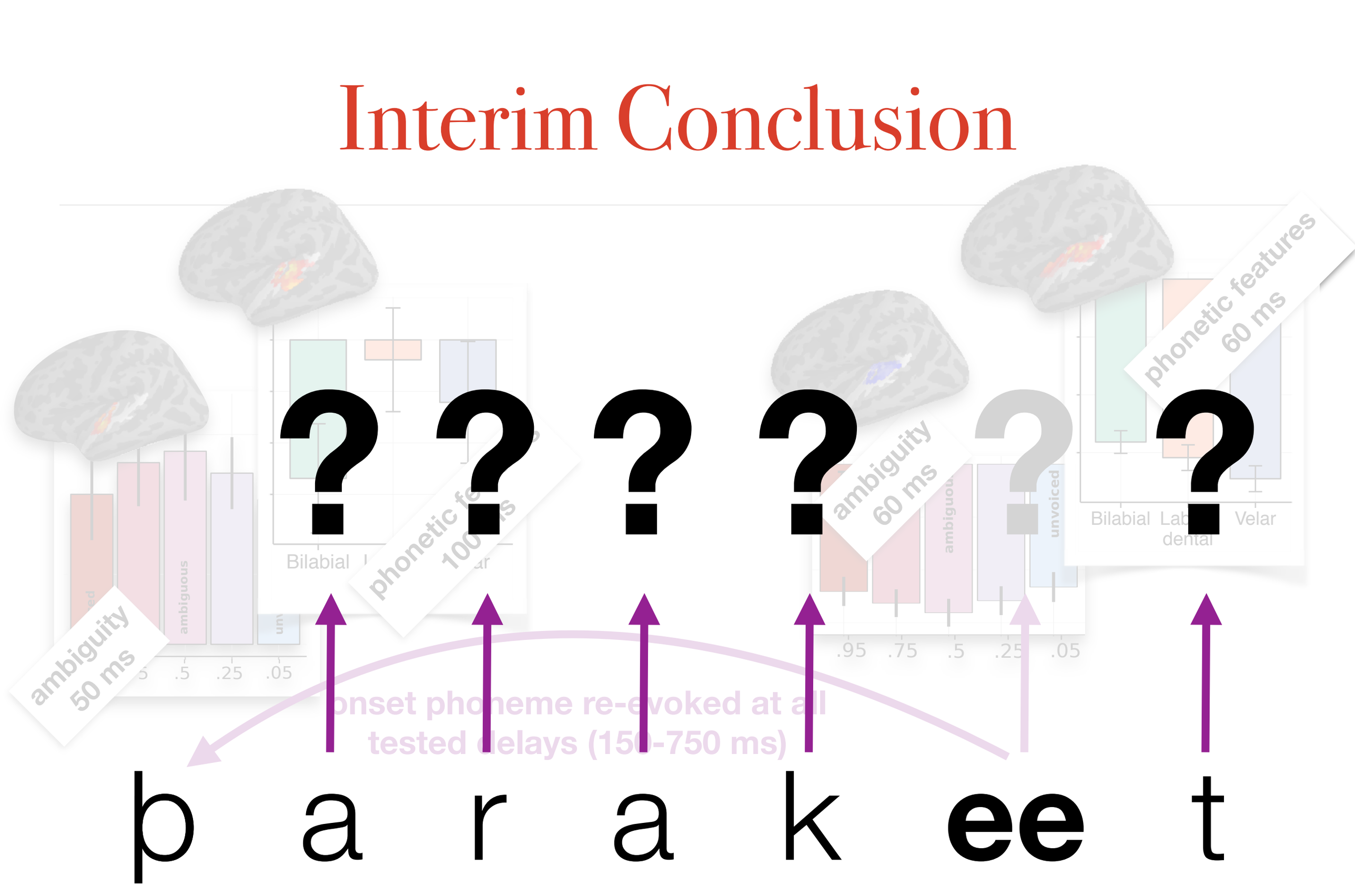
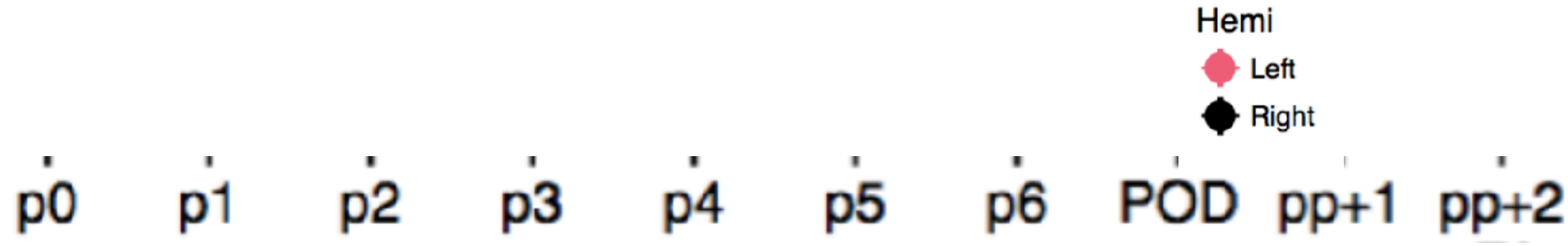
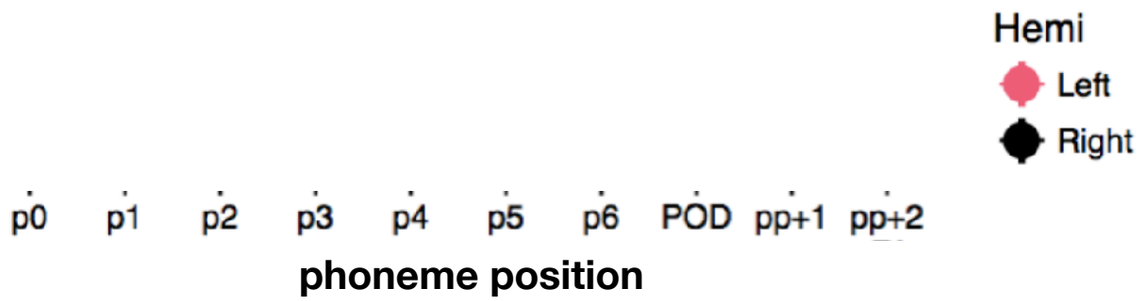


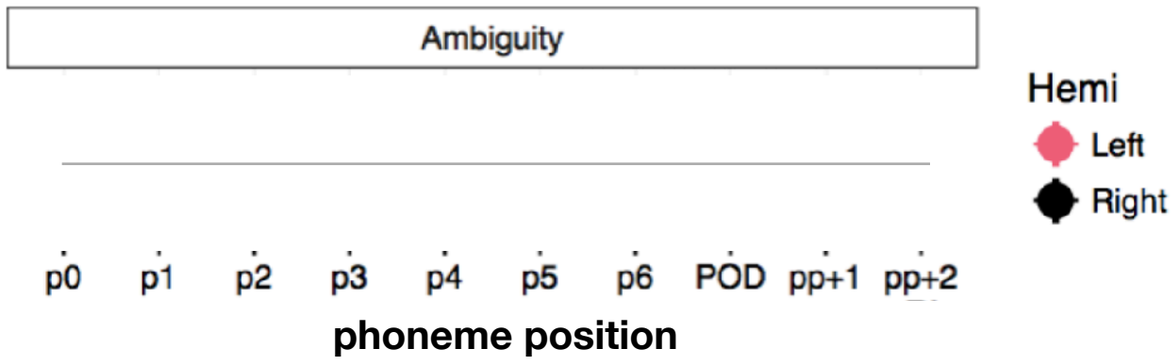
Reactivation in Intermediate Positions



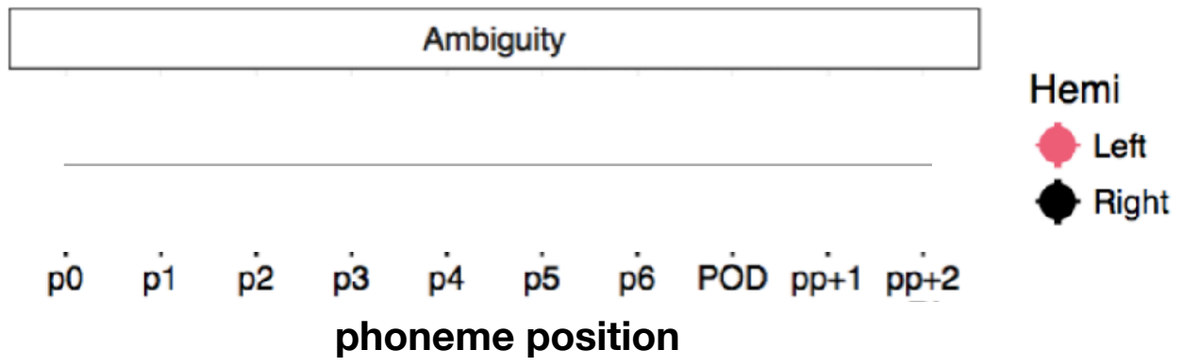
Reactivation in Intermediate Positions



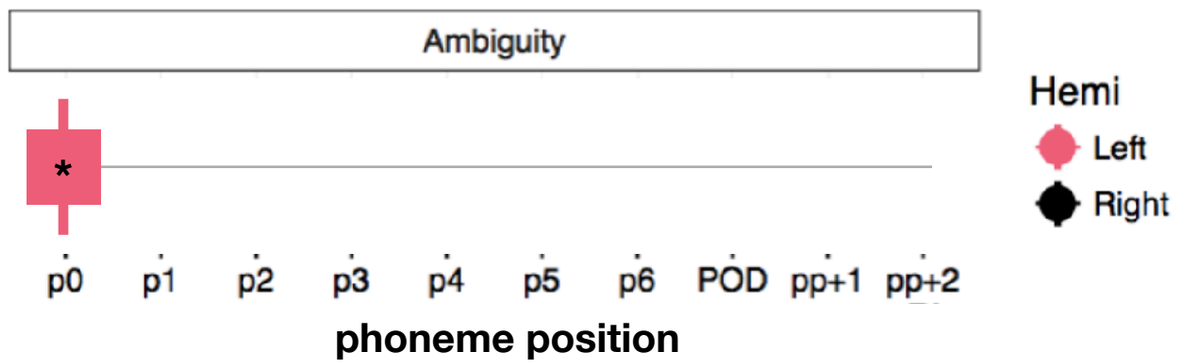
Reactivation in Intermediate Positions



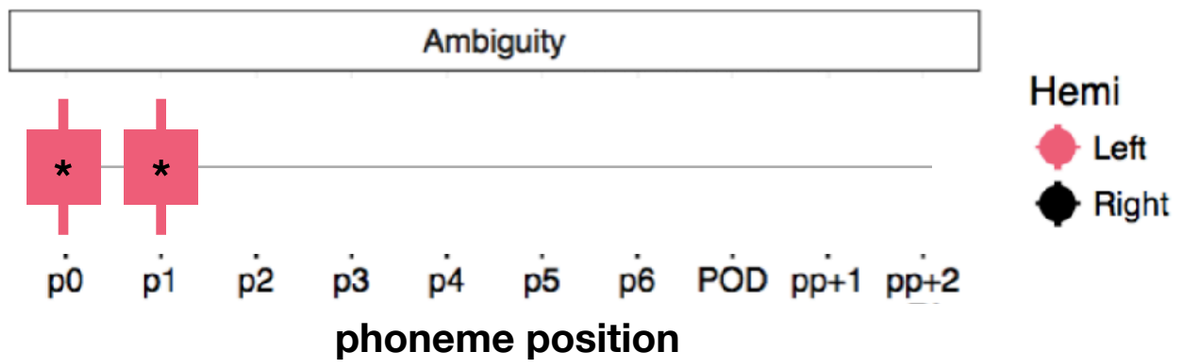
Reactivation in Intermediate Positions



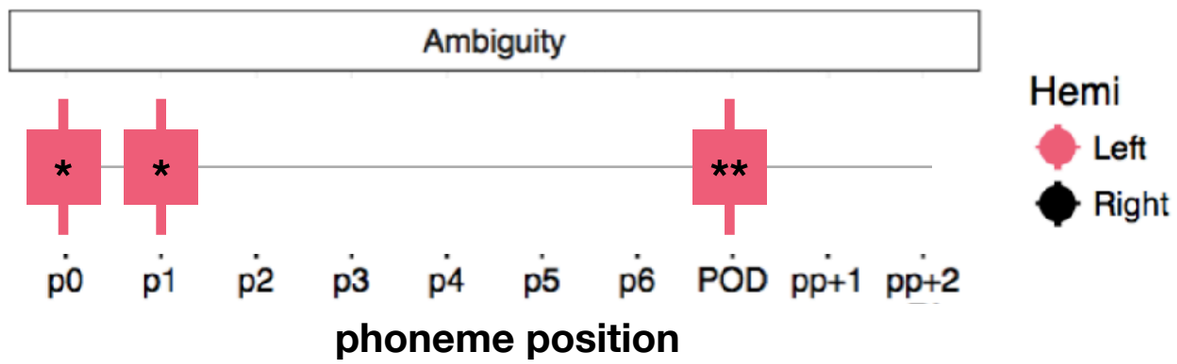
Reactivation in Intermediate Positions



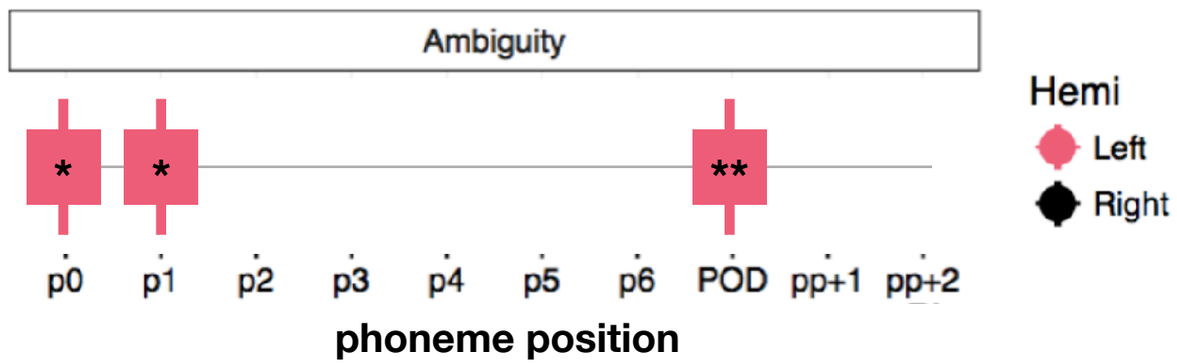
Reactivation in Intermediate Positions



Reactivation in Intermediate Positions



Reactivation in Intermediate Positions



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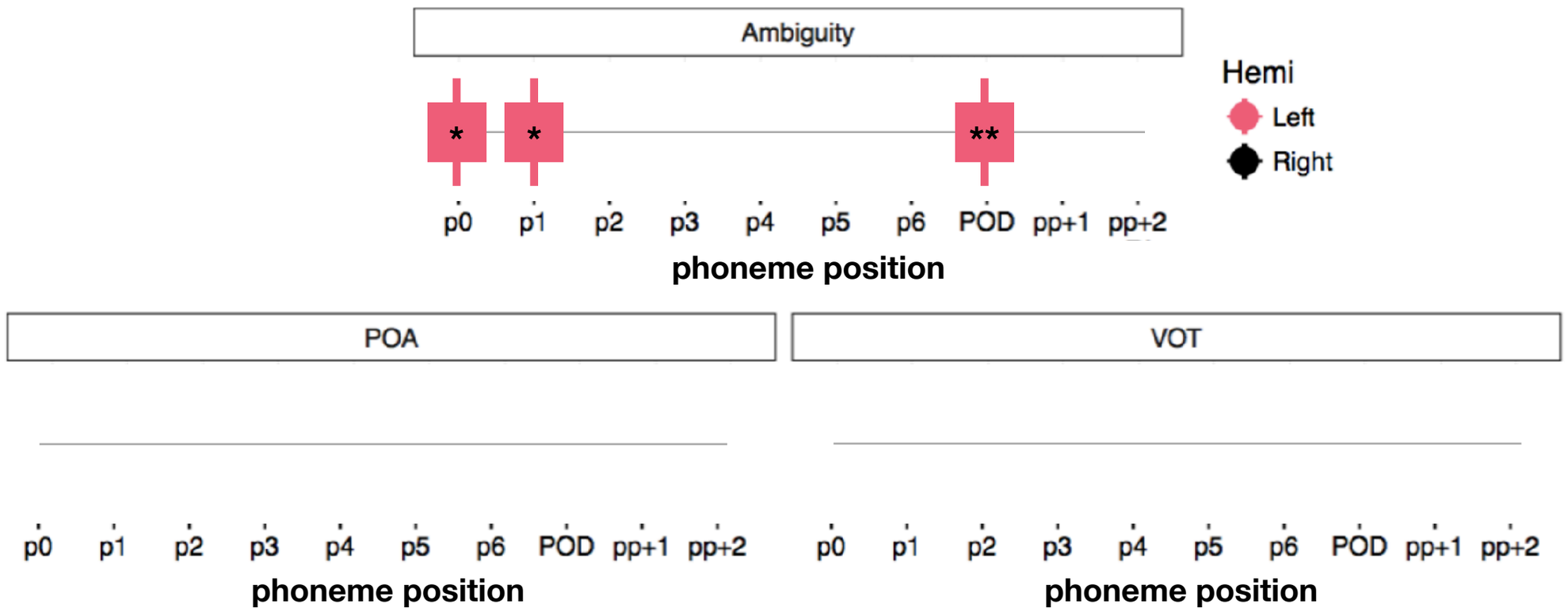
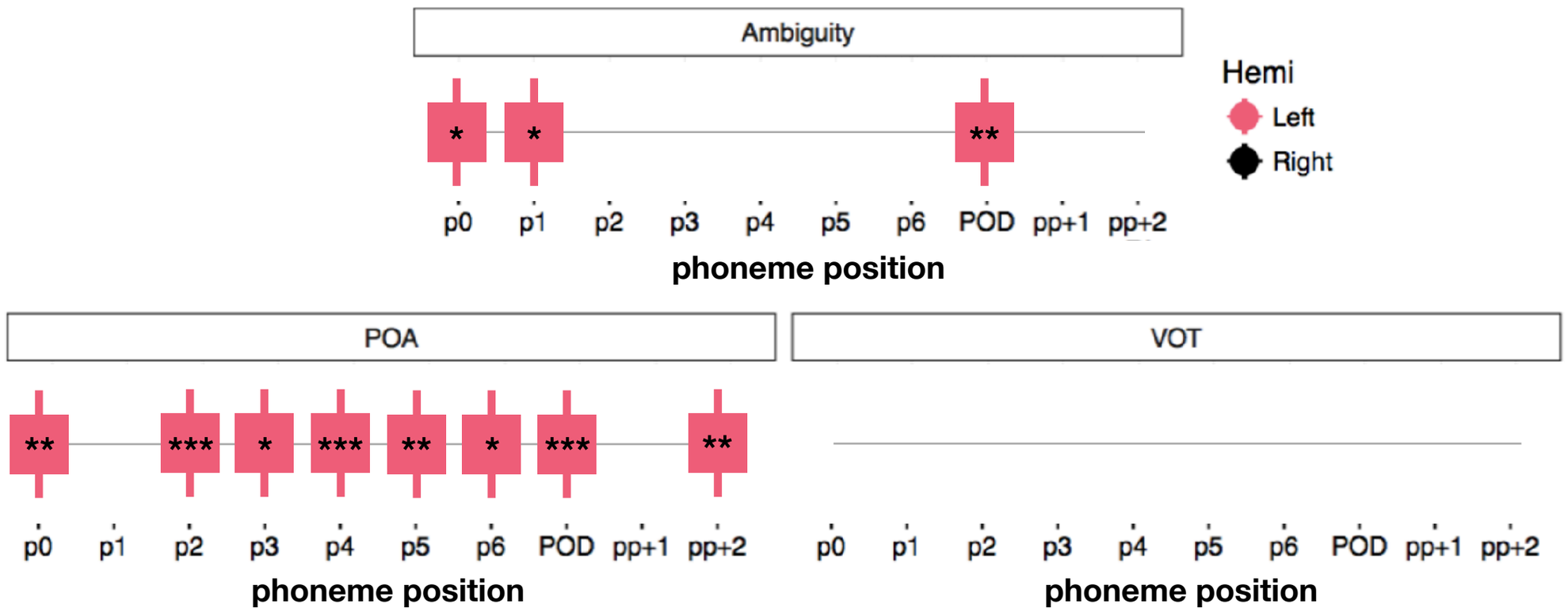
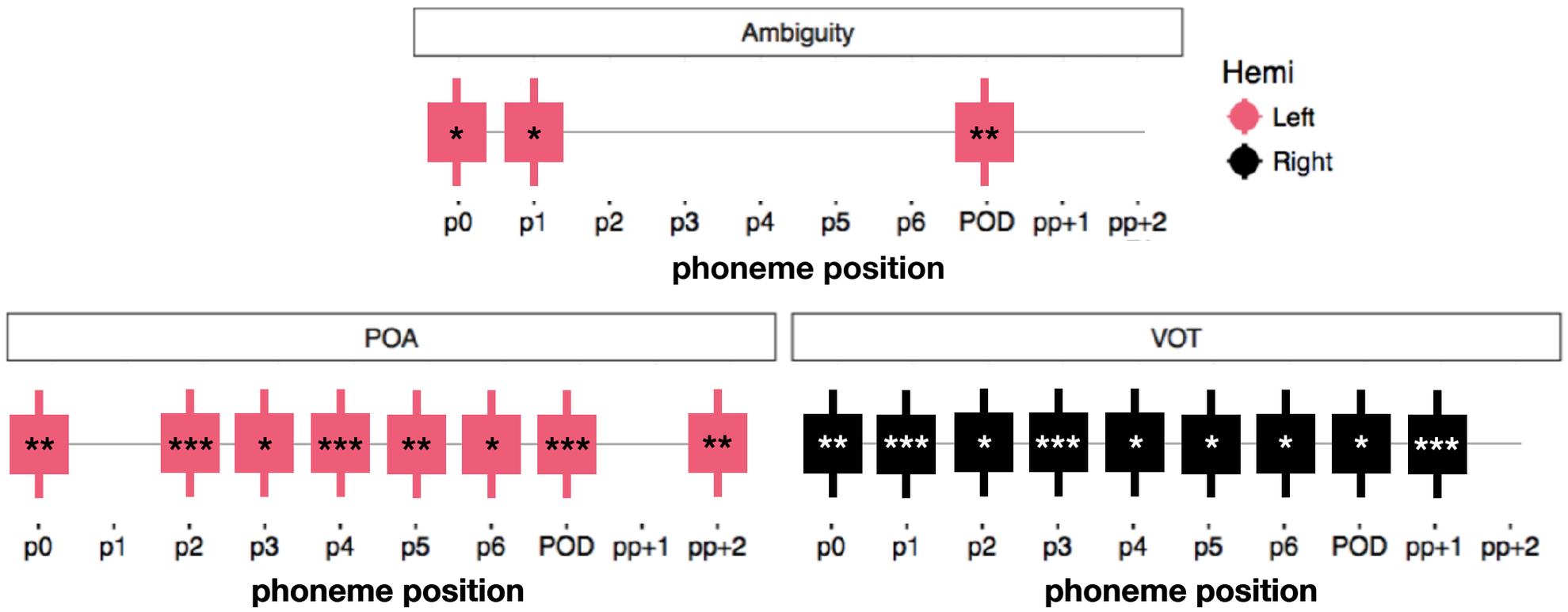


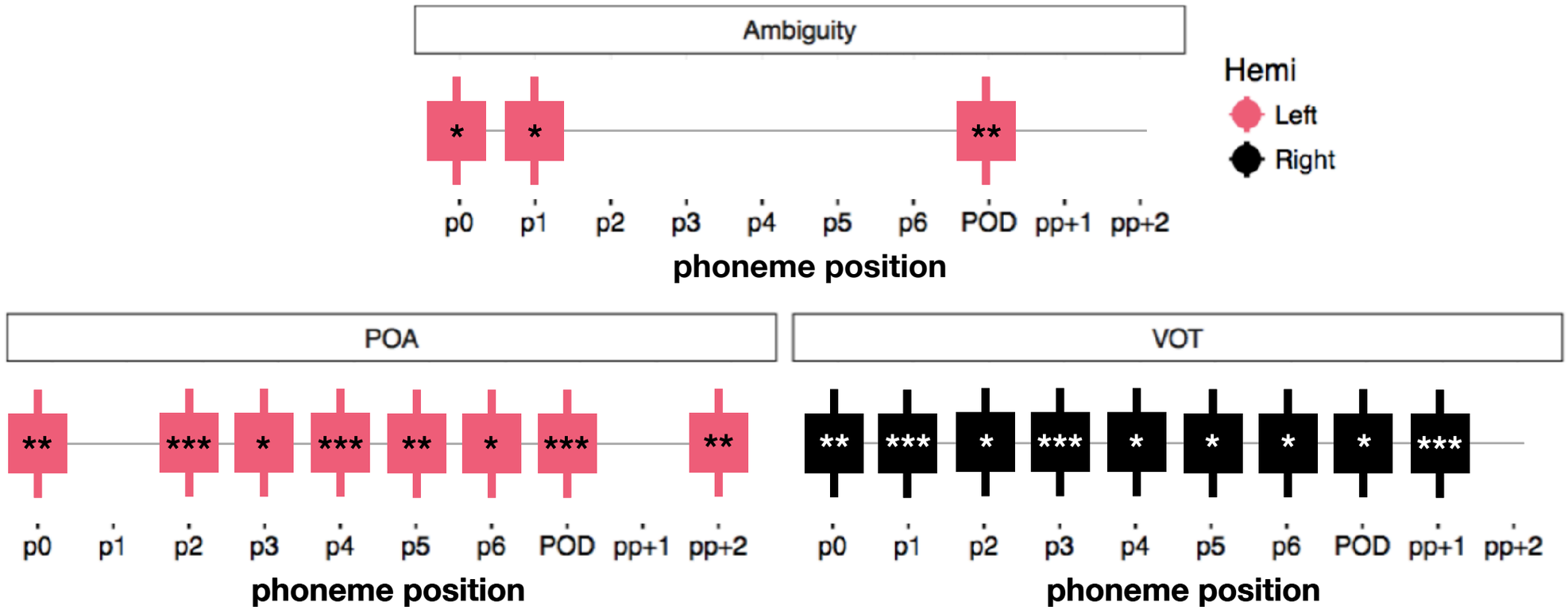
Reactivation in Intermediate Positions



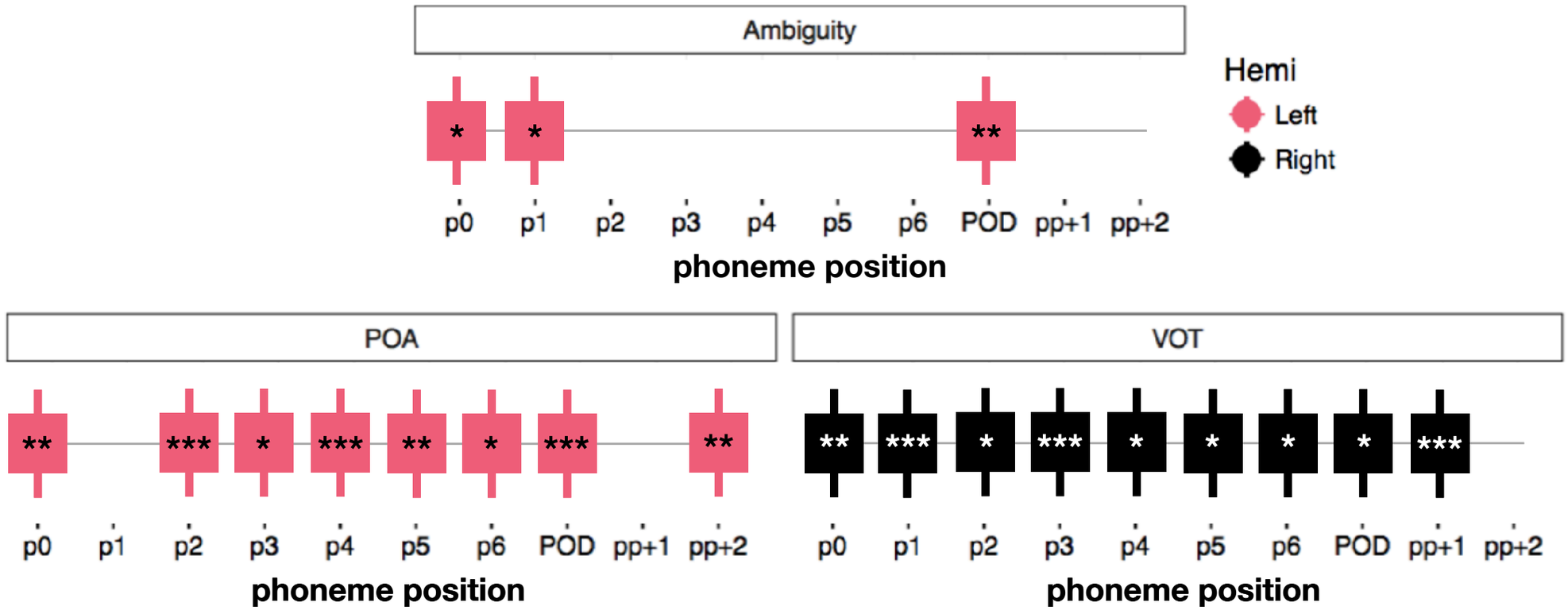
Reactivation in Intermediate Positions



Reactivation in Intermediate Positions

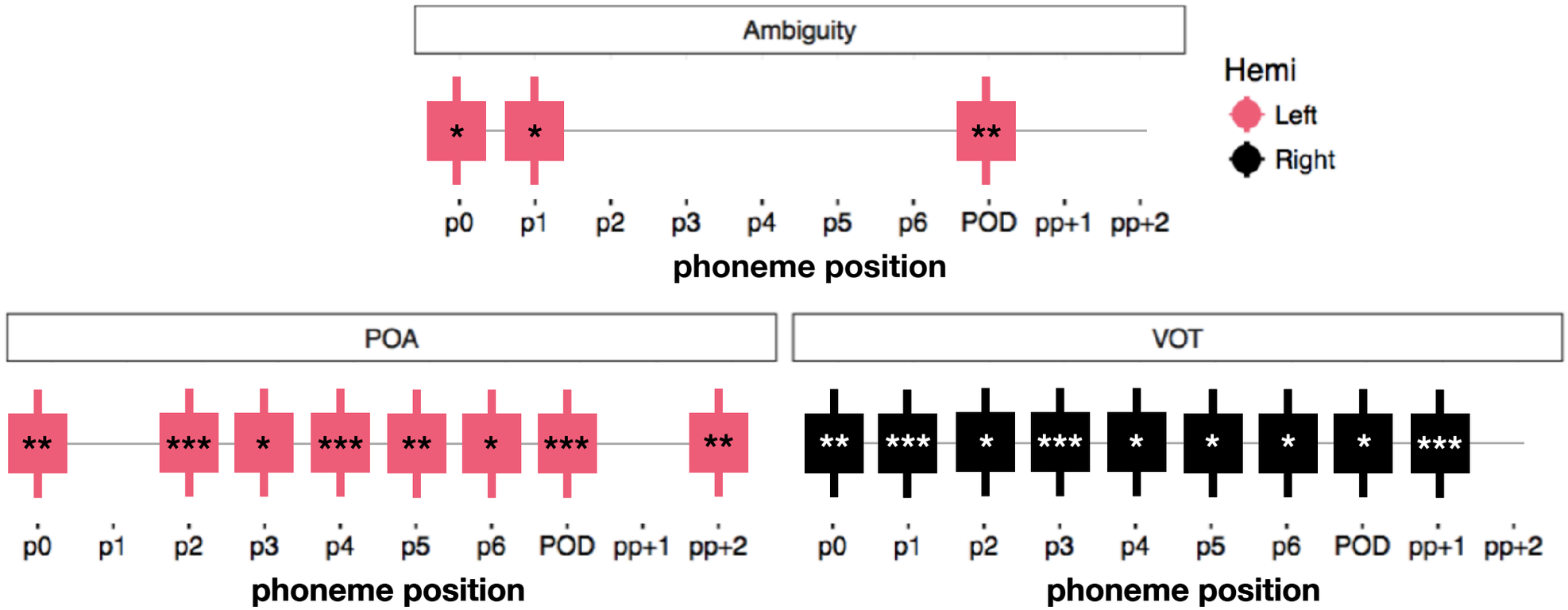


Reactivation in Intermediate Positions



- Information is re-evoked in auditory cortex

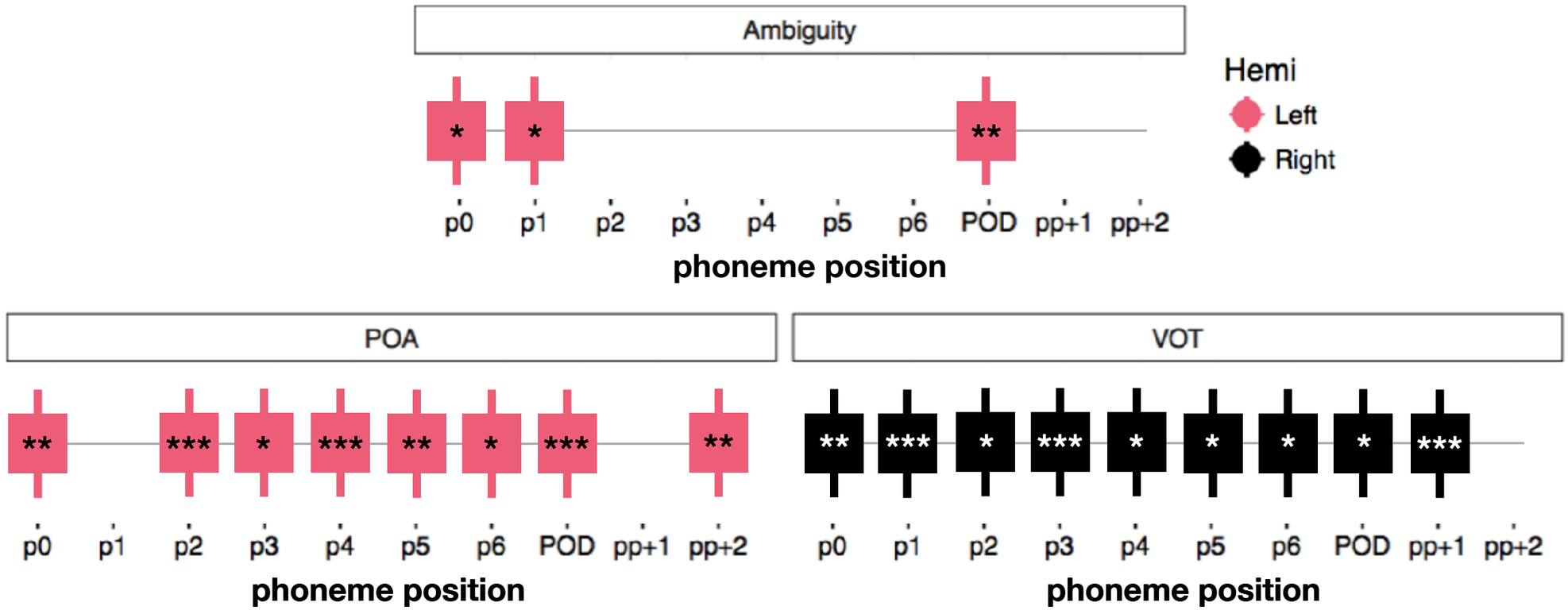
Reactivation in Intermediate Positions



- Information is re-evoked in auditory cortex

- Specifically time-locked to the onset of subsequent phonemes

Reactivation in Intermediate Positions

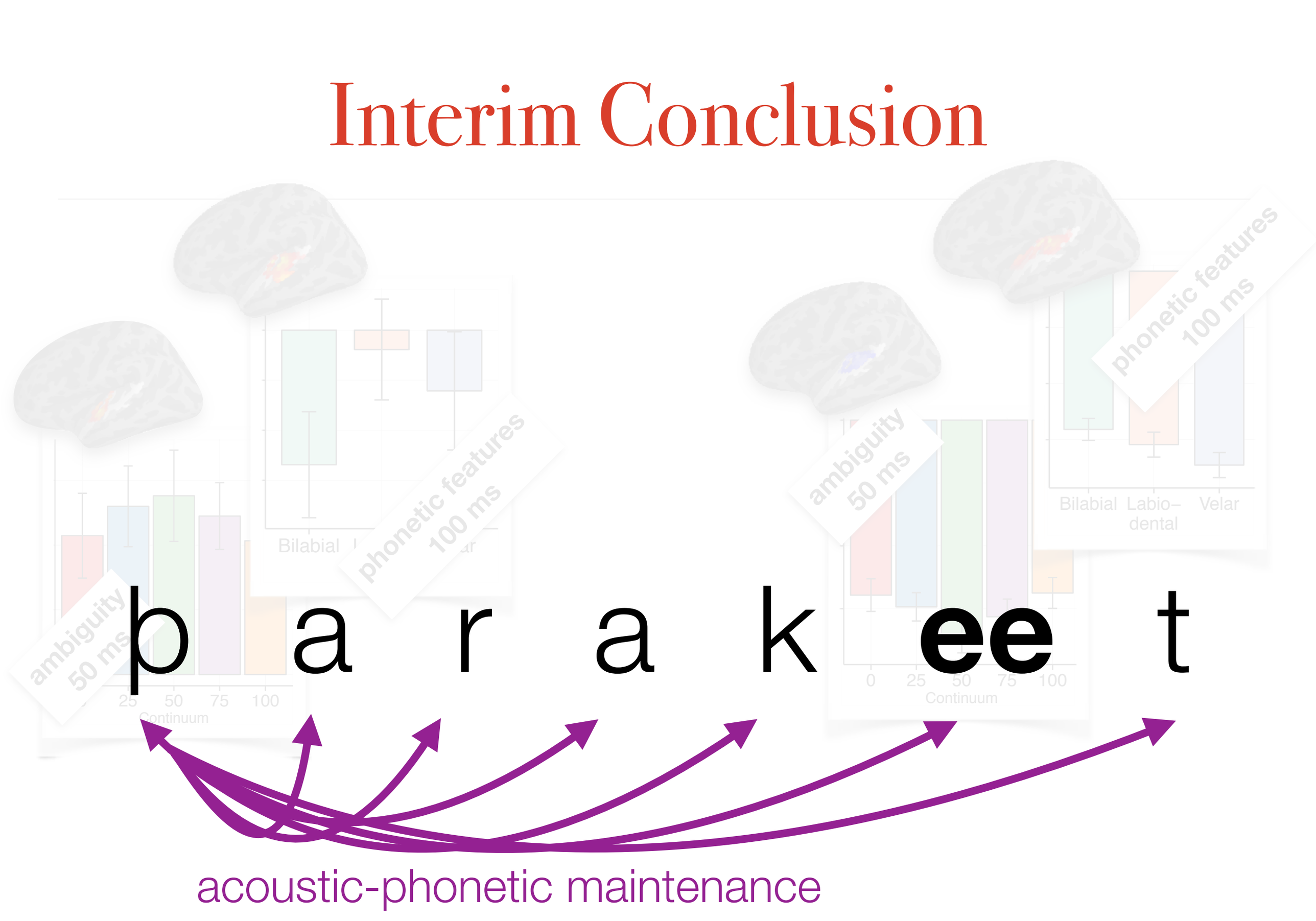


- Information is re-evoked in auditory cortex
- Specifically time-locked to the onset of subsequent phonemes
- Not specific to the ambiguous tokens — general to language processing

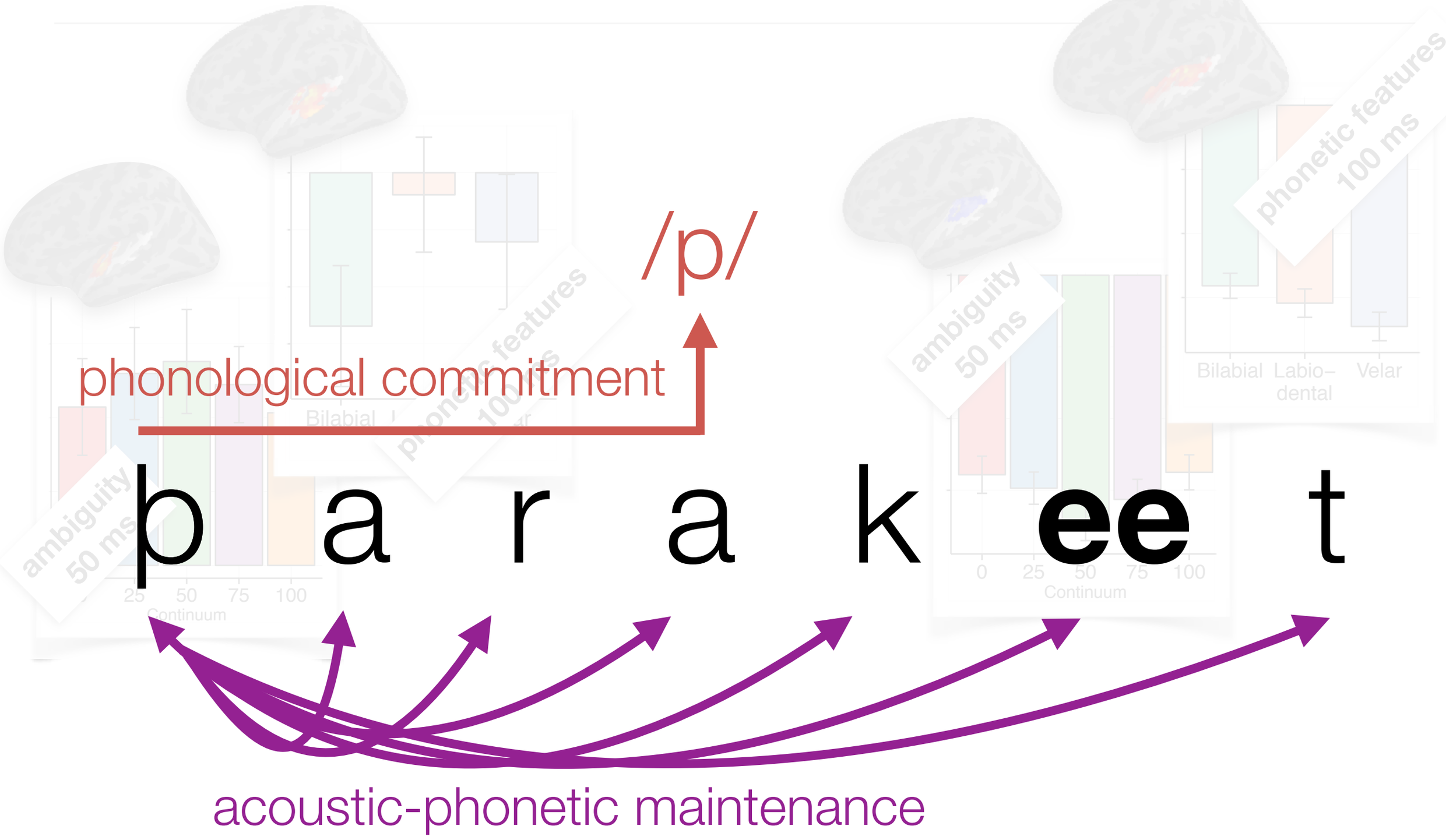
Interim Conclusion

p a r a k **ee** t

Interim Conclusion



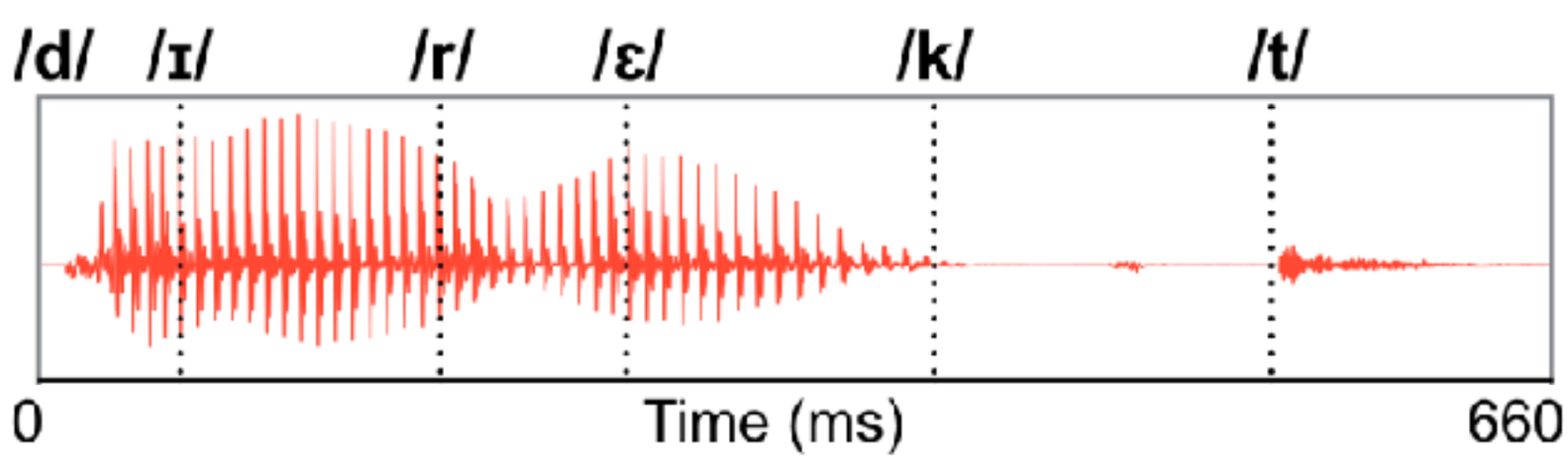
Interim Conclusion



Testing for phonological commitment

- **Surprisal**:

No commitment
Commitment



- **Entropy:**

No commitment
Commitment

Testing for phonological commitment

- **Surprisal**:

No commitment
Commitment

$$-log_2\left(P(\varphi_a|A)\frac{f(\varphi_a,\varphi_2,\ldots,\varphi_t)}{f(\varphi_a,\varphi_2,\ldots,\varphi_{t-1})}Q_a^t+ P(\varphi_b|A)\frac{f(\varphi_b,\varphi_2,\ldots,\varphi_t)}{f(\varphi_b,\varphi_2,\ldots,\varphi_{t-1})}Q_b^t\right)$$

- **Entropy:**

No commitment
Commitment

$$P(w|C,A) = P(w|C_a)P(\varphi_a|A)+ P(w|C_b)P(\varphi_b|A)$$

Testing for phonological commitment

- **Surprisal**:

No commitment
Commitment

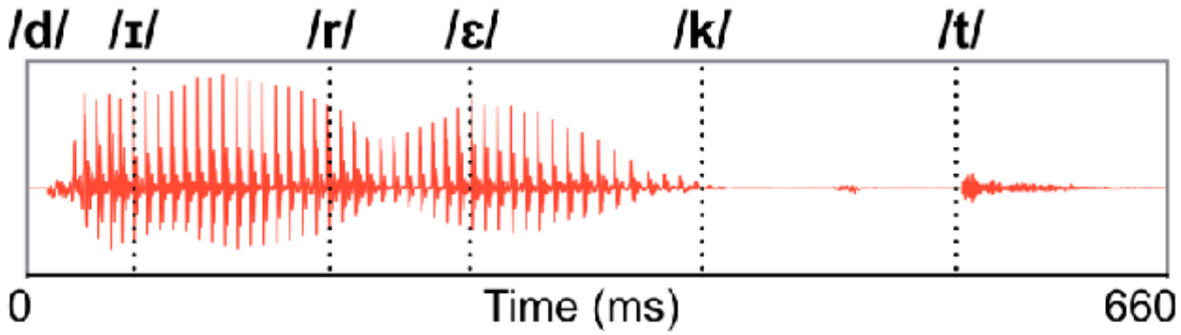
$$-log_2\left(P(\varphi_a|A)\frac{f(\varphi_a,\varphi_2,\ldots,\varphi_t)}{f(\varphi_a,\varphi_2,\ldots,\varphi_{t-1})}Q_a^t + P(\varphi_b|A)\frac{f(\varphi_b,\varphi_2,\ldots,\varphi_t)}{f(\varphi_b,\varphi_2,\ldots,\varphi_{t-1})}Q_b^t\right)$$

- **Entropy:**

No commitment
Commitment

$$P(w|C,A) = P(w|C_a)P(\varphi_a|A) + P(w|C_b)P(\varphi_b|A)$$

Model Setup



Gwilliams et al., *CMCL*, 2018

Model Setup

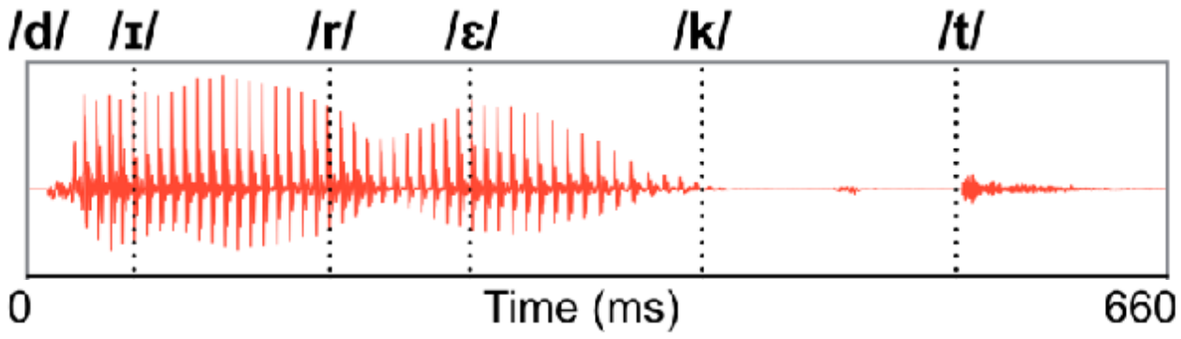
- **Critical variables**:

no commitment entropy

no commitment surprisal

commitment entropy

commitment surprisal



Gwilliams et al., *CMCL*, 2018

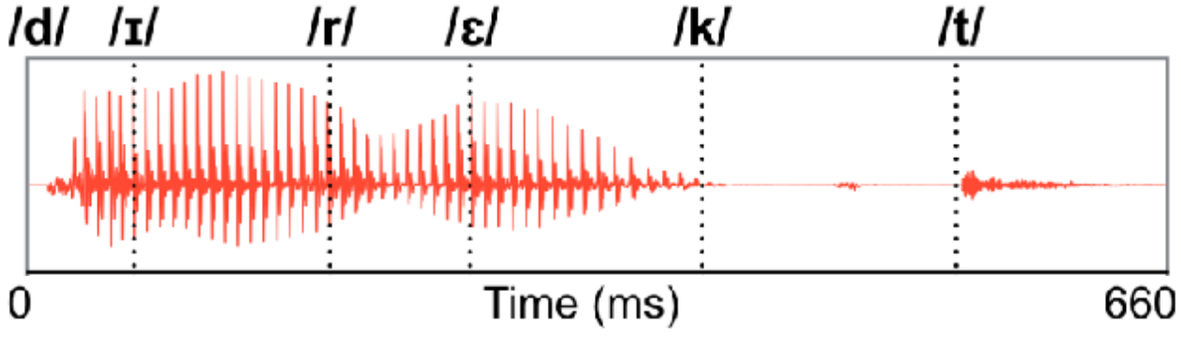
Model Setup

- **Critical variables**:

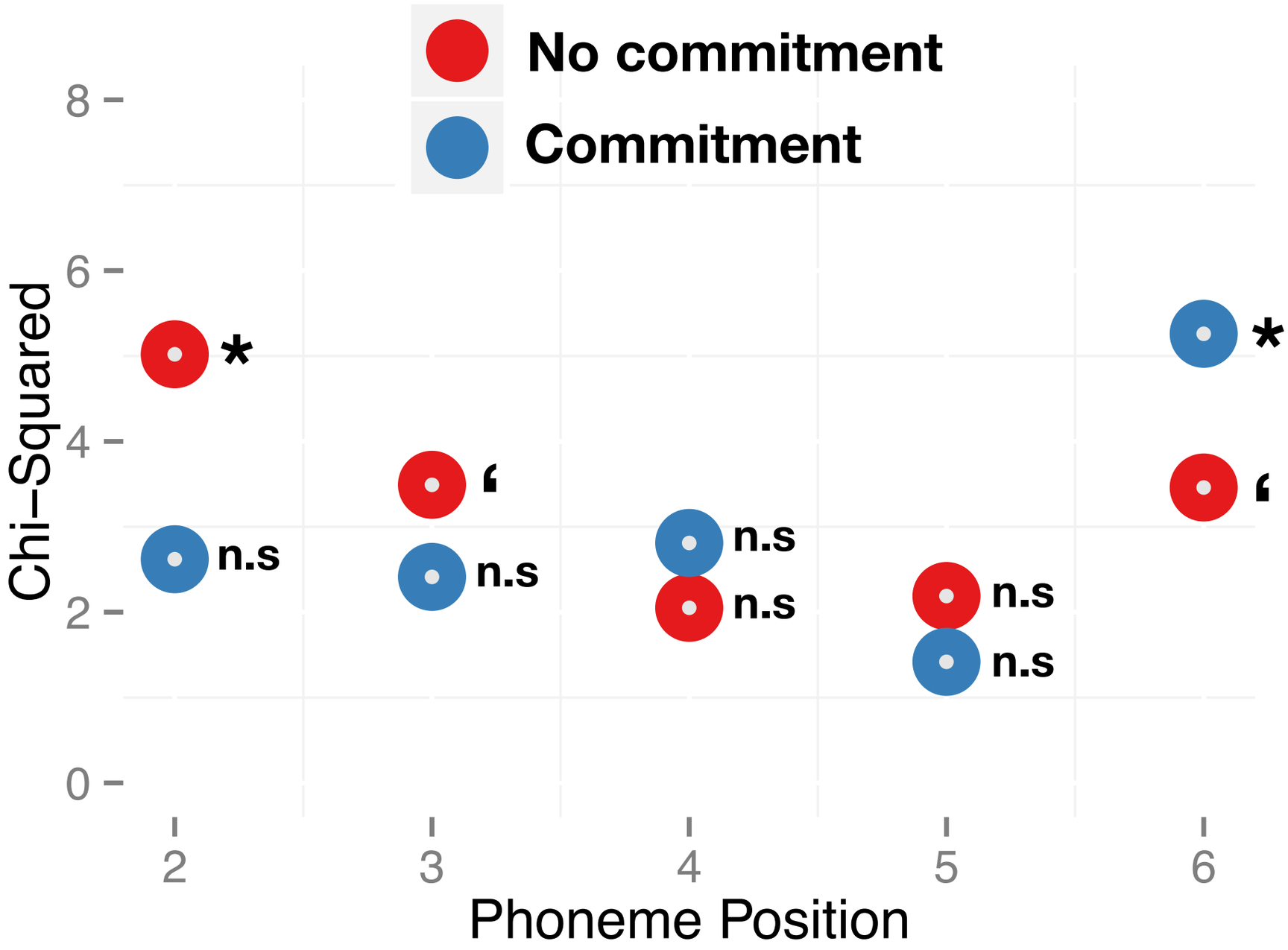
no commitment entropy
no commitment surprisal
commitment entropy
commitment surprisal

- **Control variables**:

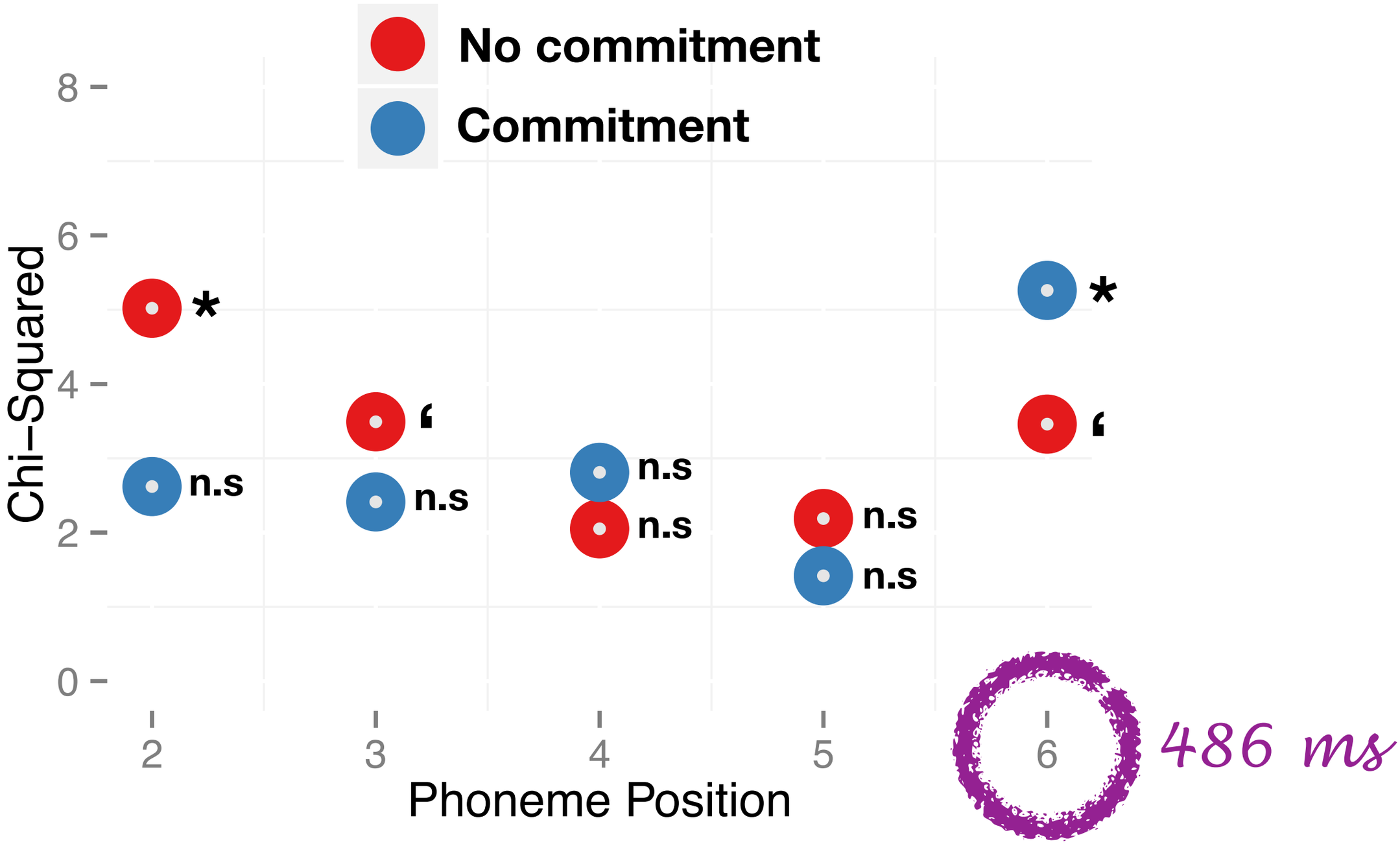
phoneme latency (ms)
phoneme latency (number of phonemes)
trial number
block number
stimulus amplitude
phoneme pair
ambiguity



Results


No commitment
Commitment
8
6
4
2
0
Chi–Squared
n.s
n.s
n.s
n.s
n.s
n.s
*
*
2
3
4
5
6
Phoneme Position

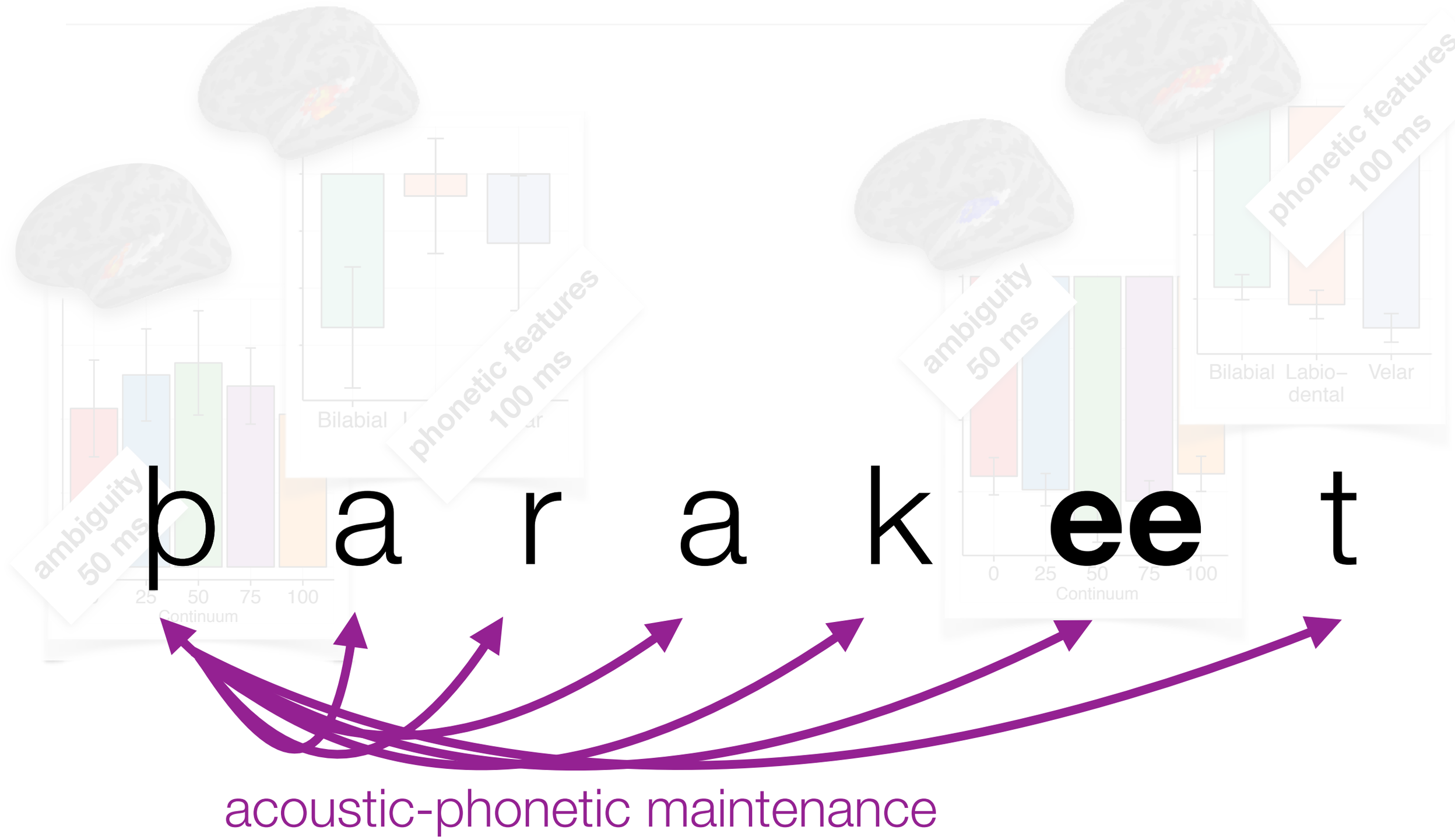
Results


No commitment
Commitment
Chi–Squared
8
6
4
2
0
n.s
n.s
n.s
n.s
n.s
n.s
*
*
2
3
4
5
6
Phoneme Position
486 ms

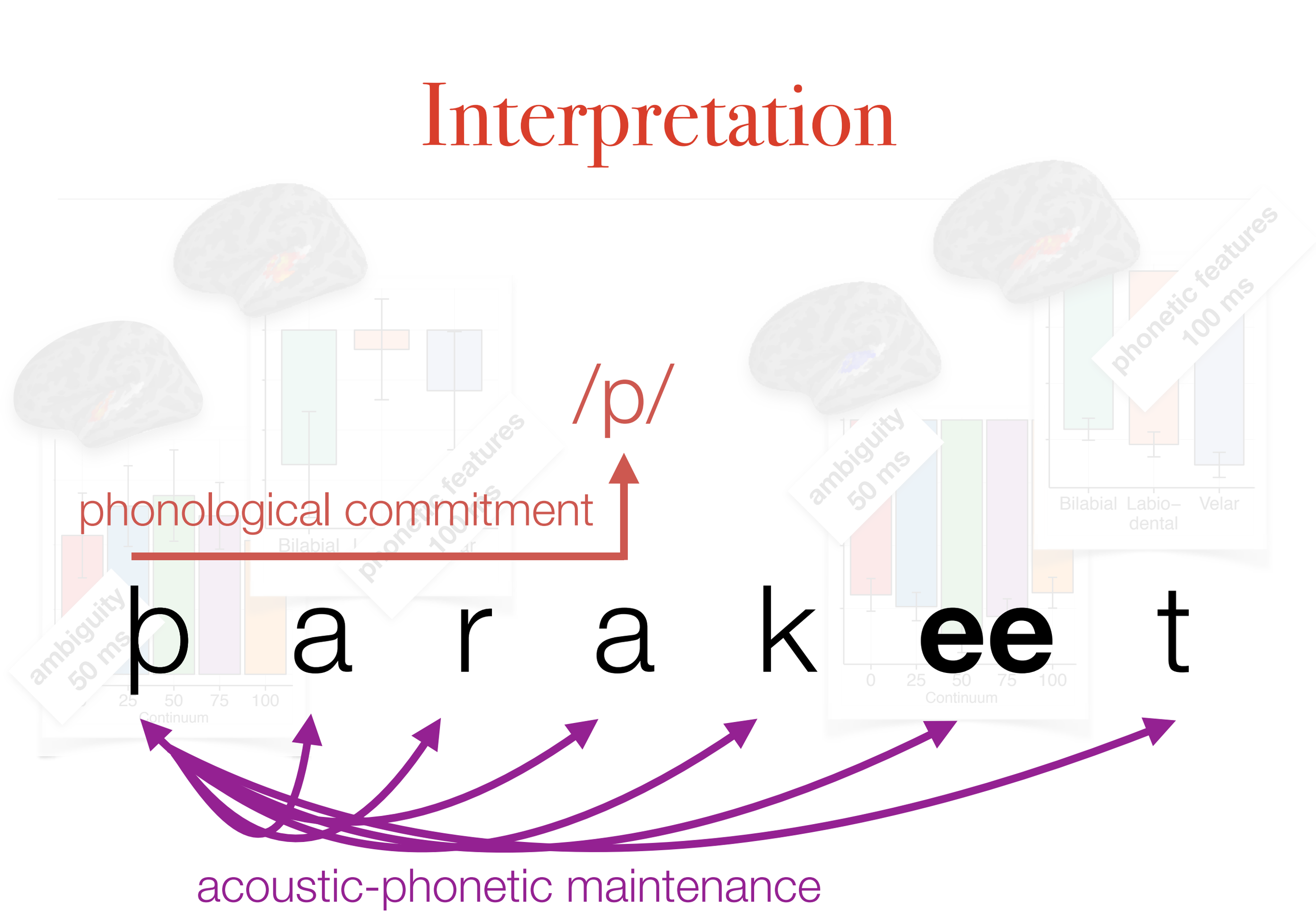
Interpretation

p a r a k **ee** t

Interpretation

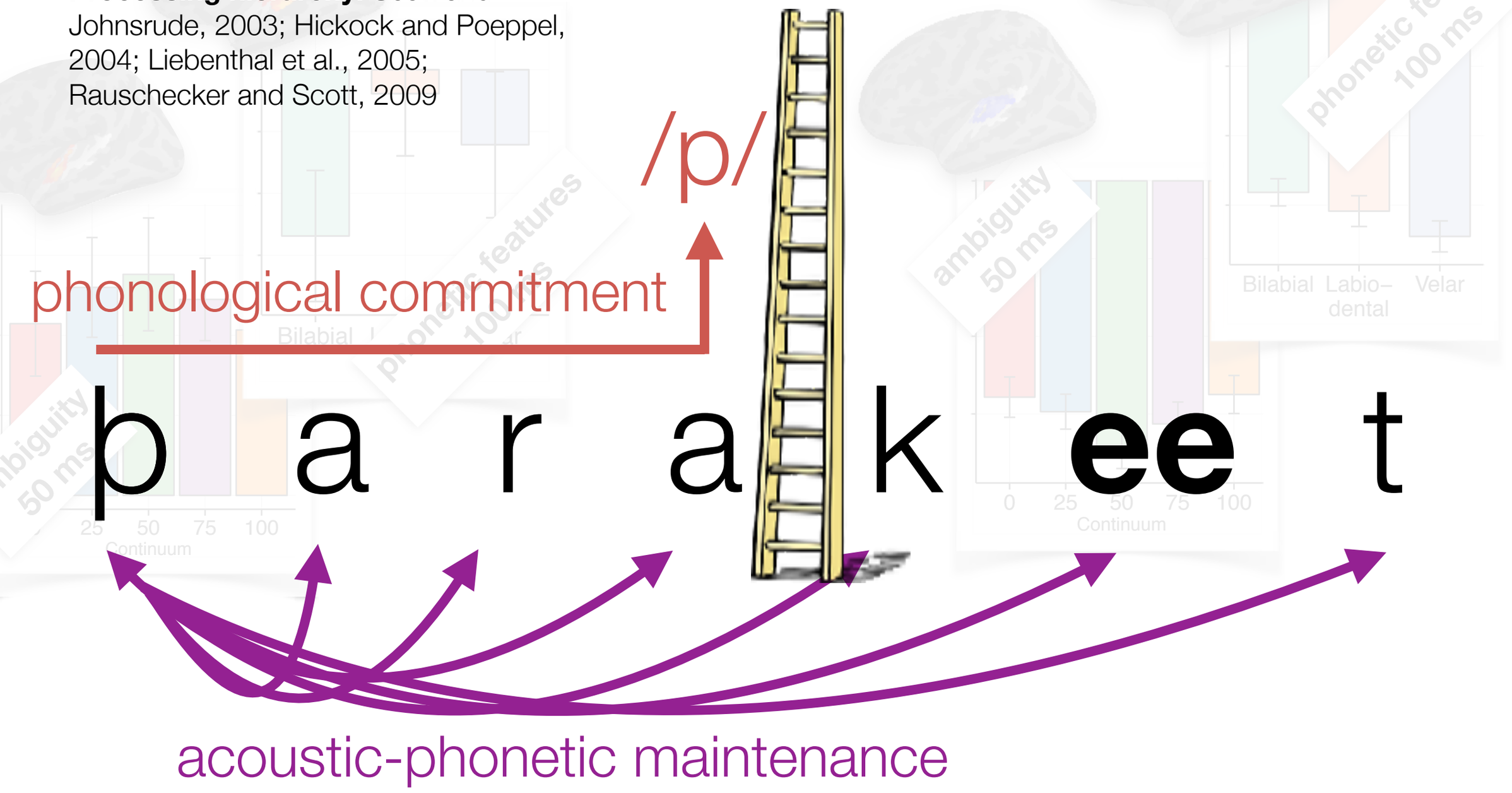


Interpretation



Interpretation

Processing hierarchy: Scott and Johnsrude, 2003; Hickock and Poeppel, 2004; Liebenthal et al., 2005; Rauschecker and Scott, 2009



Interpretation

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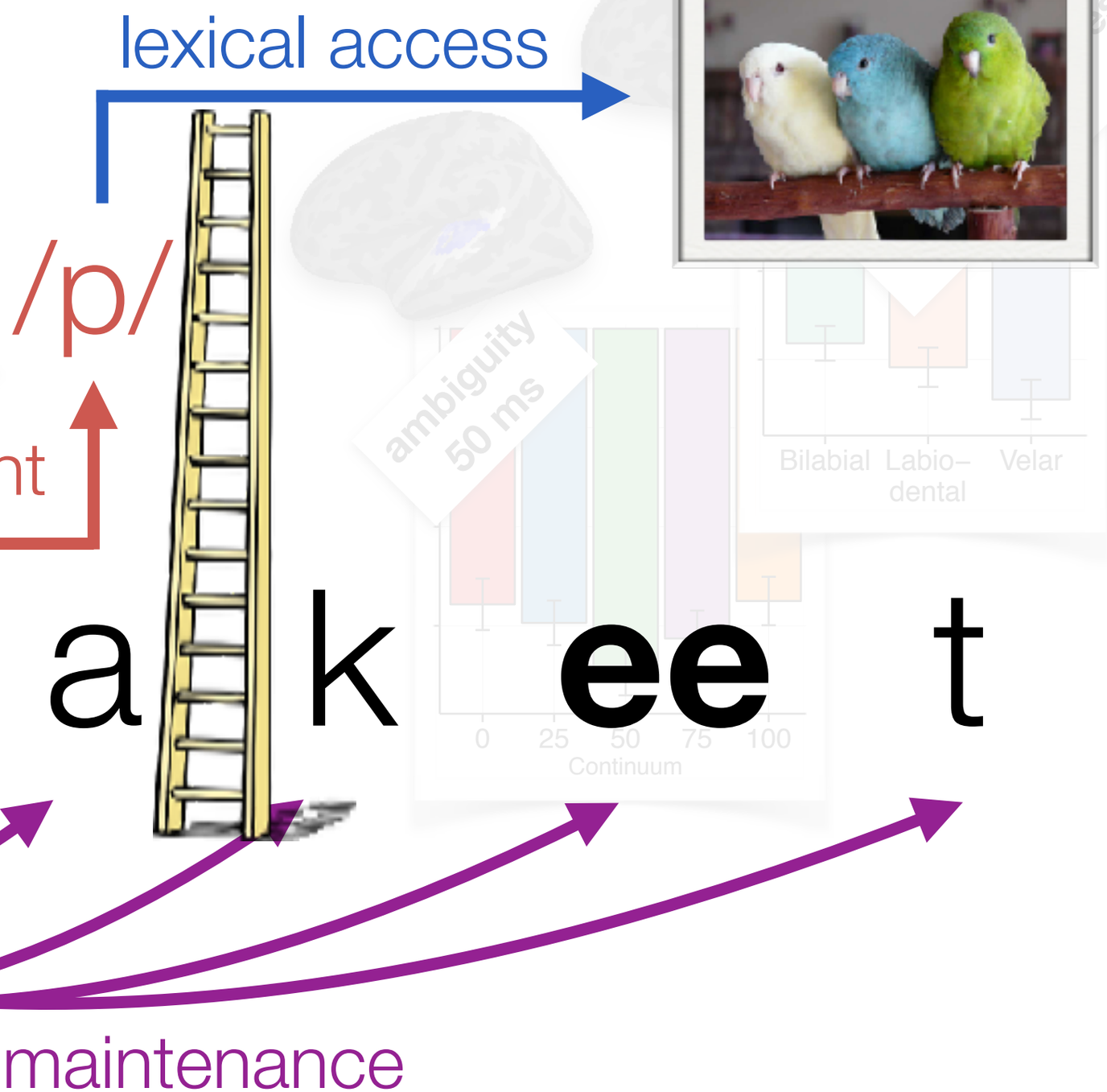
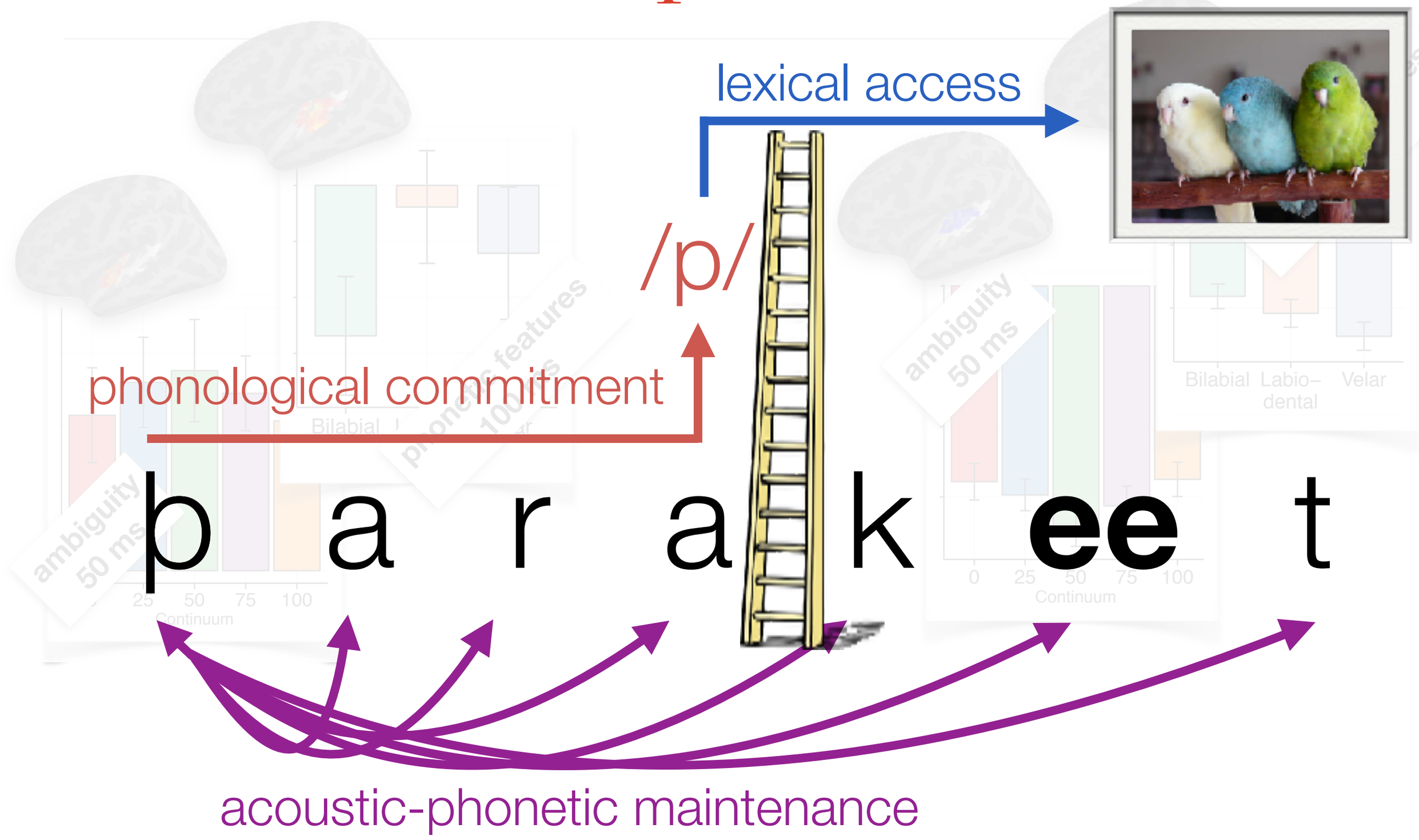


Interpretation

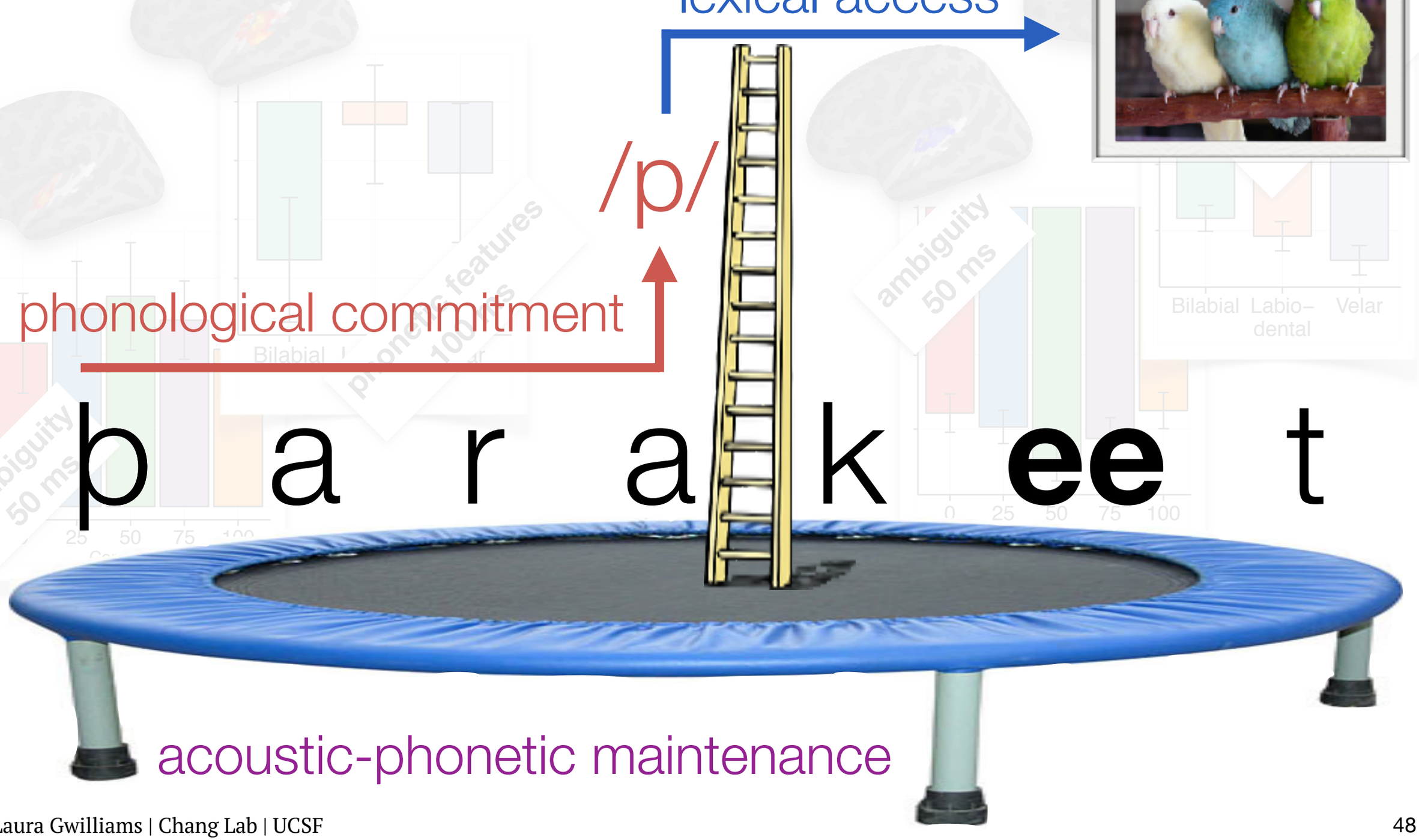


Interpretation

lexical access

/p/

phonological commitment



p a r a k **ee** t

acoustic-phonetic maintenance

Interpretation

Processing is not purely feedforward, or feed "up": TRACE model: McClelland and Elman, 1986; McMurray et al. 2009. cf. MERGE: Norris et al. 2000

lexical access

/p/

phonological commitment

p a r a k **ee** t

acoustic-phonetic maintenance

Interpretation

lexical access

/p/

prediction-error learning

phonological commitment

b a r a k **ee** t

acoustic-phonetic maintenance

With big thanks to:

- My supervisors, **Alec Marantz** and **David Poeppel**, as well as everyone in the **Neuroscience of Language Lab** and **Poeppel Lab**!

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Thank you!

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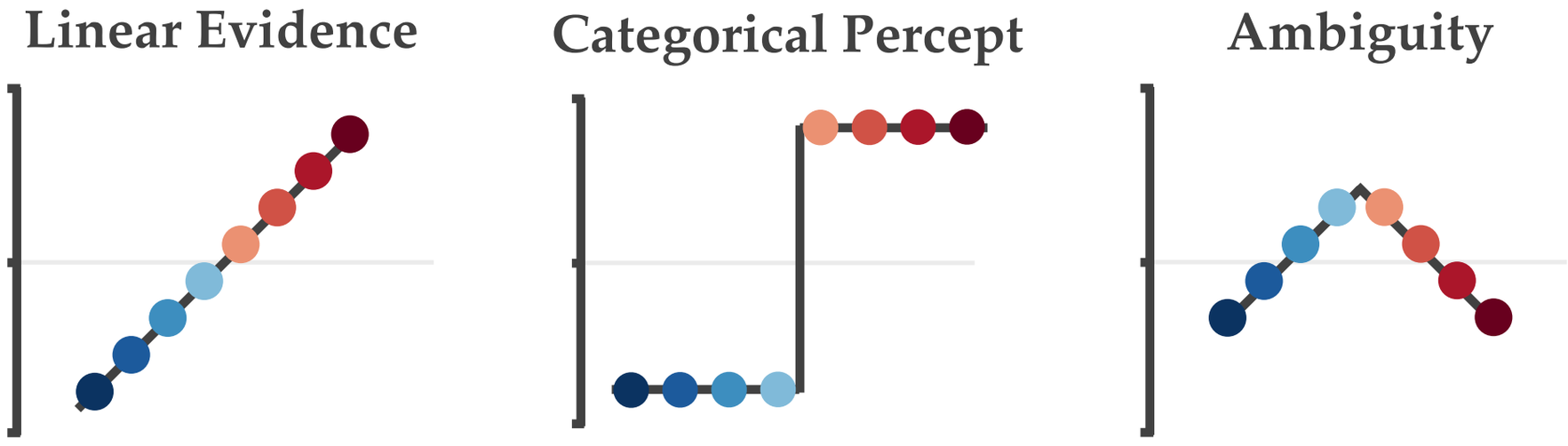
Predictive Coding



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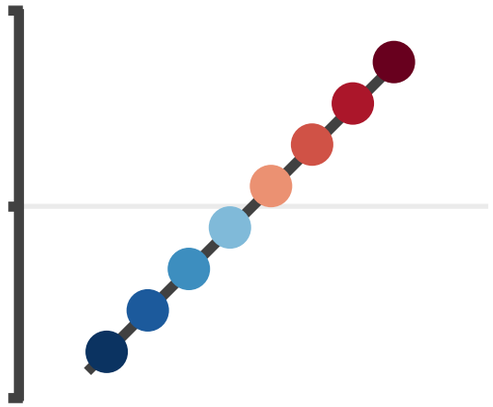
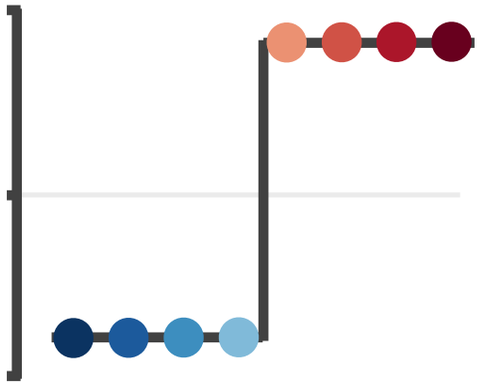
Predictive Coding

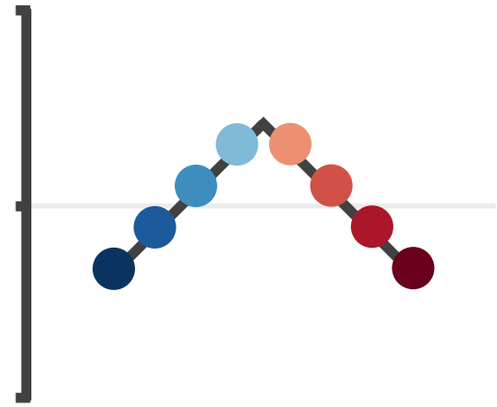
Linear Evidence



Categorical Percept

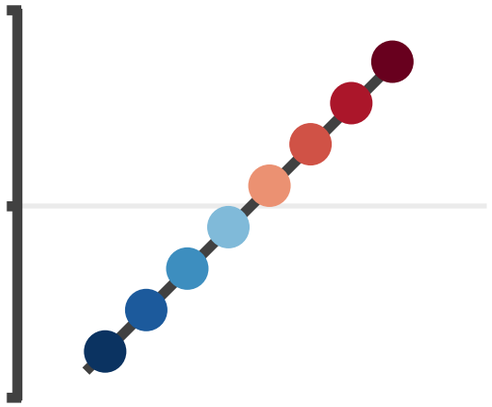


Ambiguity

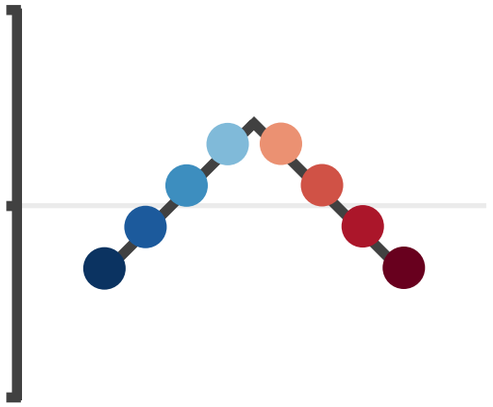


Neutralisation

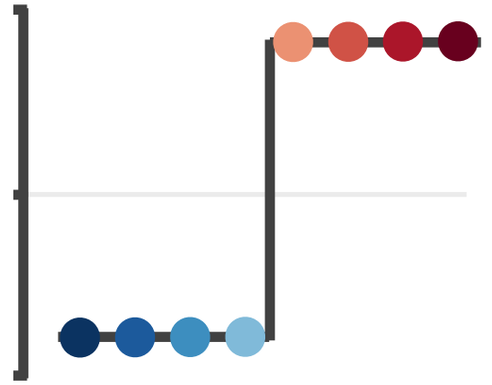
Linear Evidence



Ambiguity



Categorical Percept



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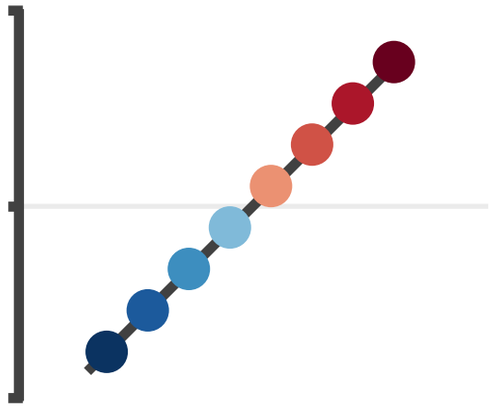
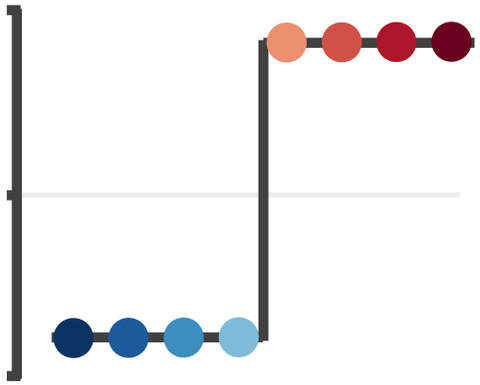
Predictive Coding

Linear Evidence



Categorical Percept



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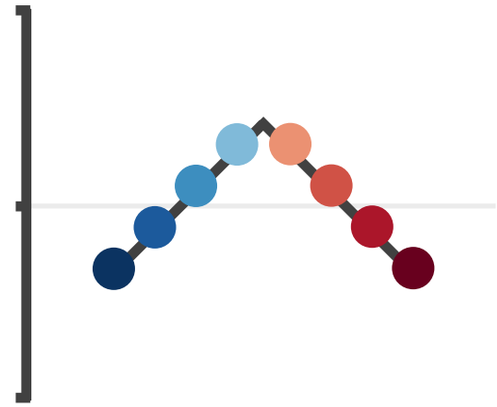
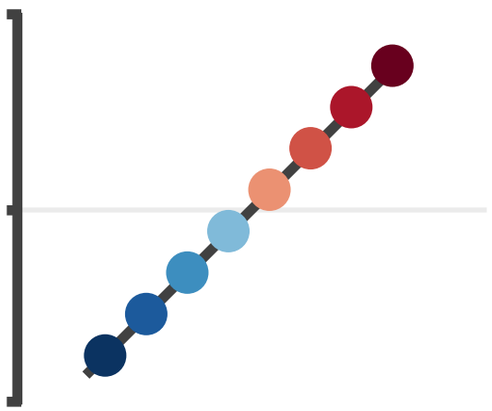


Neutralisation

Linear Evidence



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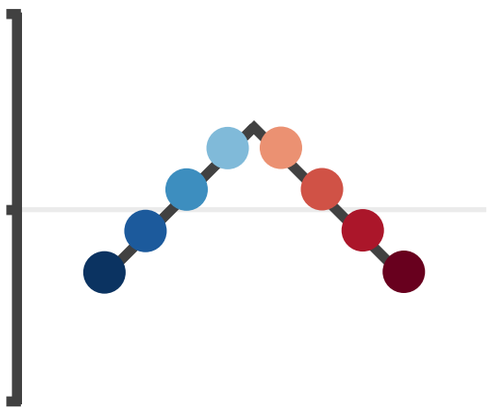
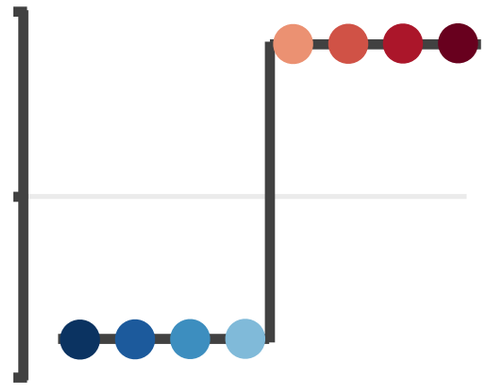
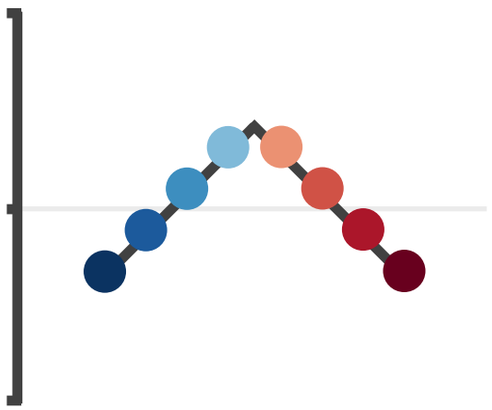


Categorical Percept

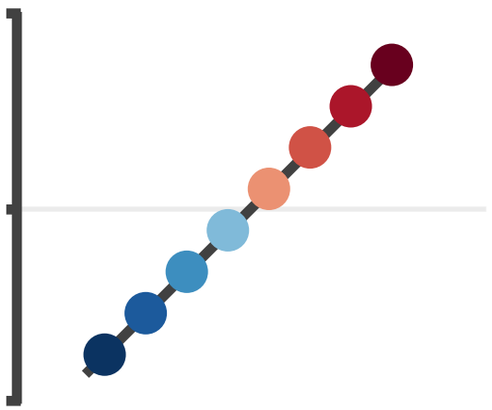


Cut-through connection

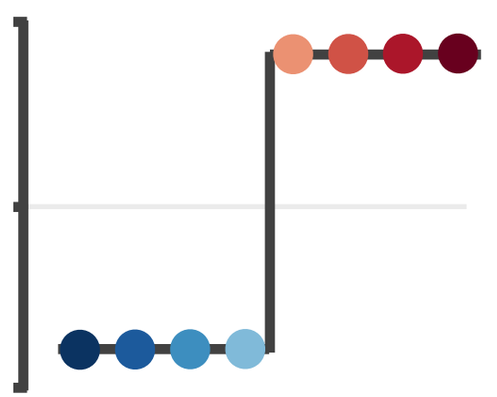
Ambiguity



Linear Evidence



Categorical Percept



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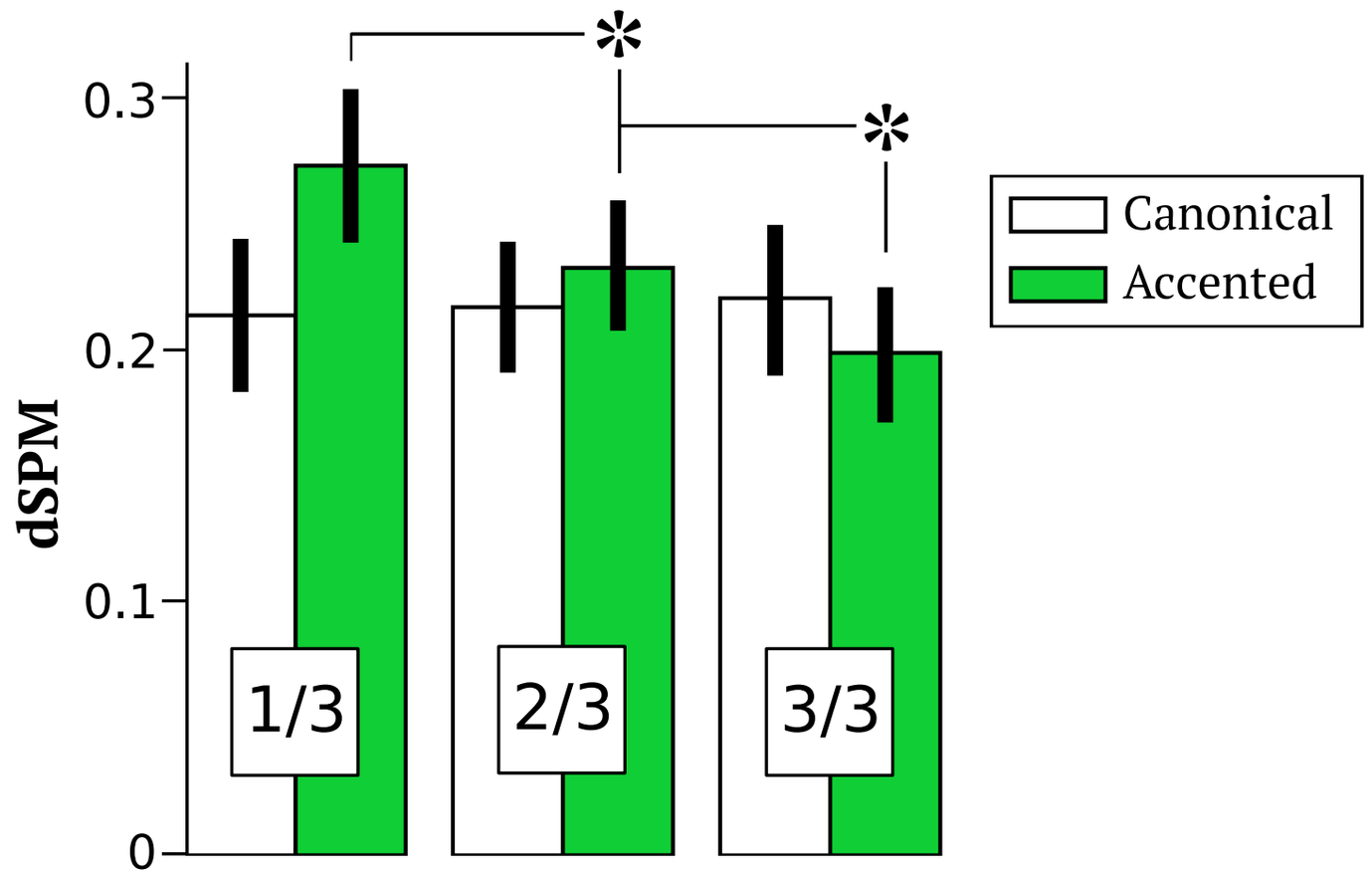
Interpretation

Interpretation

- Attunement is proposed to involve **re-tuning perceptual boundaries** between phonological categories (Norris et al., 2003; Kraljic and Samuel, 2005, 2006, 2007; Maye et al., 2008; see Samuel & Kraljic, 2009 for a review)

Interpretation



- Attunement is proposed to involve **re-tuning perceptual boundaries** between phonological categories (Norris et al., 2003; Kraljic and Samuel, 2005, 2006, 2007; Maye et al., 2008; see Samuel & Kraljic, 2009 for a review)

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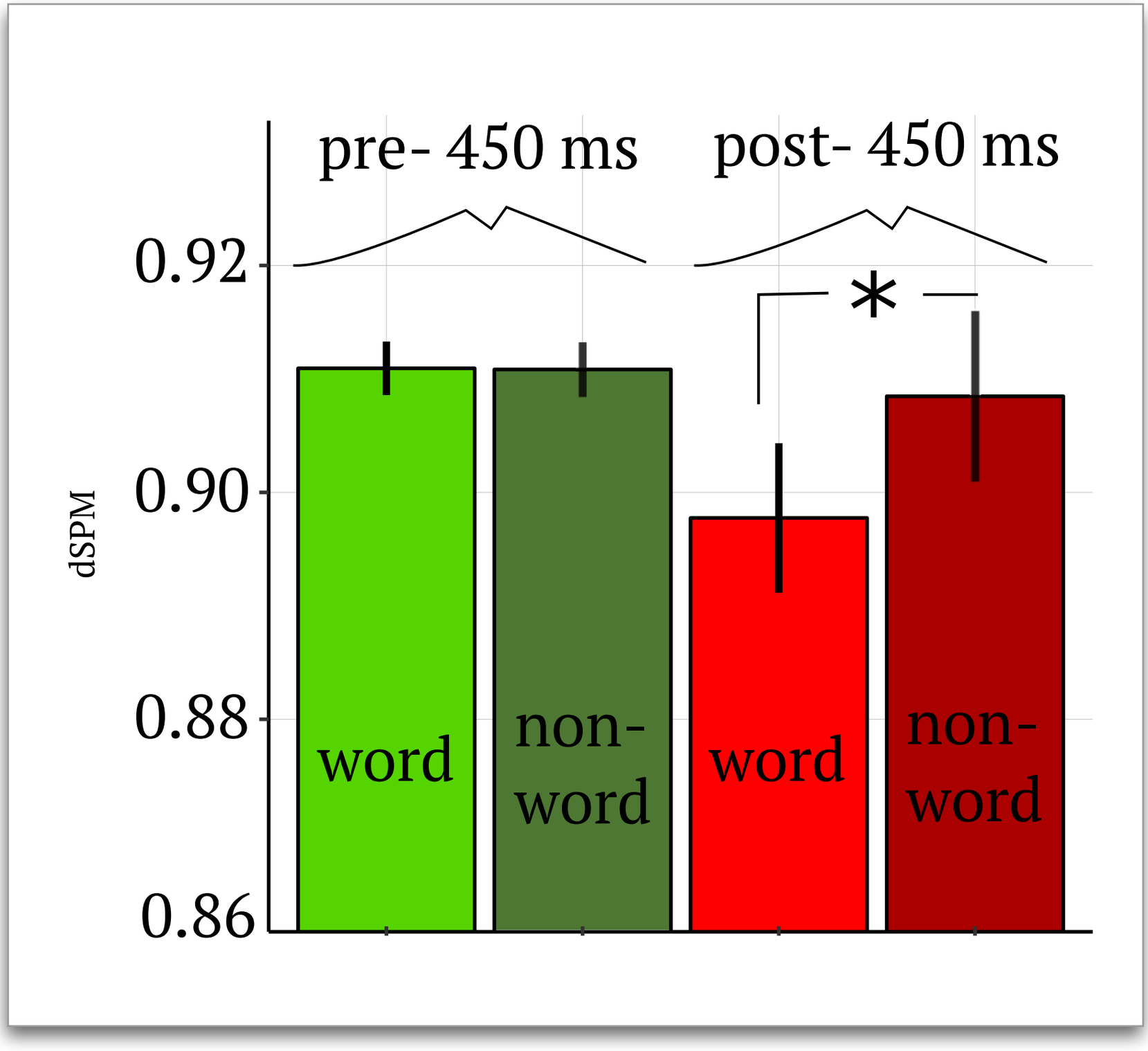

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