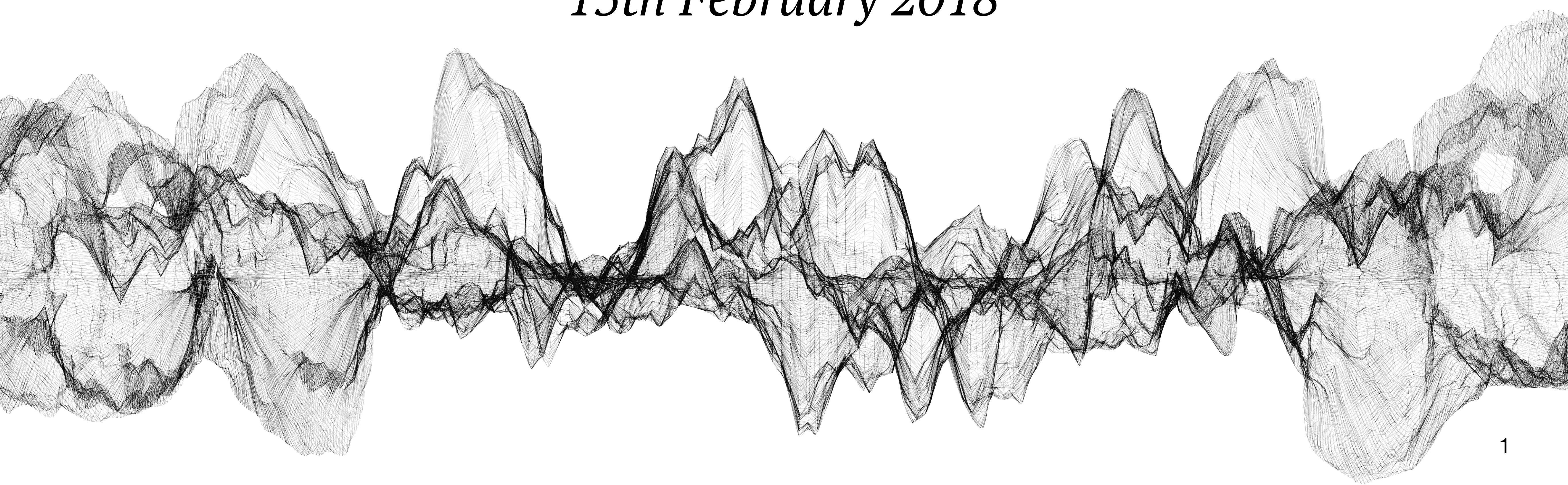
NEW YORK UNIVERSITY

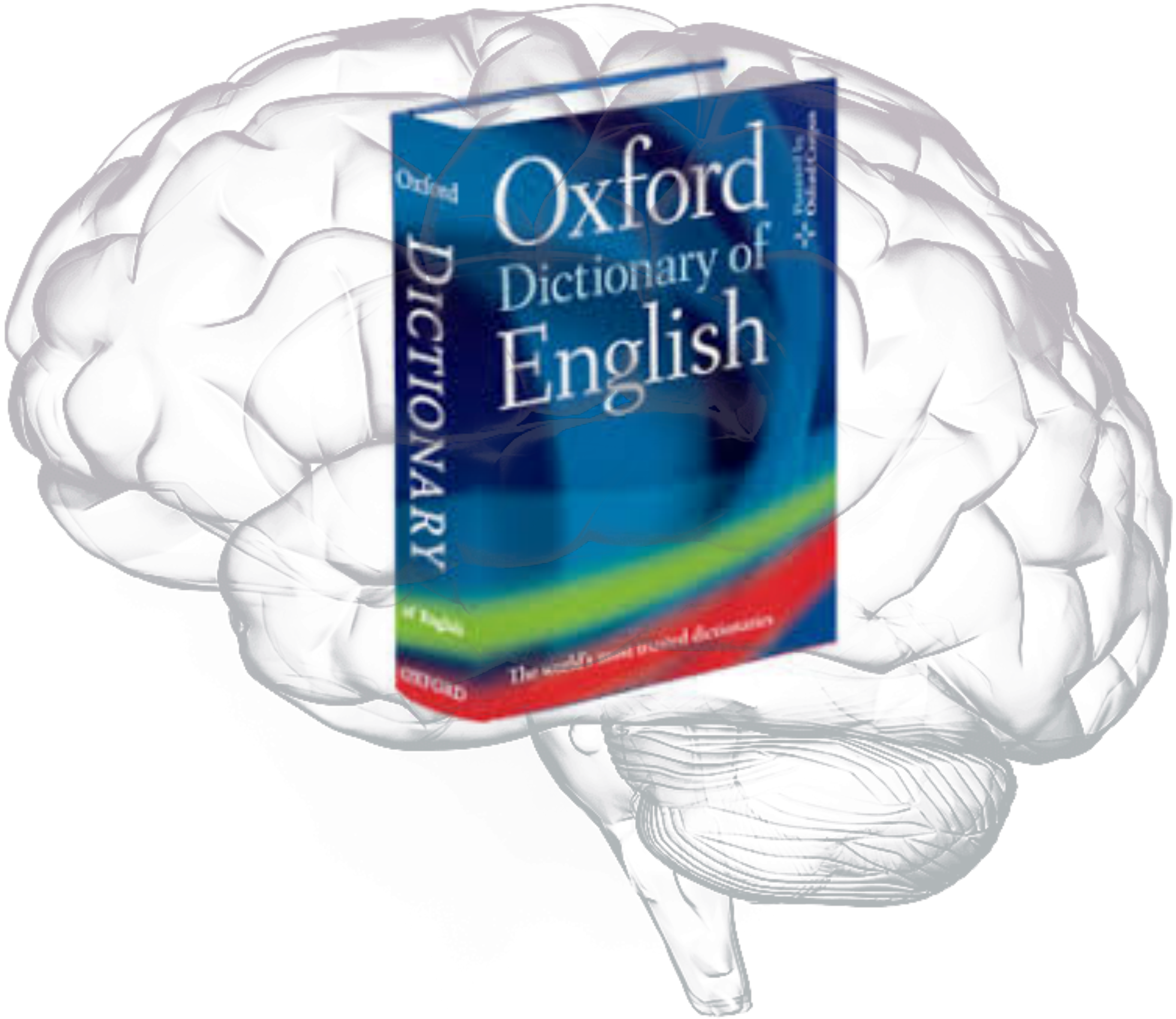
Back to the future: Investigating the neural mechanisms supporting speech comprehension

Laura Gwilliams

15th February 2018



How is language organised in the brain?



What computations are performed?

What computations are performed?

the fat cat disappeared

What computations are performed?

the fat cat disappeared

Speech is fast

Magneto-encephalography (MEG)

record

Magneto-encephalo$\boxed{\text{graphy}}$ (MEG)

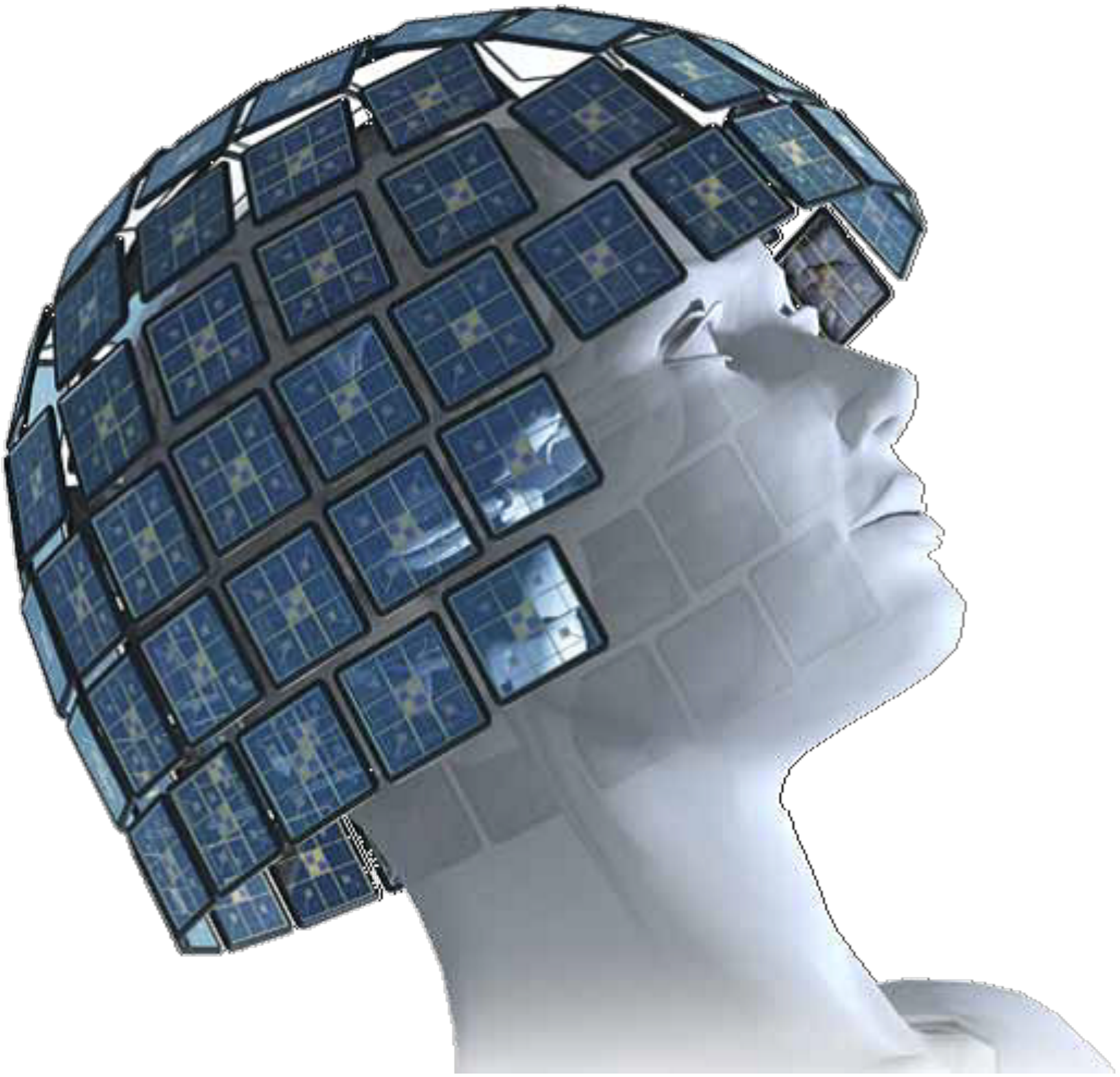
magnetic

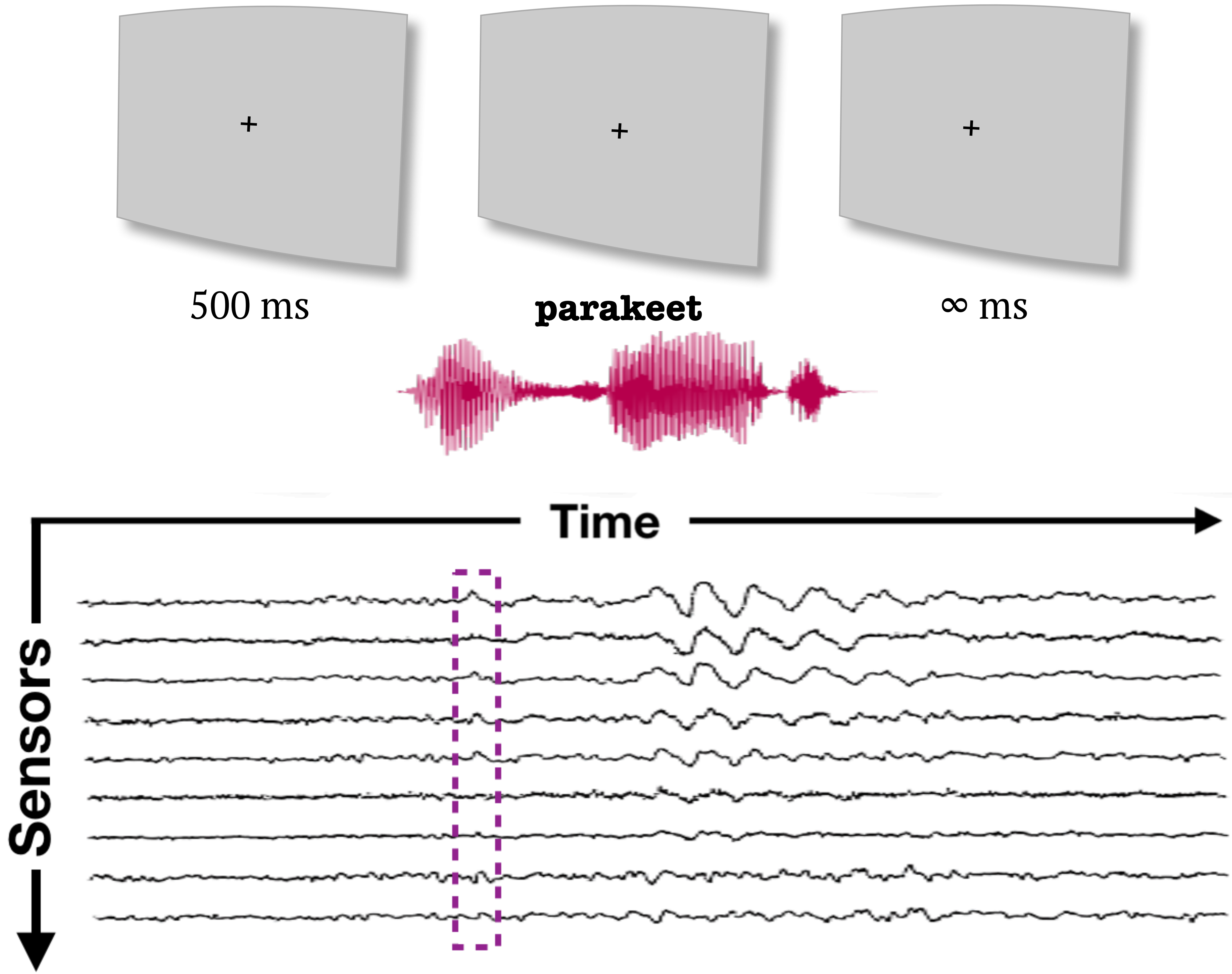
record

Magneto-encephalography (MEG)

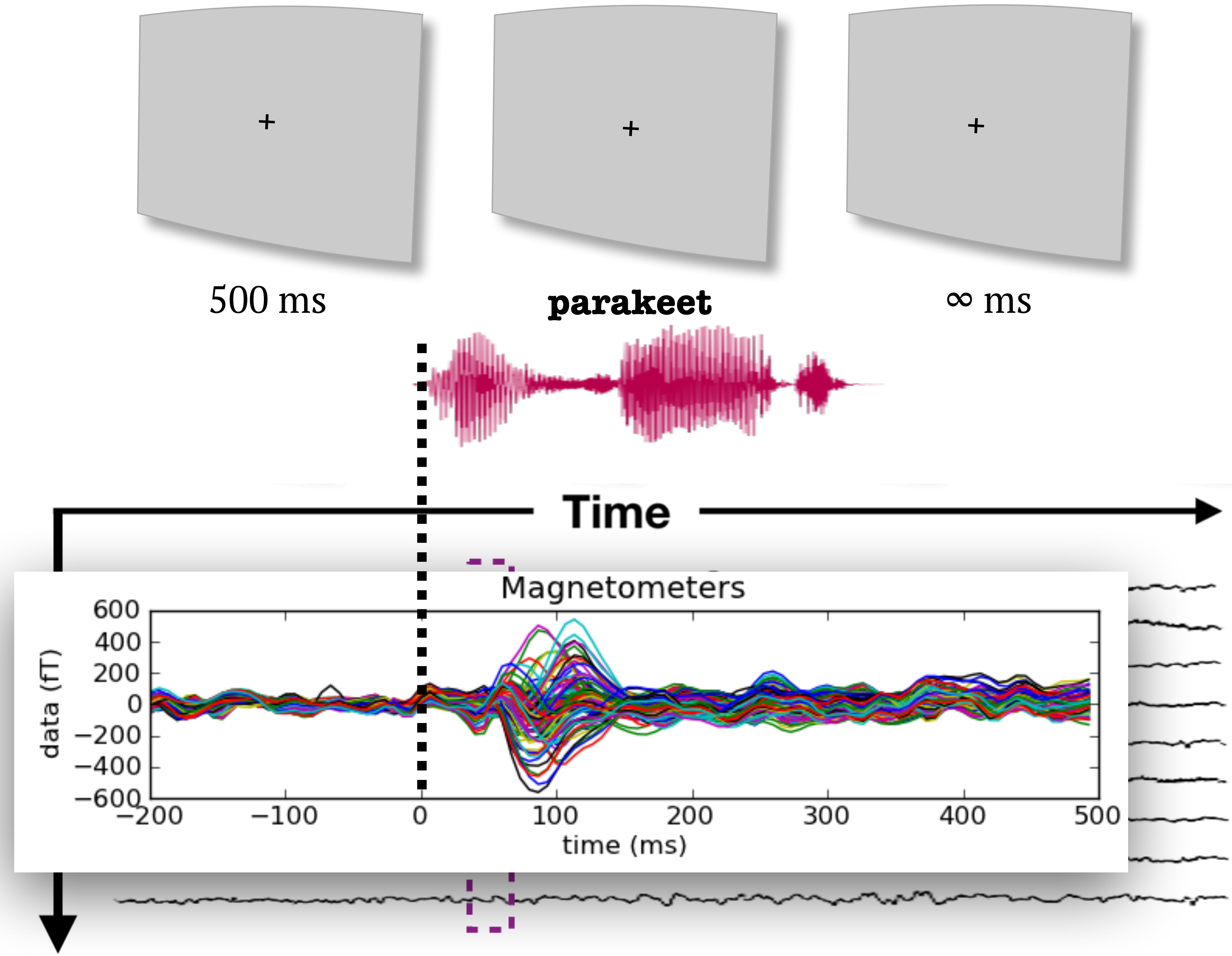
magnetic brain record

Magneto-encephalography (MEG)

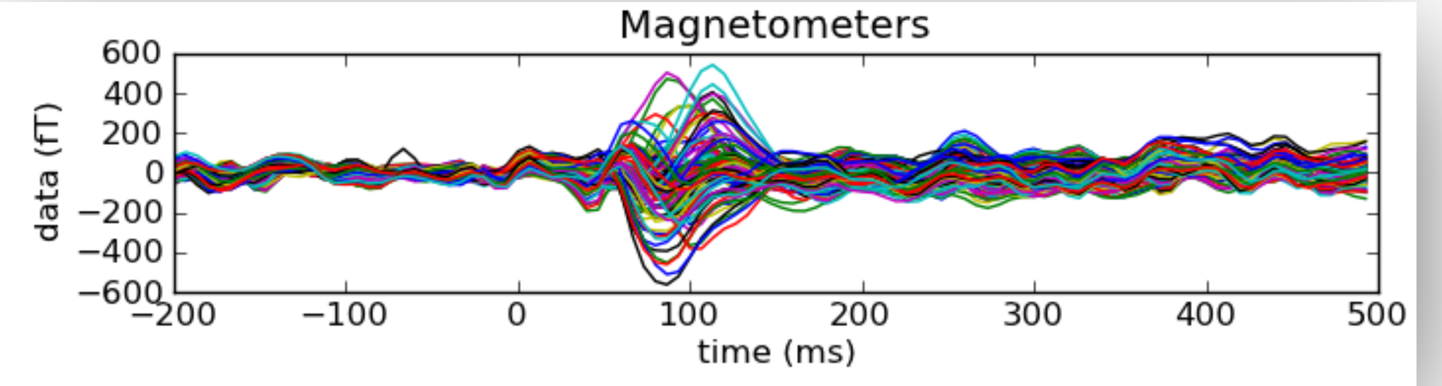


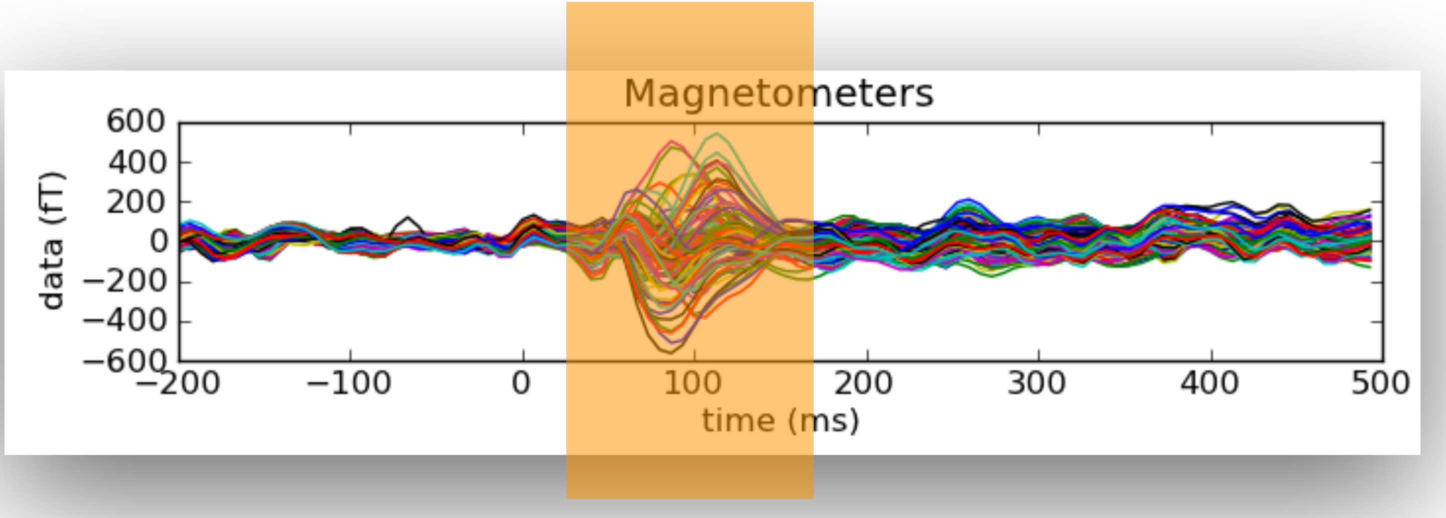


500 ms
parakeet
∞ ms
Time
Sensors

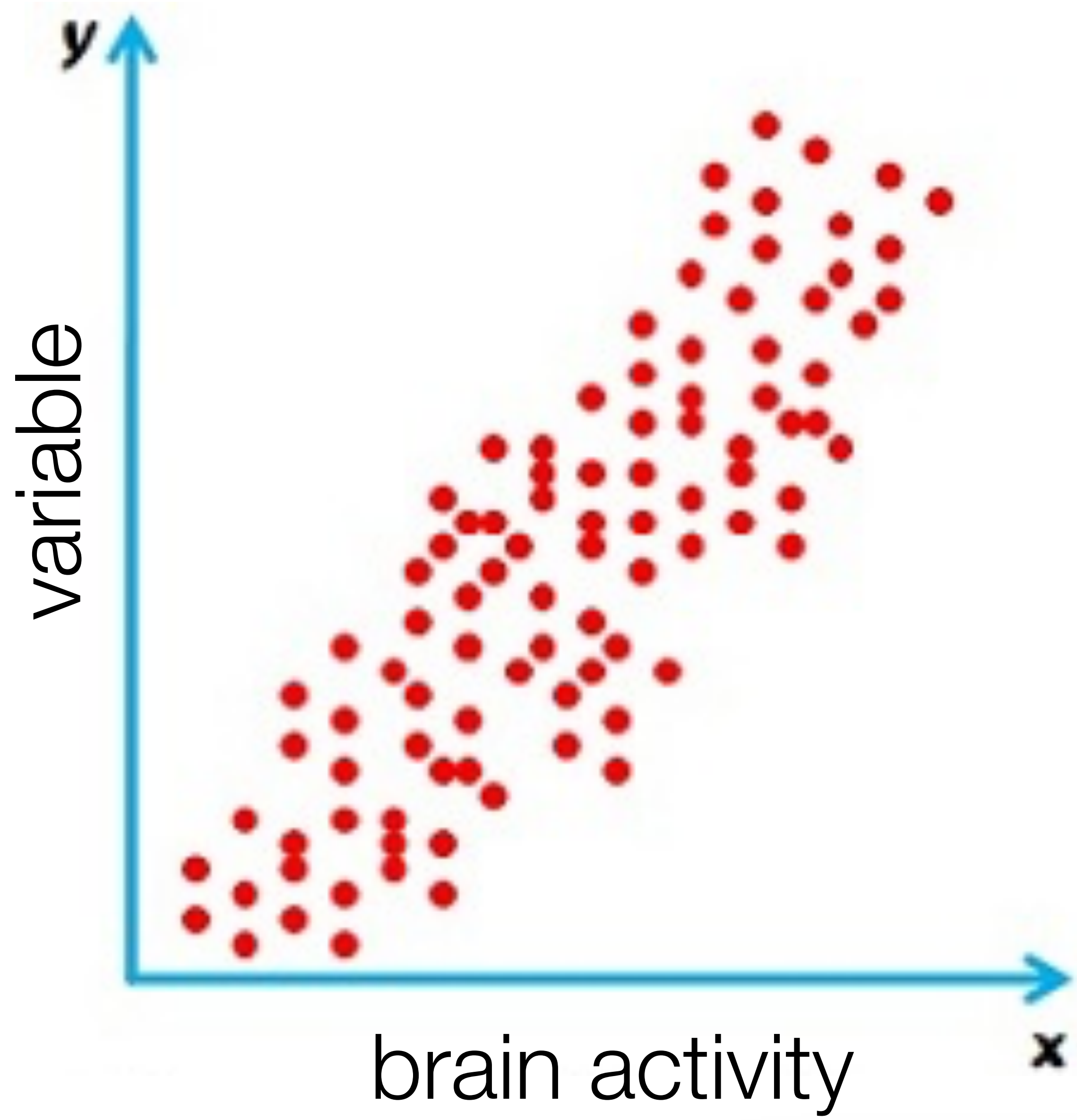


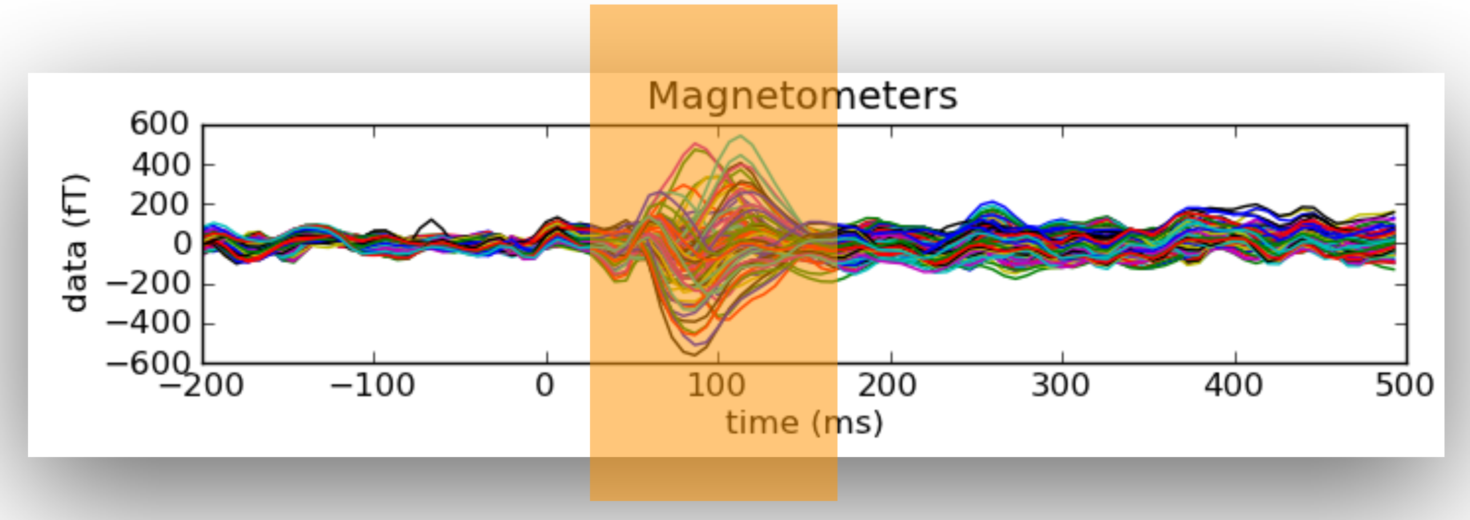
500 ms
parakeet
∞ ms
Time
Magnetometers
data (fT)
time (ms)
600
400
200
0
−200
−400
−600
−200
−100
0
100
200
300
400
500


Magnetometers
data (fT)
600
400
200
0
−200
−400
−600
−200
−100
0
100
200
300
400
500
time (ms)

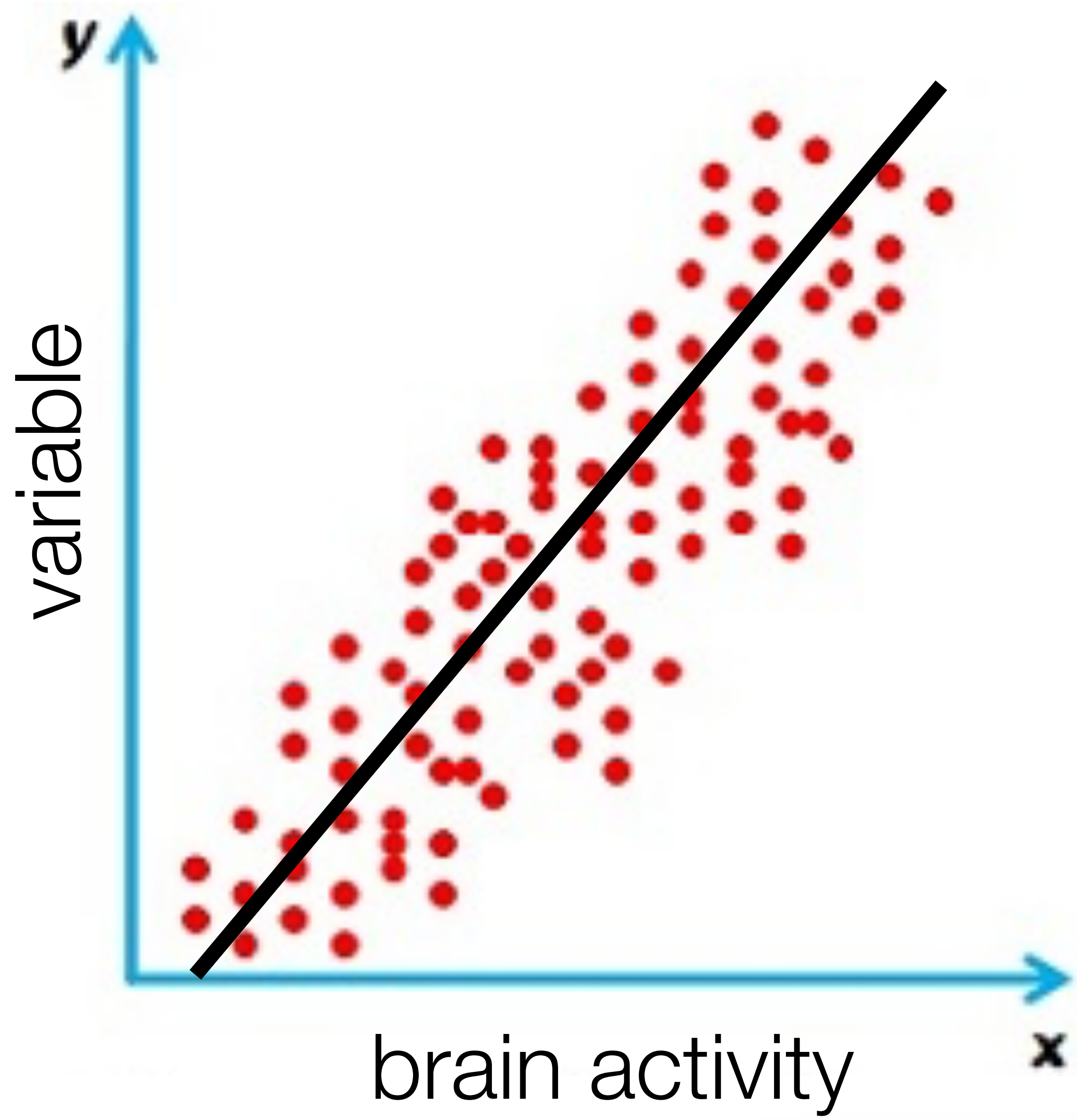


Magnetometers
600
400
200
0
−200
−400
−600
data (fT)
−200
−100
0
100
200
300
400
500
time (ms)

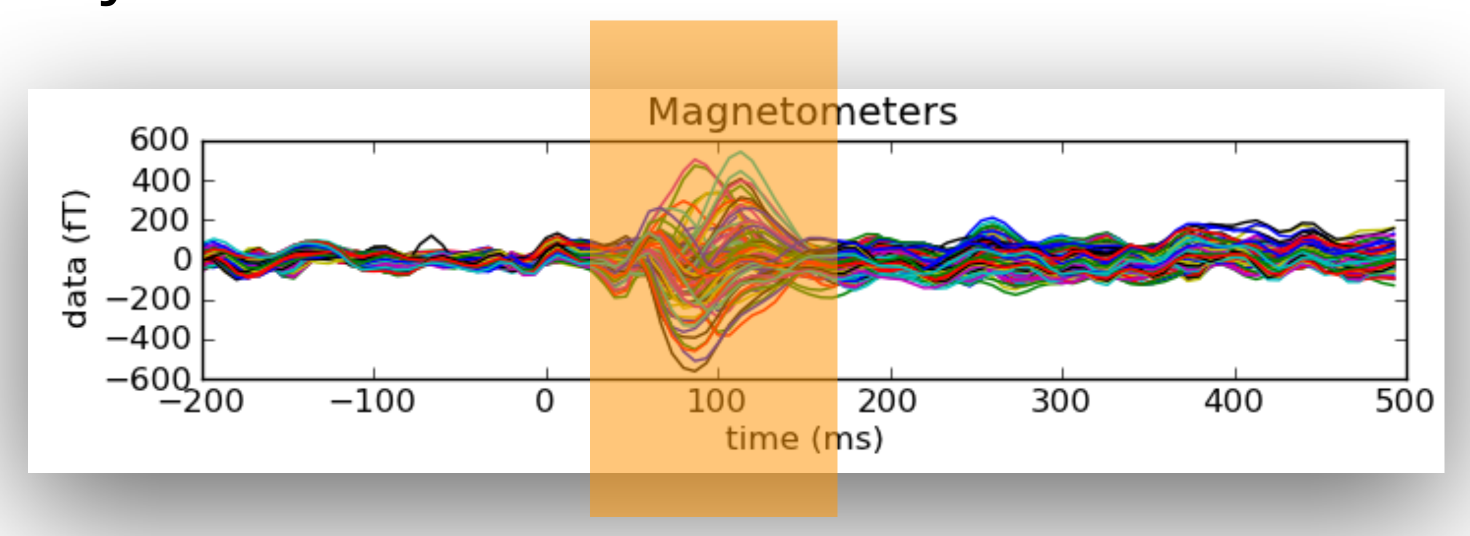

y
variable
brain activity
x


Magnetometers
data (fT)
600
400
200
0
−200
−400
−600
−200
−100
0
100
200
300
400
500
time (ms)

Regression



y
variable
x
brain activity



Magnetometers
600
400
200
0
−200
−400
−600
data (fT)
−200
−100
0
100
200
300
400
500
time (ms)

Predictive Feedforward Mechanisms

Q1: *How are words neurally encoded?*

Gwilliams & Marantz (2015) **Brain & Language**

How are words neurally encoded?

As whole words

As morphemes

Some combination, perhaps dependant upon frequency

How are words neurally encoded?

As whole words disappeared

As morphemes

Some combination, perhaps dependant upon frequency

How are words neurally encoded?

As whole words disappeared

As morphemes dis appear ed

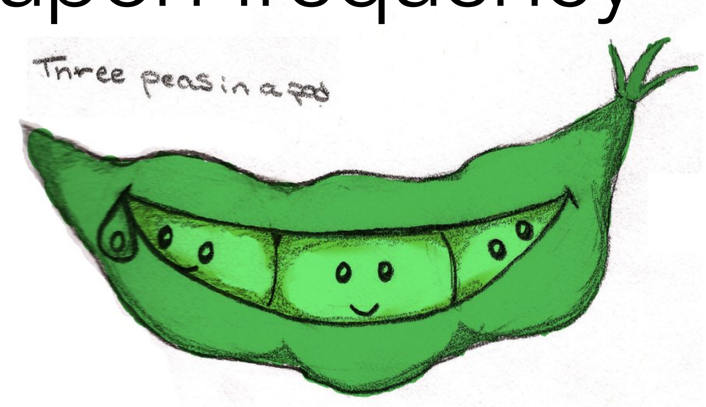
Some combination, perhaps dependant upon frequency

How are words neurally encoded?

As whole words disappeared

As morphemes dis appear ed

Some combination, perhaps dependant upon frequency



How are words neurally encoded?

As whole words **disappeared**

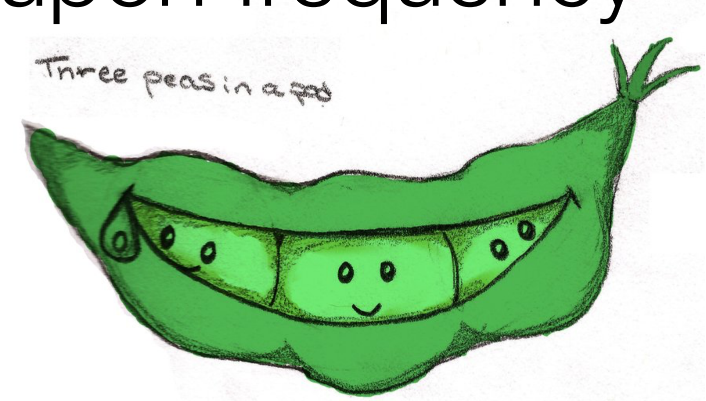
Visual: Butterworth, 1983; Janssen, Bi & Caramazza, 2008; Norris & McQueen, 2008

As morphemes **dis appear ed**

Visual: Taft & Forster, 1975; 1976; Cutler & Norris, 1988; Marslen-Wilson, Tyler, Waksler & Older, 1994; Pinker & Ullman, 2002

Some combination, perhaps dependant upon frequency

Visual: Coltheart, Rastle, Perry, Langdon & Ziegler, 2001



biggest

ballet

blind

bath

baptists

bond

barricade

ballots

booking

b

break

band

bound

black

boasts

balance

backed

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

ballet

bath

baptists

barricade

ballots

b a

band

balance

backed

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

ballet

ballots

b a l

balance

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

ballots

b a l ə

balance

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

b a l ə n

balance

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

Arabic Morphology

Arabic Morphology

K A T A B A

Arabic Morphology

K A T A B A

semantic root { ktb }

Arabic Morphology

K A T A B A

kitab

semantic root { ktb }

katib

Arabic Morphology

syntactic pattern { _a_a_a }

KATABA

kitab

semantic root { ktb }

katib

Arabic Morphology

syntactic pattern { _a_a_a }

- perfective verb
- active voice
- third person

K A T A B A

kitab

semantic root { ktb }

katib

kafaqa

kunuta

kusuna

kiyana

kataba

kubr

kabara

kammas

katwa

k

kirniq

kalaba

kuda’a

kazq

karij

katama

kasira

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

kafaqa

kataba

kabara

kammas

katwa

k a

kalaba

kazq

karij

katama

kasira

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

kataba

katwa

k a t

katama

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

kataba

k a t a

katama

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

kataba

k a t a b

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

kfq knt ksn

kyn ktb

kbr

kbr ktw

kms

k

knq klb

kd

kzq

krj

ktm ksr

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

ktb

ktw

k - t

ktm

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

ktb

k - t - b

based on the **Cohort model** of spoken word recognition: Marslen-Wilson, 1978

Quantifying different model predictions

Word probability: Considers all preceding phonemes

$$P(b|kata)$$

Morphological probability: Considers just root phonemes

$$P(b|kt)$$

Quantifying different model predictions

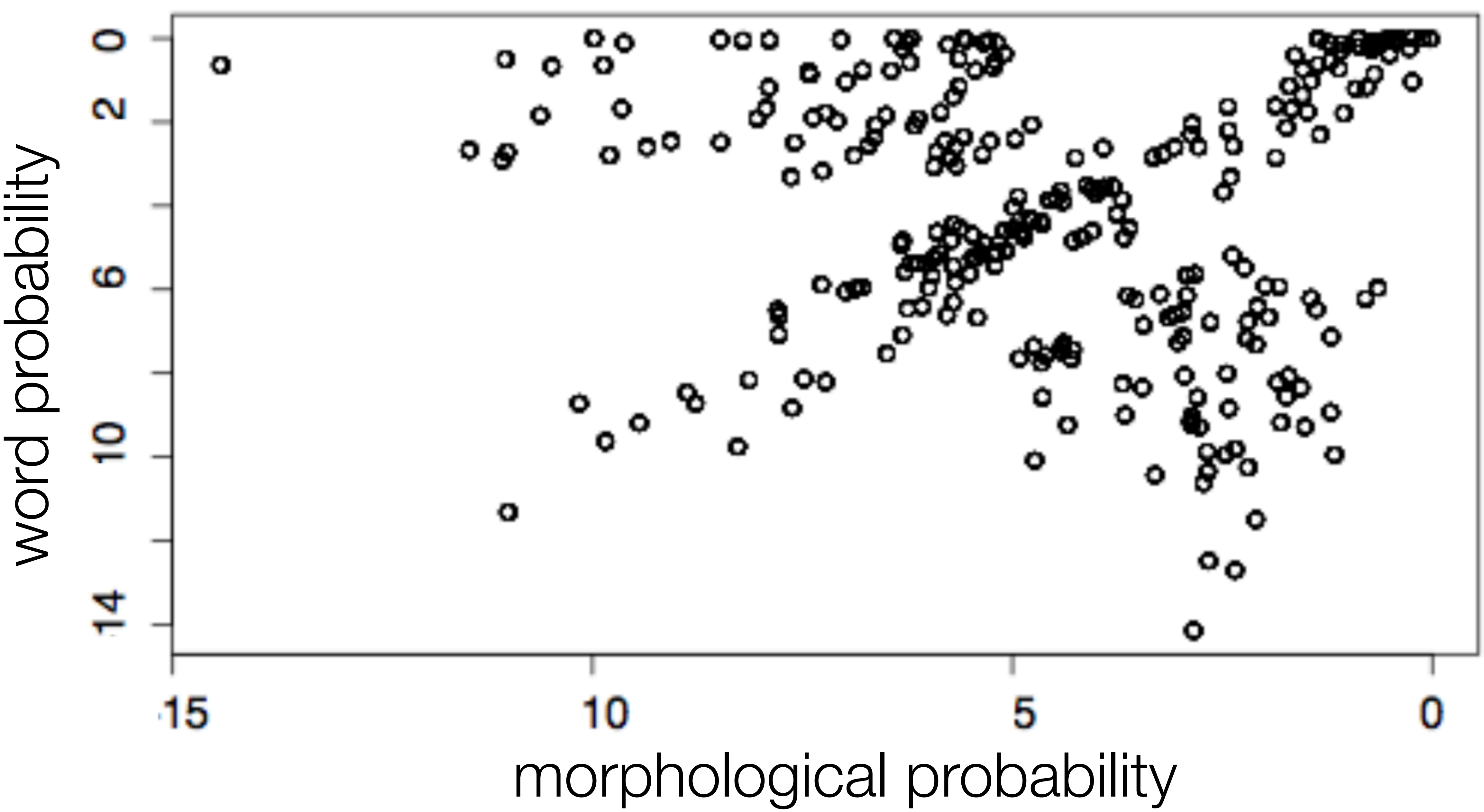
Linear Surprisal: Considers all preceding phonemes

$$-log(P(b|kata))$$

Morphological Surprisal: Considers just root phonemes

$$-log(P(b|kt))$$

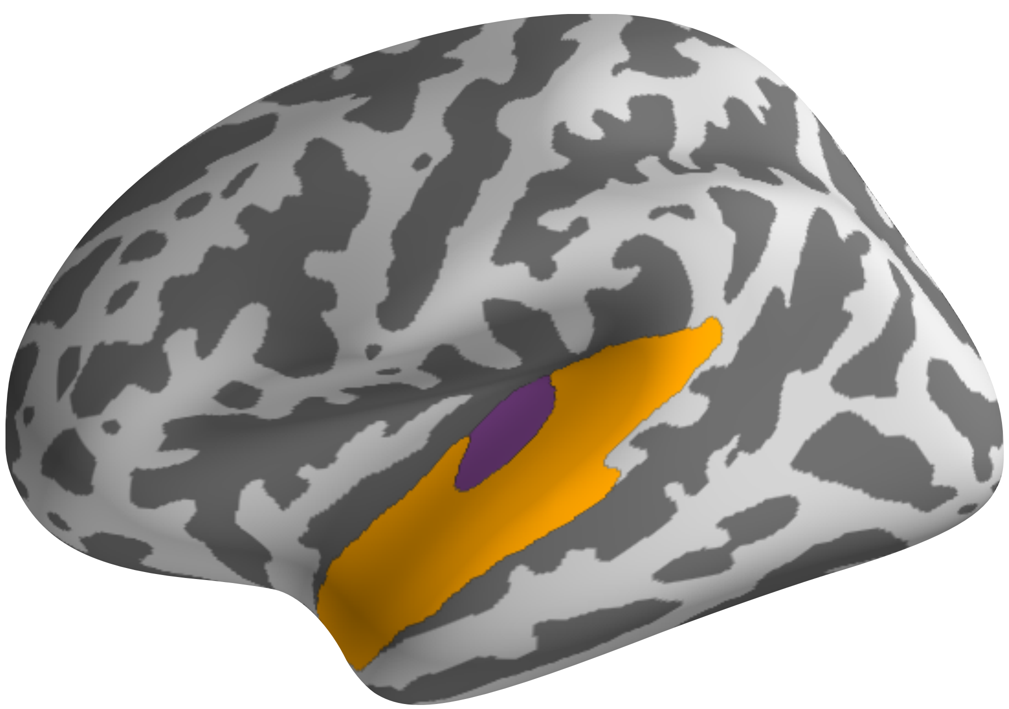
Features orthogonalised by design



Auditory cortex is sensitive to phoneme surprisal

- Activity in transverse temporal gyrus (TTG) and superior temporal gyrus (STG) is modulated by phoneme surprisal

Gagnepain et al., 2010; Ettinger, Linzen & Marantz, 2014

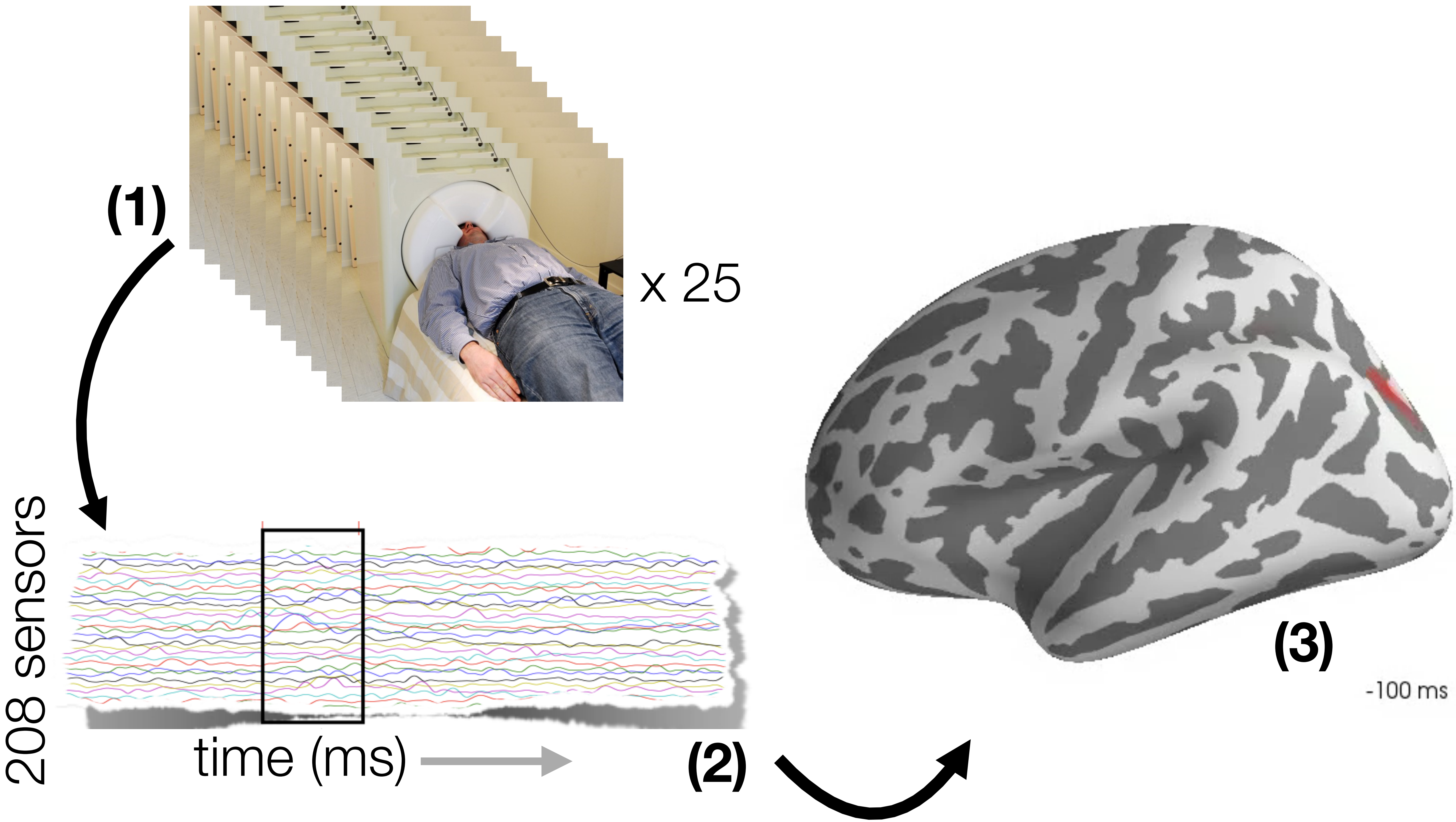


Procedure & Analysis

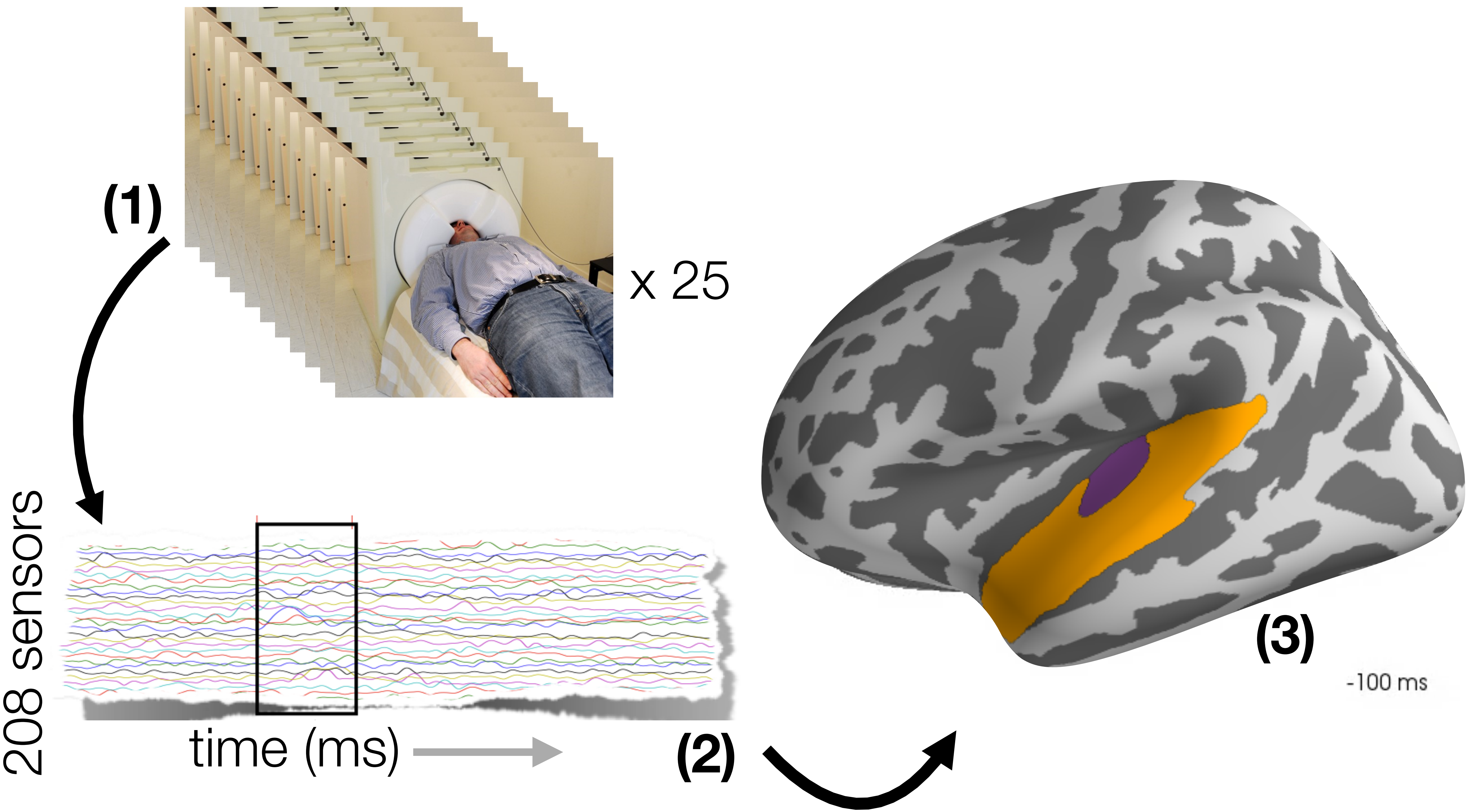
Procedure & Analysis

x 25

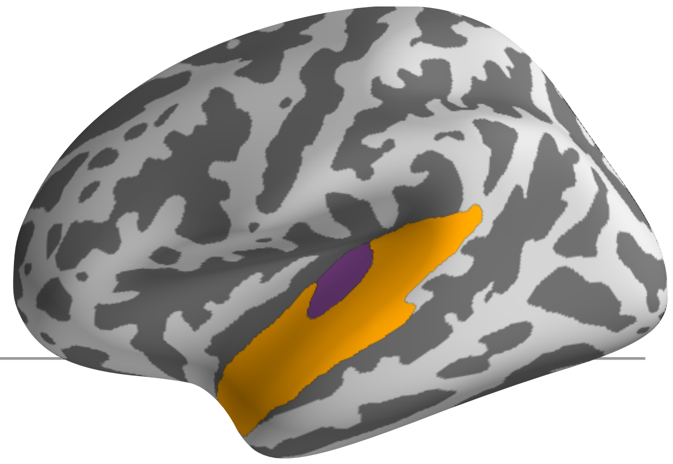
Procedure & Analysis

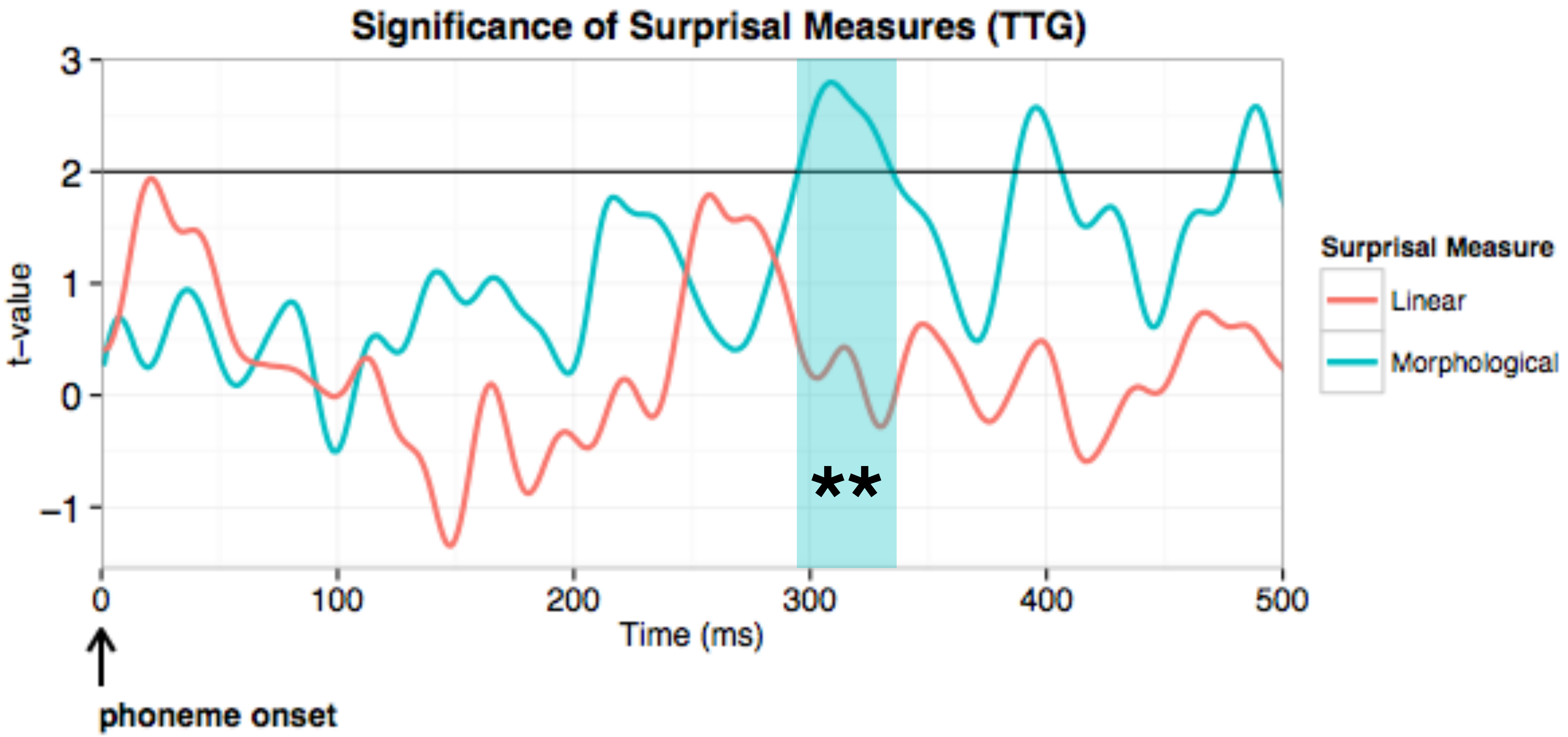


Procedure & Analysis

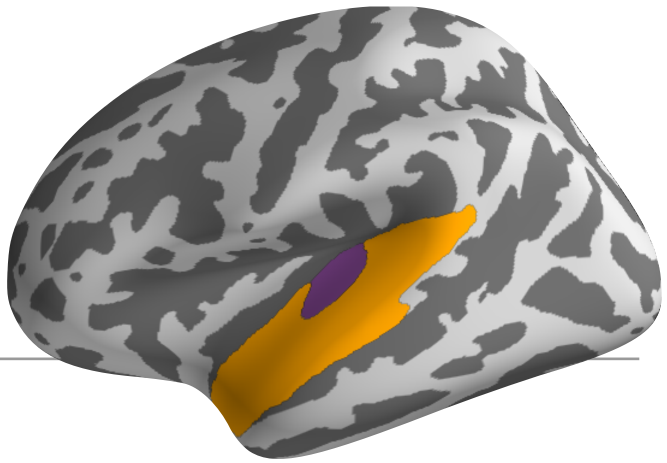


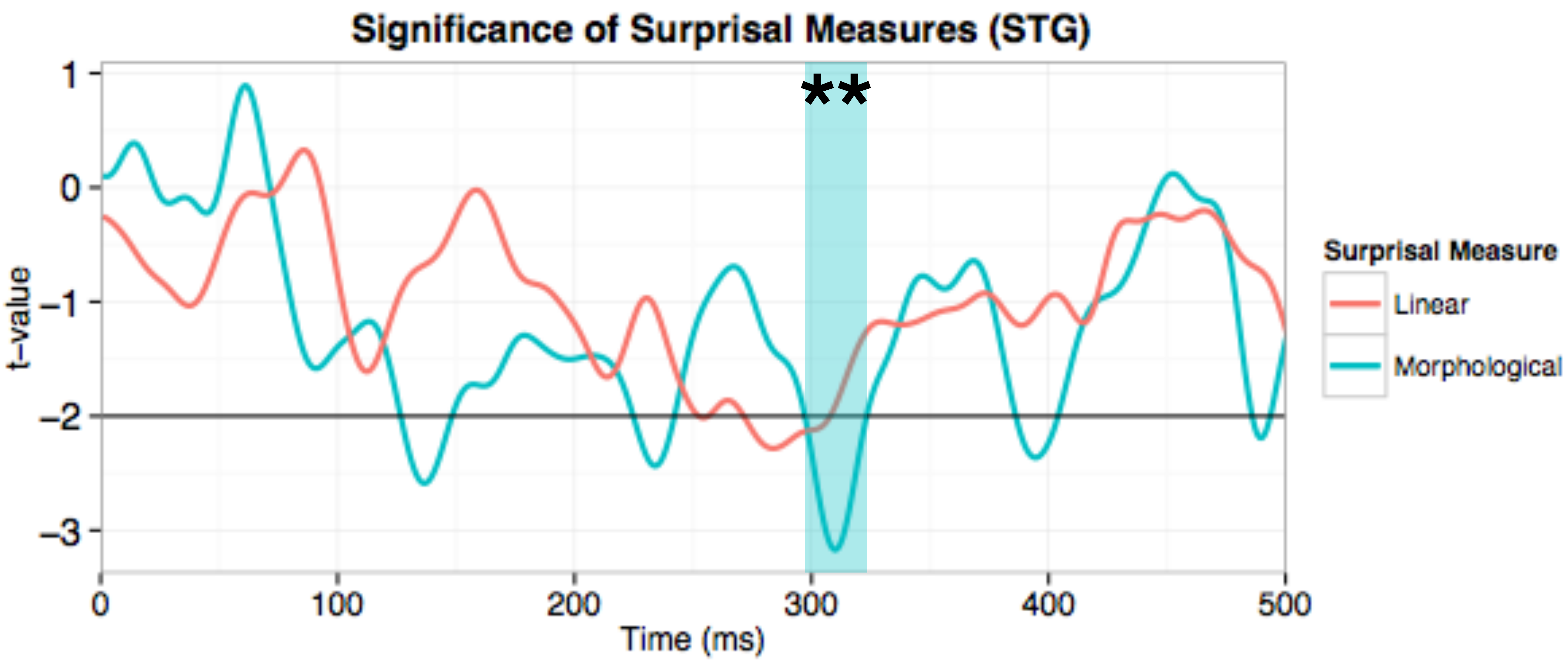
Results




Significance of Surprisal Measures (TTG)
t–value
3
2
1
0
–1
**
0
100
200
300
400
500
Time (ms)
phoneme onset
Surprisal Measure
Linear
Morphological

Results




Significance of Surprisal Measures (STG)
**
1
0
−1
−2
−3
t−value
0
100
200
300
400
500
Time (ms)
Surprisal Measure
Linear
Morphological

Interim conclusion

Interim conclusion

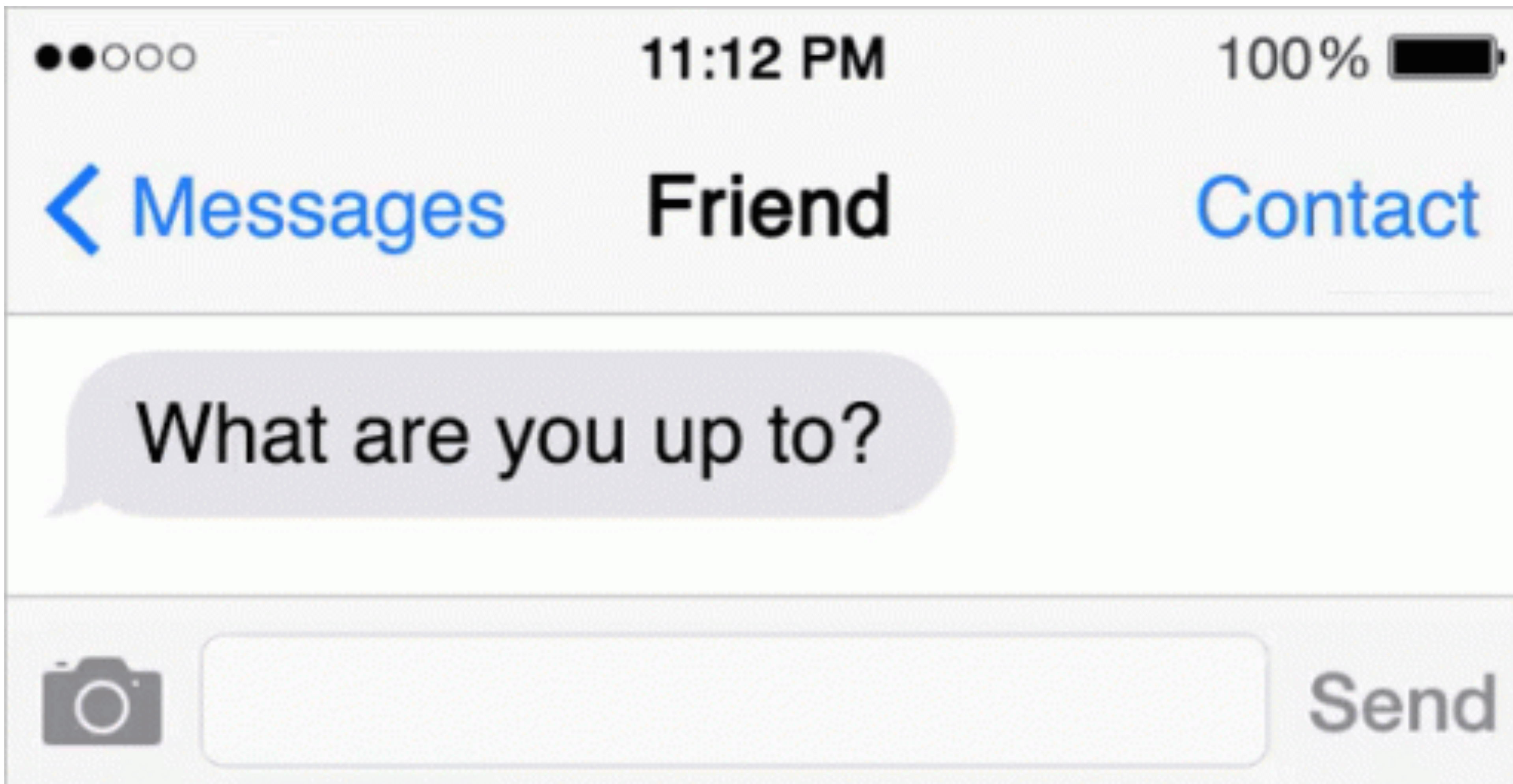
- The brain predicts upcoming phonemes
- Processing is **sensitive to morphological structure**
- Suggests that **the brain encodes morphemes**, at least in addition to lexical representations

Postdictive Feedback Mechanisms

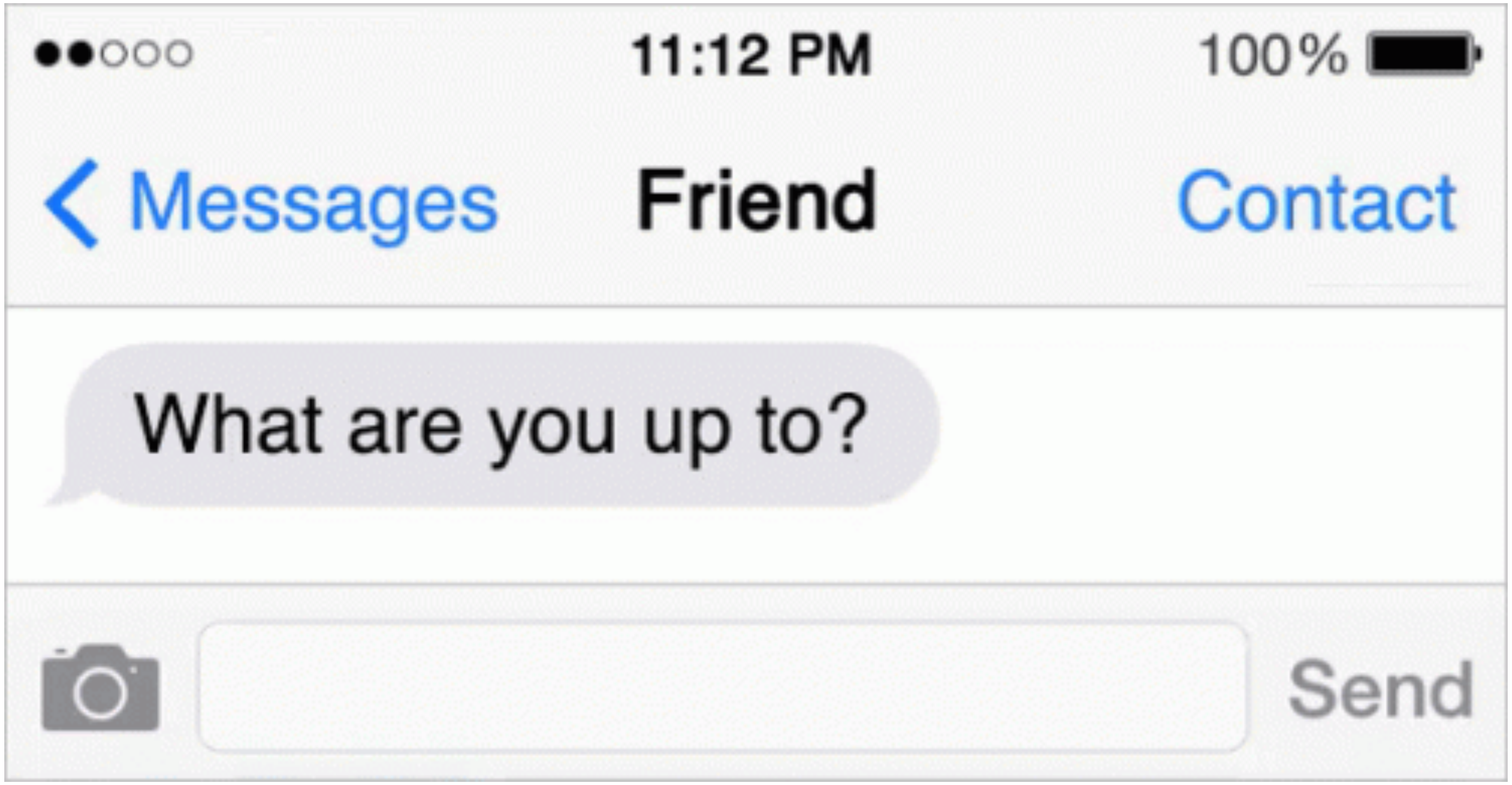
Q2: *How does subsequent context bias phonological perception?*

Gwilliams, Linzen, Poeppel & Marantz (submitted)

Future Influences on Perception

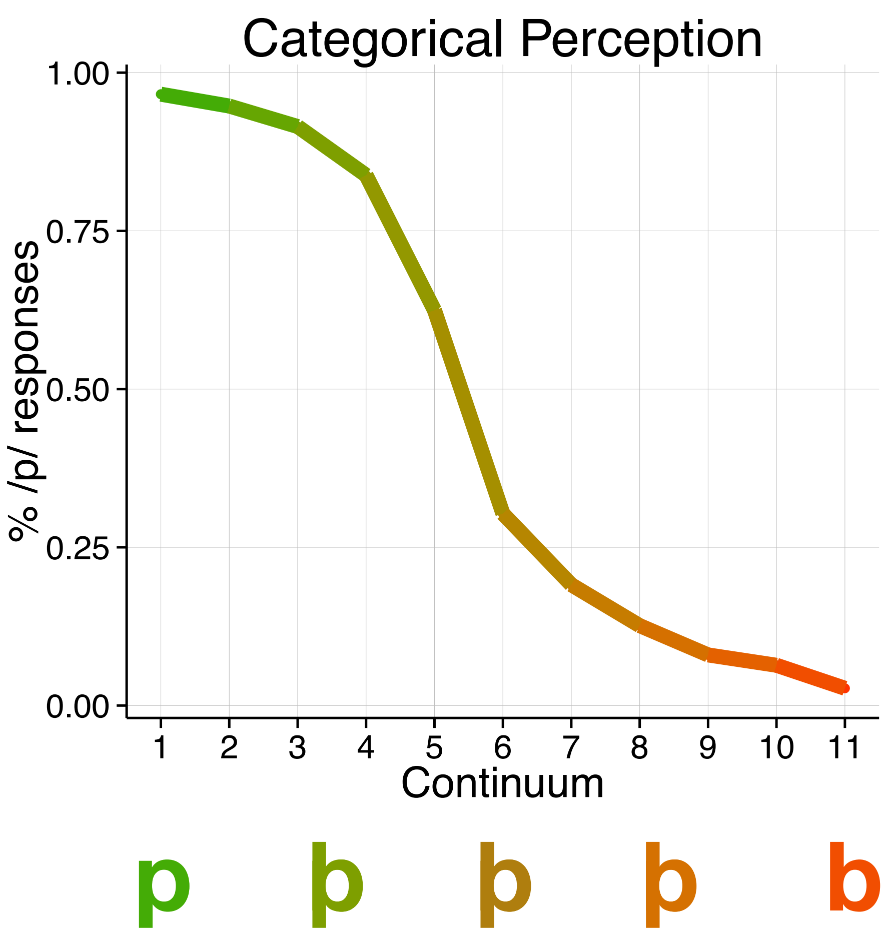


Future Influences on Perception

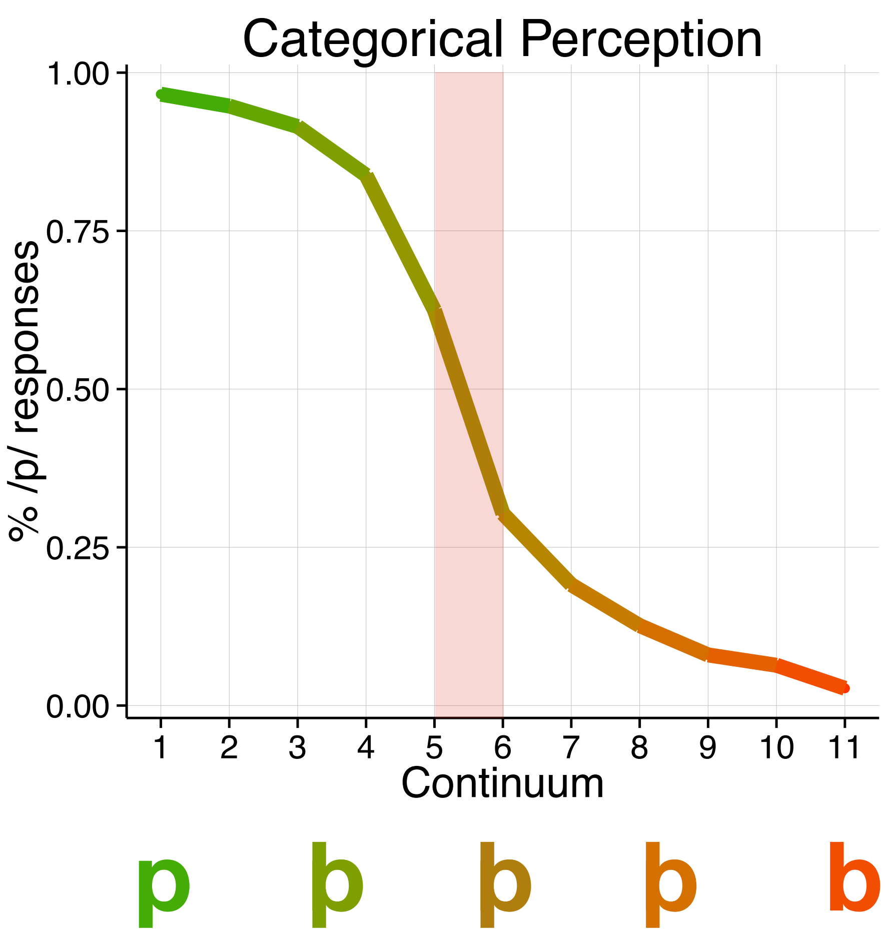


Future Influences on Perception

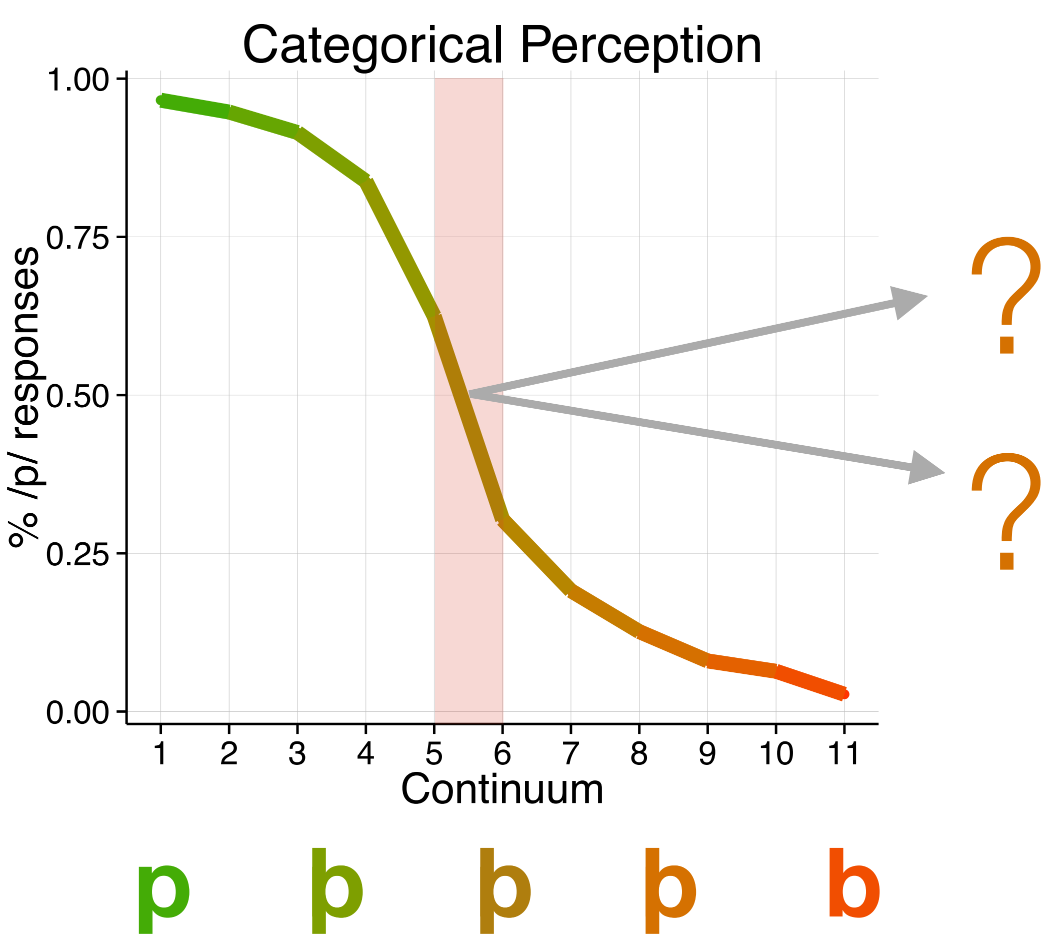
Future Influences on Perception



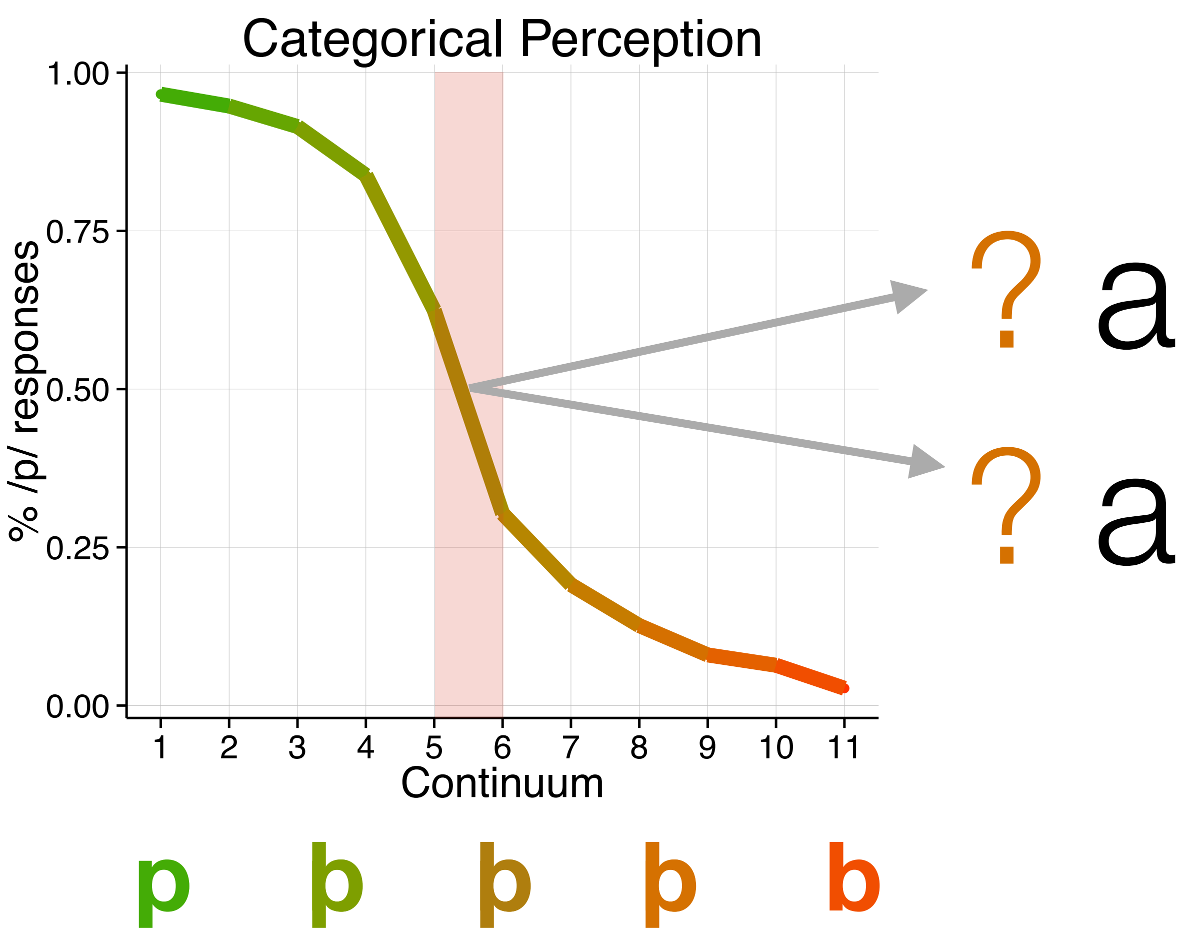
Future Influences on Perception



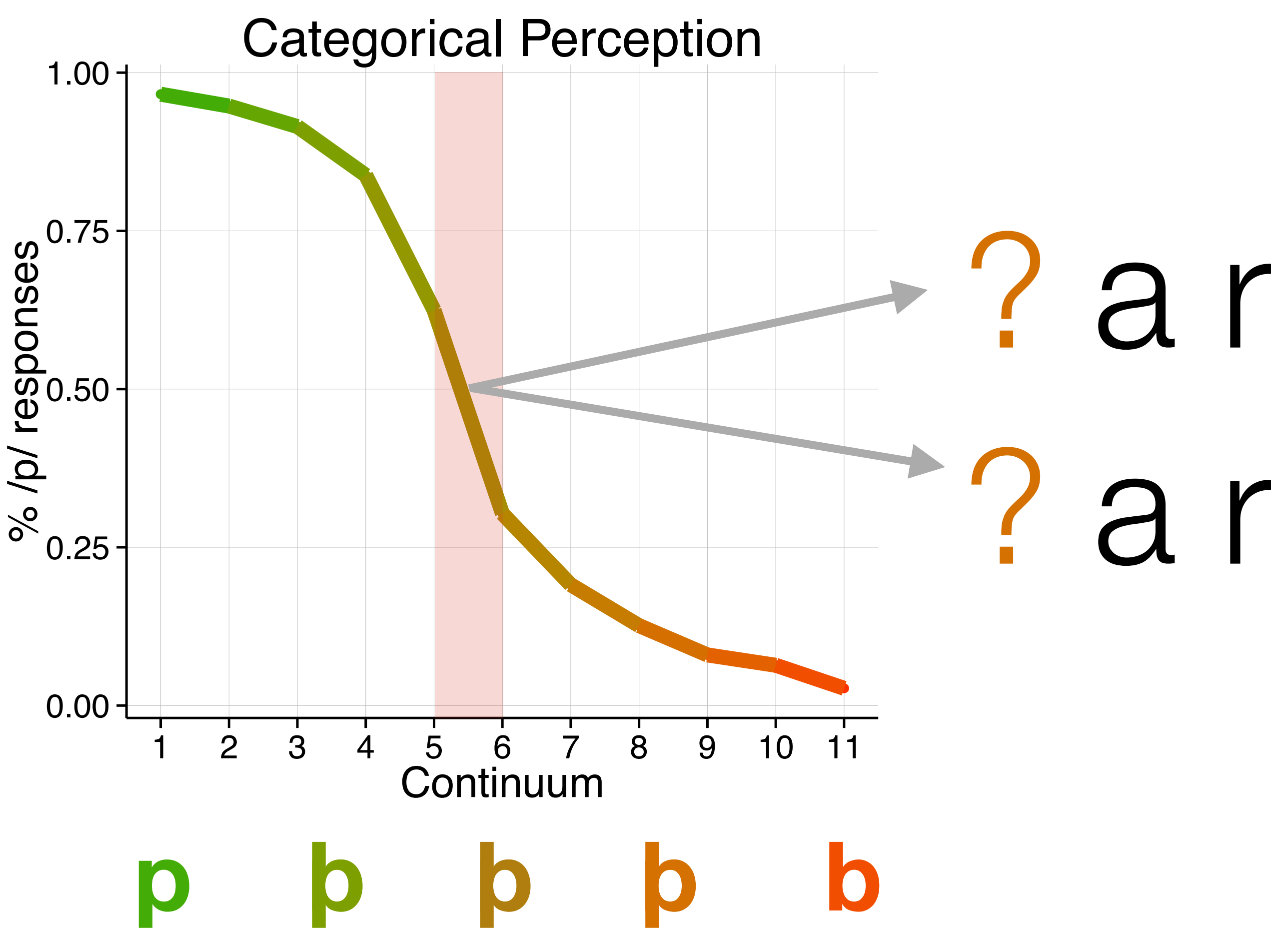
Future Influences on Perception



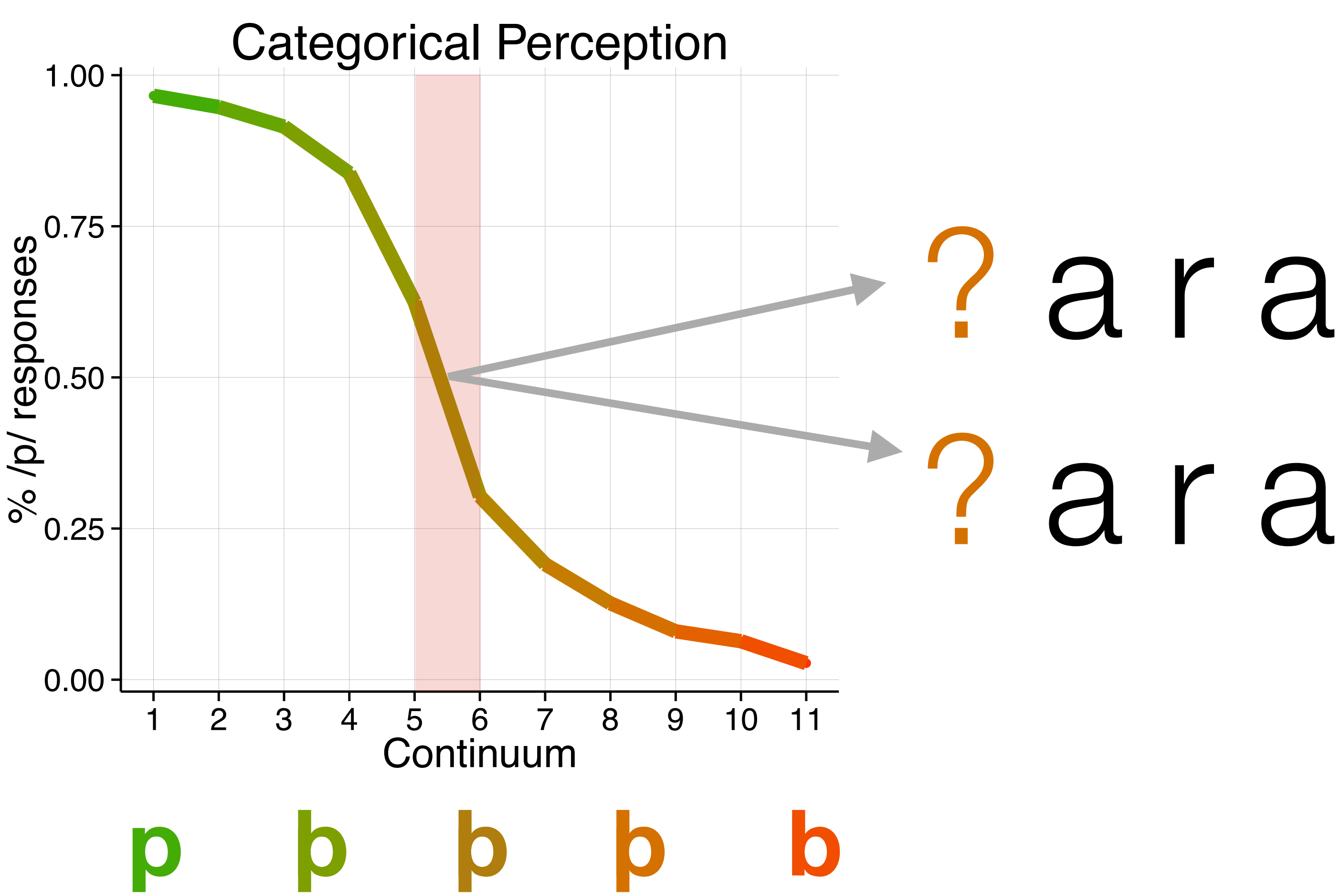
Future Influences on Perception



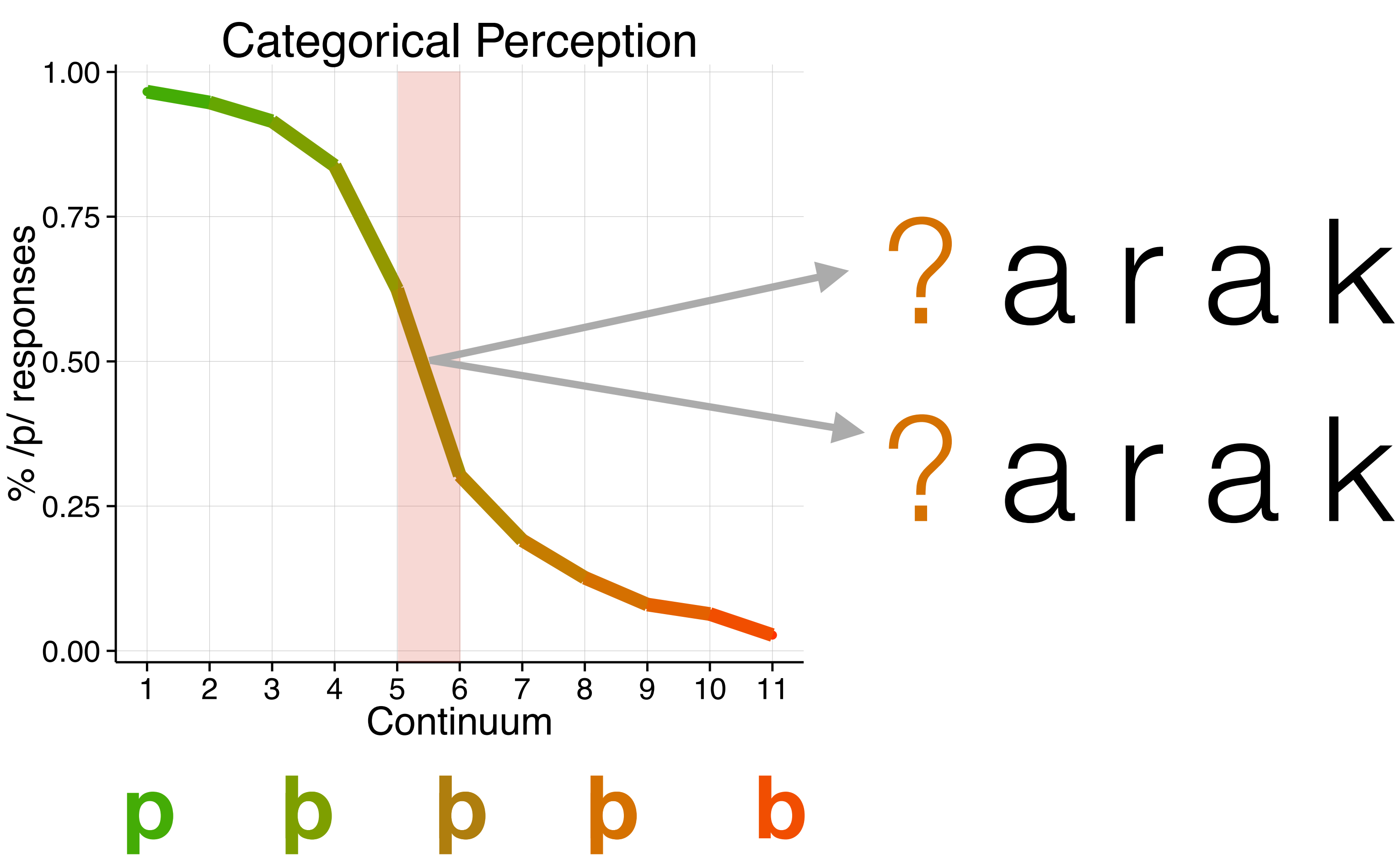
Future Influences on Perception



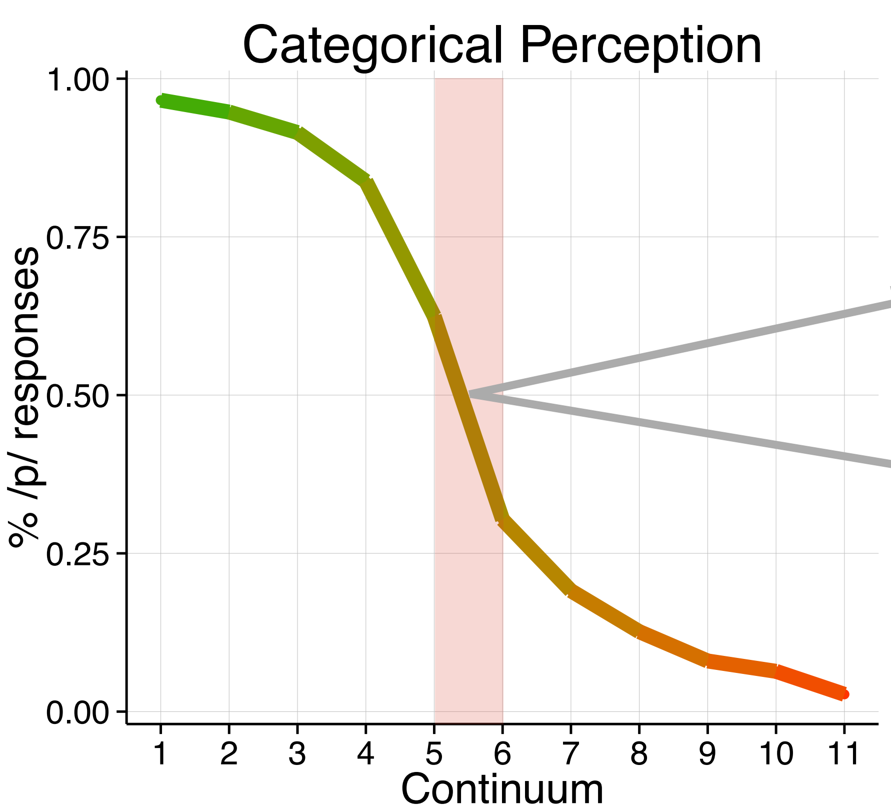
Future Influences on Perception



Future Influences on Perception



Future Influences on Perception



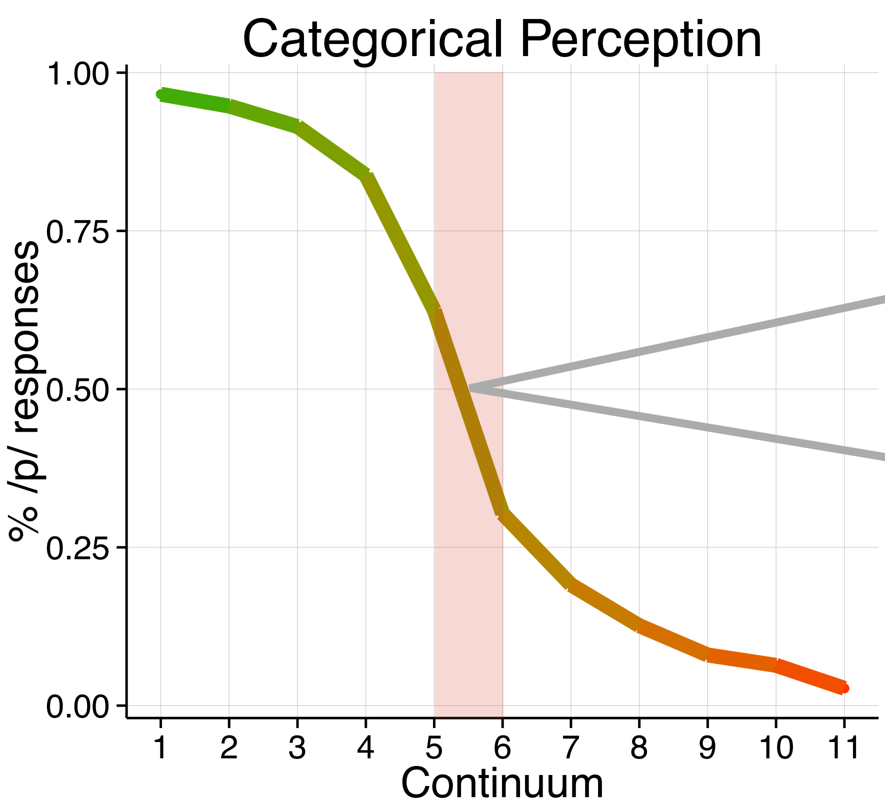
p b b b b

? a r a k **ee** t

? a r a k **ai** d

“**P**oint **of** **D**isambiguation” (POD)

Future Influences on Perception



p b b b b

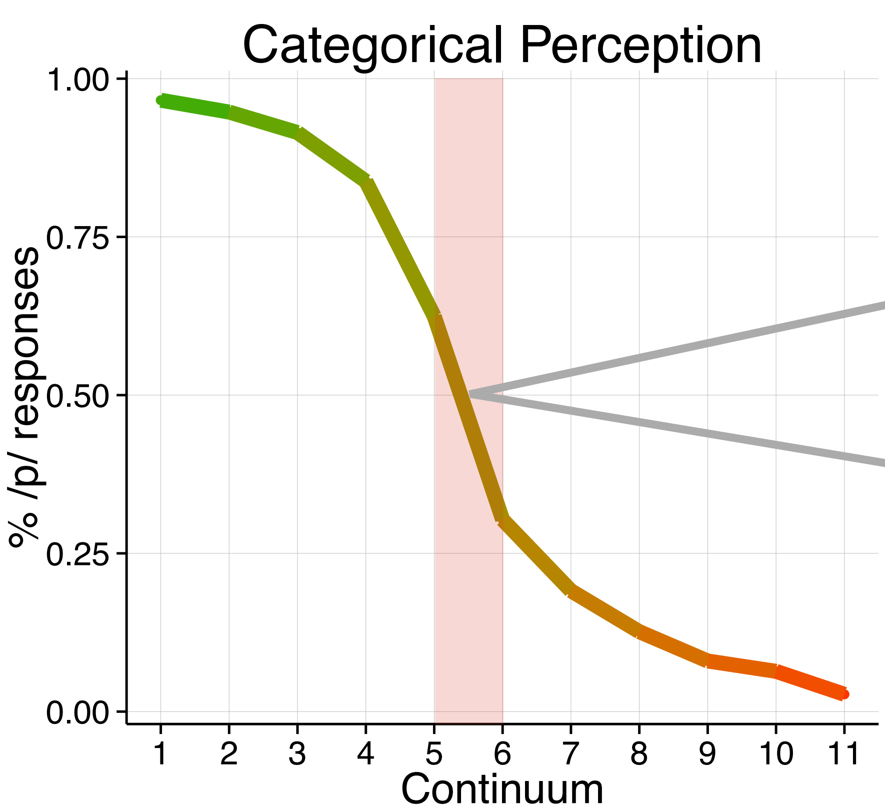
? a r a k **ee** t

? a r a k **ai** d

"**P**oint **of** **D**isambiguation" (POD)

Future Influences on Perception

(this is a parakeet)



p b b b b

p a r a k **ee** t

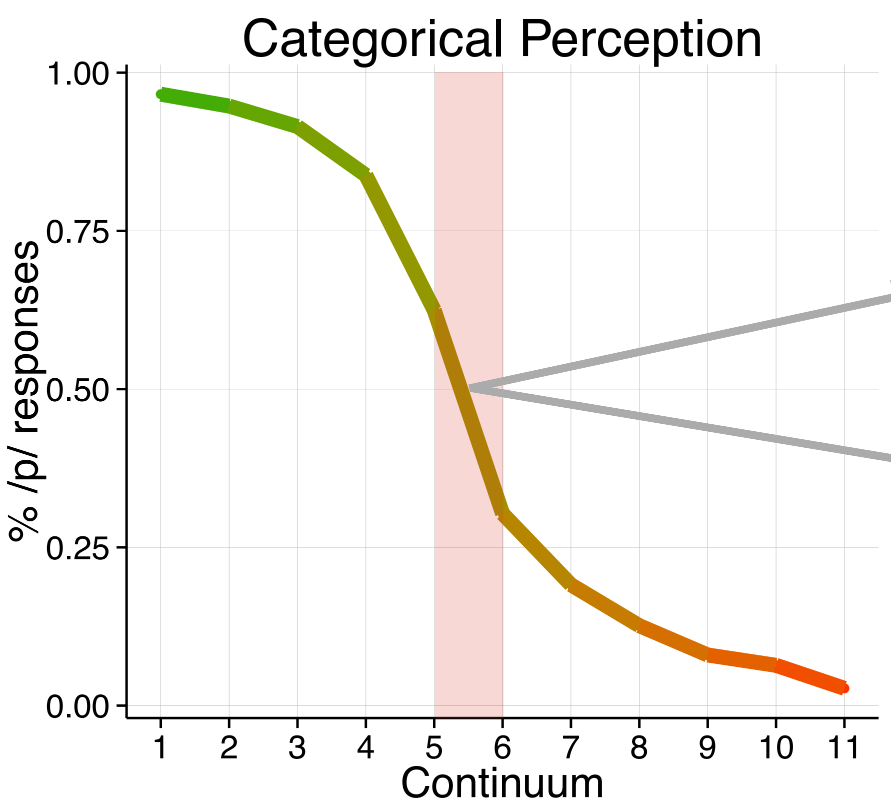
b a r a k **ai** d

(this is a barricade)

“**P**oint **of** **D**isambiguation” (POD)

Future Influences on Perception

(this is a parakeet)



p b b b b

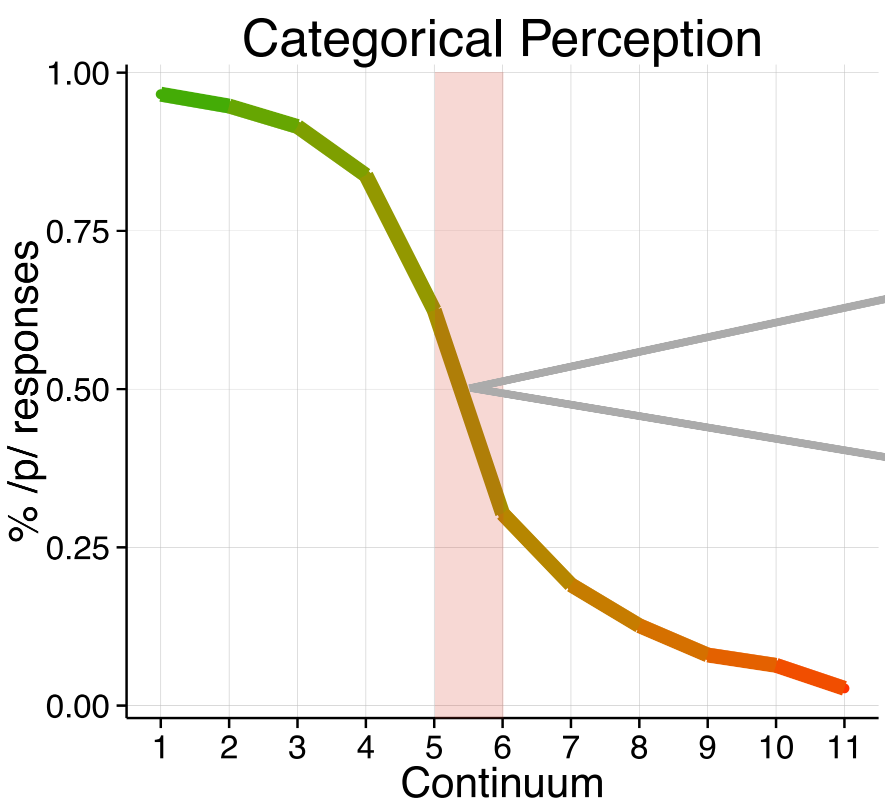
p a r a k **ee** t

b a r a k **ai** d

(this is a barricade)

“**P**oint **of** **D**isambiguation” (POD)

Future Influences on Perception



p b b b b

(this is a parakeet)

p a r a k **ee** t

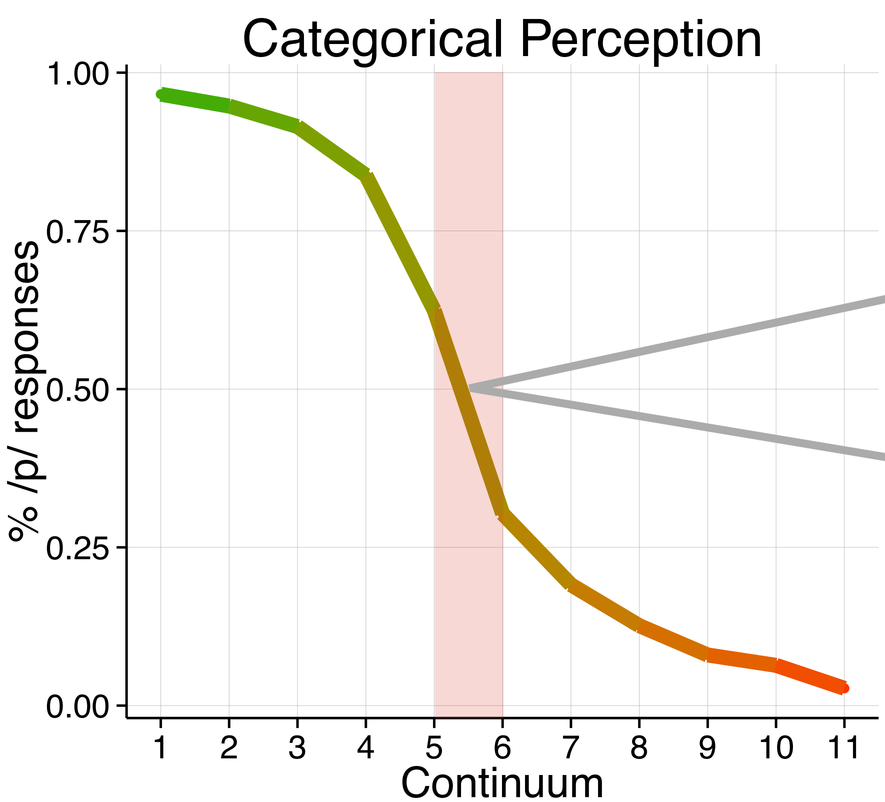
b a r a k **ai** d

(this is a barricade)

"**P**oint **of** **D**isambiguation" (POD)

Future Influences on Perception

(this is a parakeet)



p **b** **b** **b** **b**

p a r a k **ee** t

b a r a k **ai** d

(this is a barricade)

"**P**oint **of** **D**isambiguation" (POD)

Today's Questions

p a r a k **ee** t

Today's Questions

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

?

b a r a k **ee** t

Today's Questions

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

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

?   ?

b a r a k **ee** t

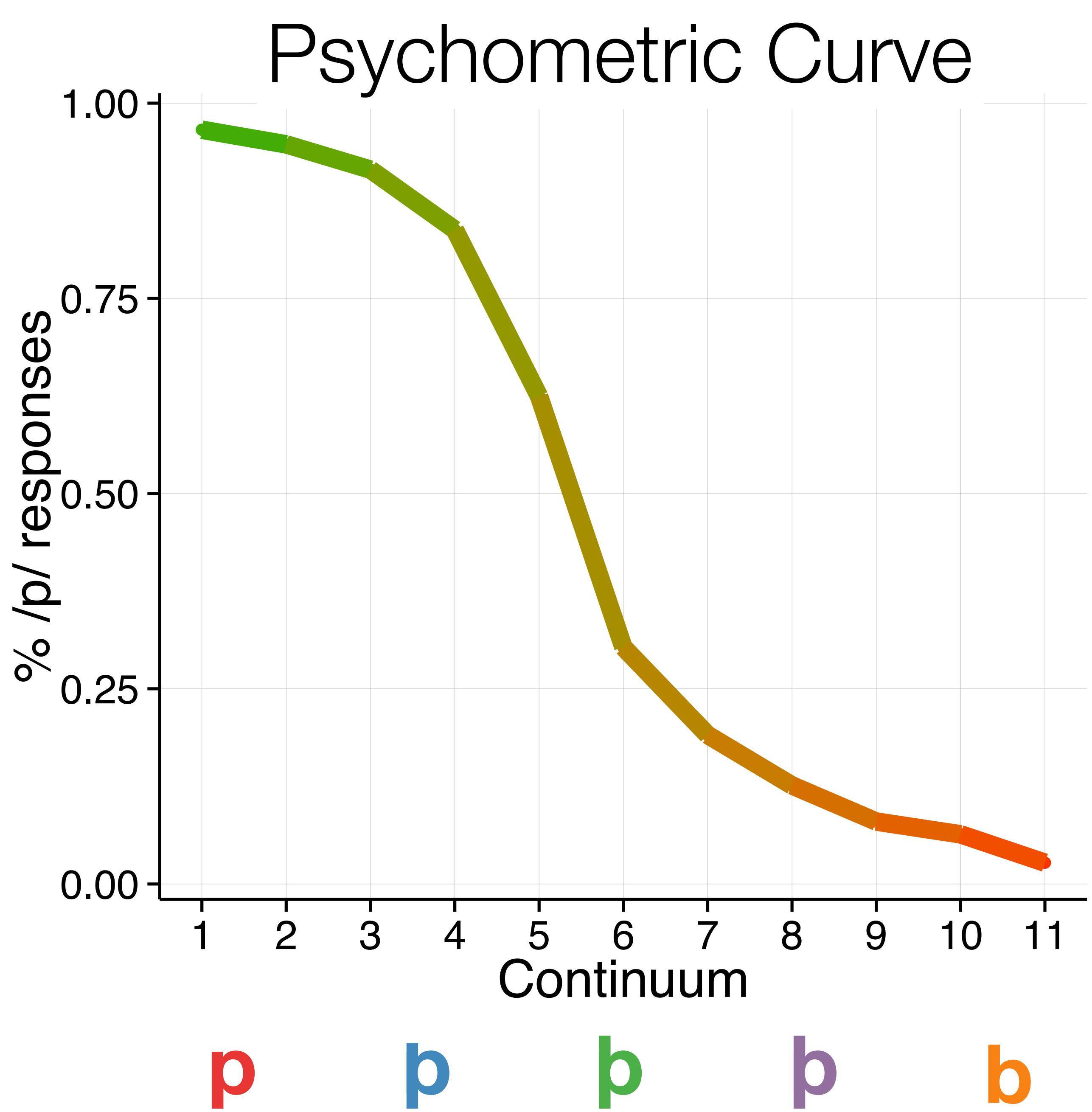
Design & Materials

53 x ?

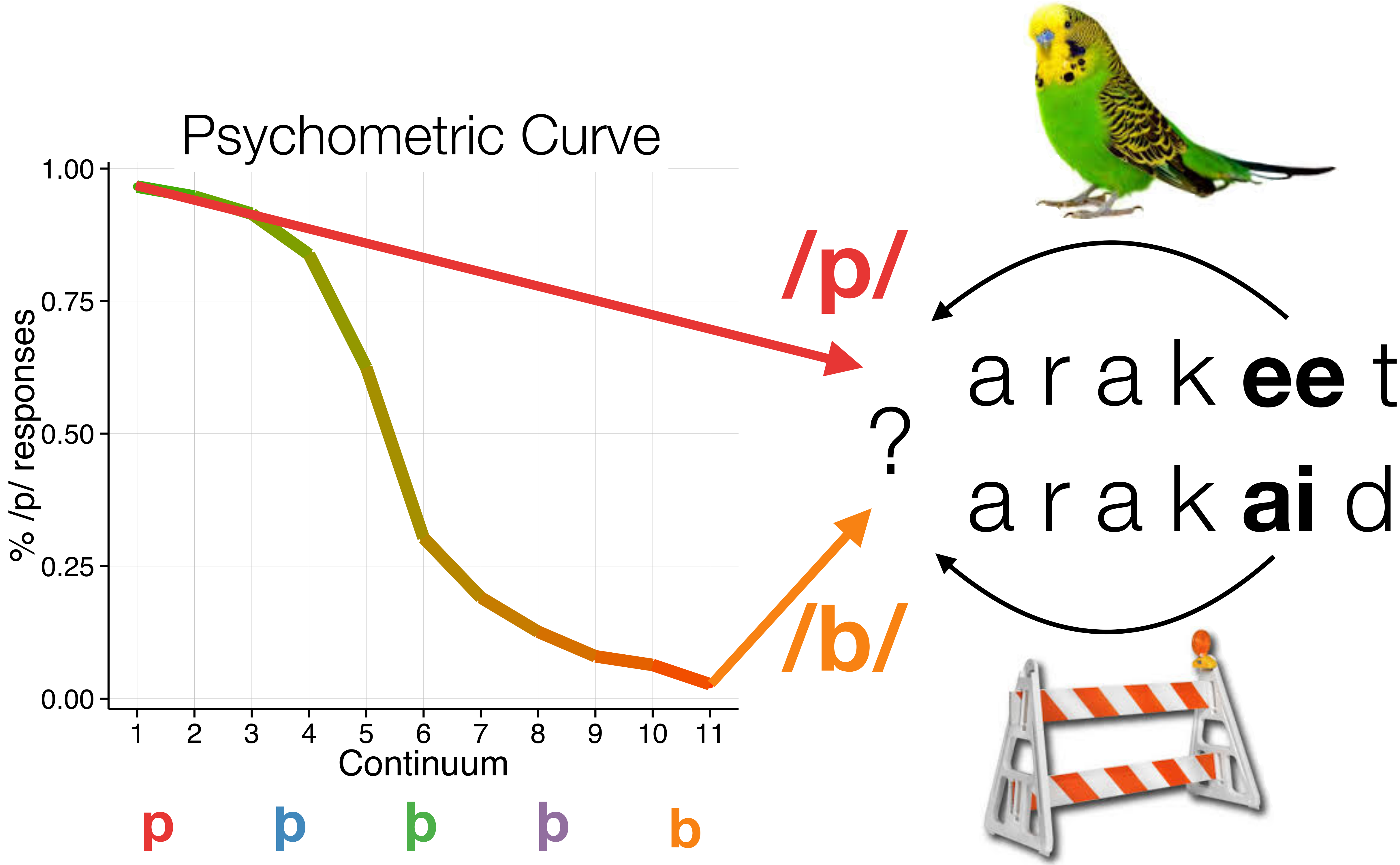
a r a k **ee** t

a r a k **ai** d

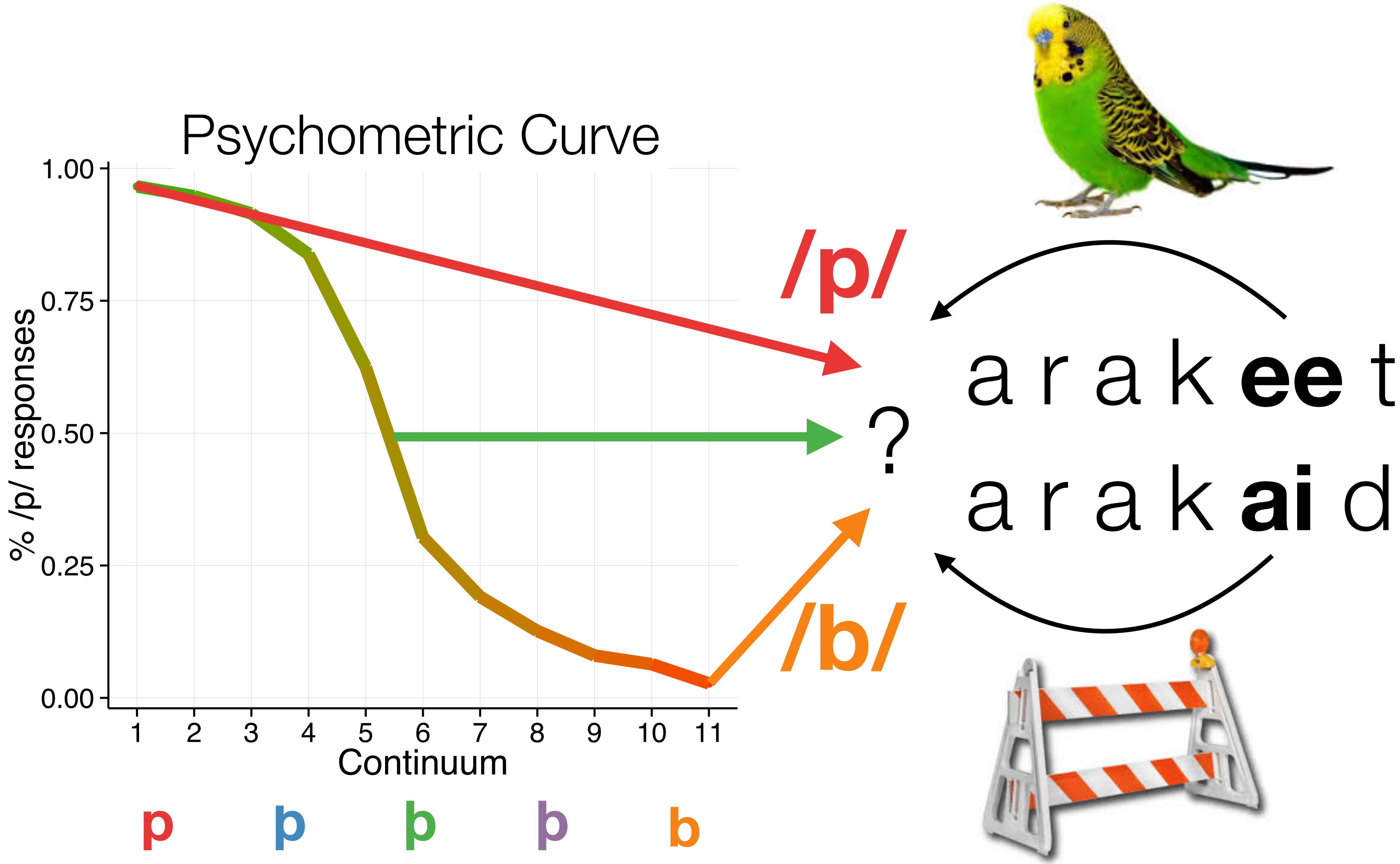
Design & Materials



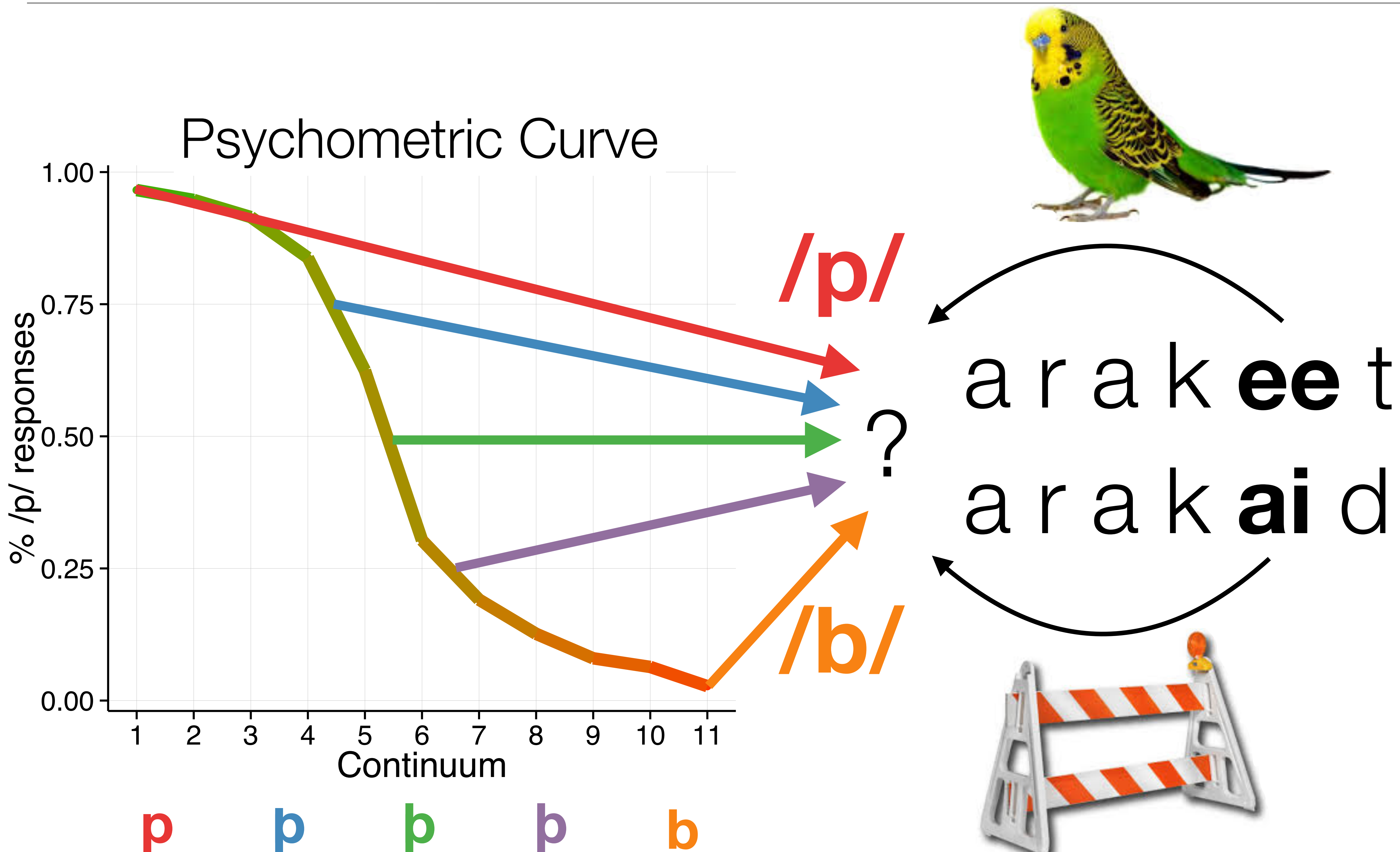
Design & Materials



Design & Materials

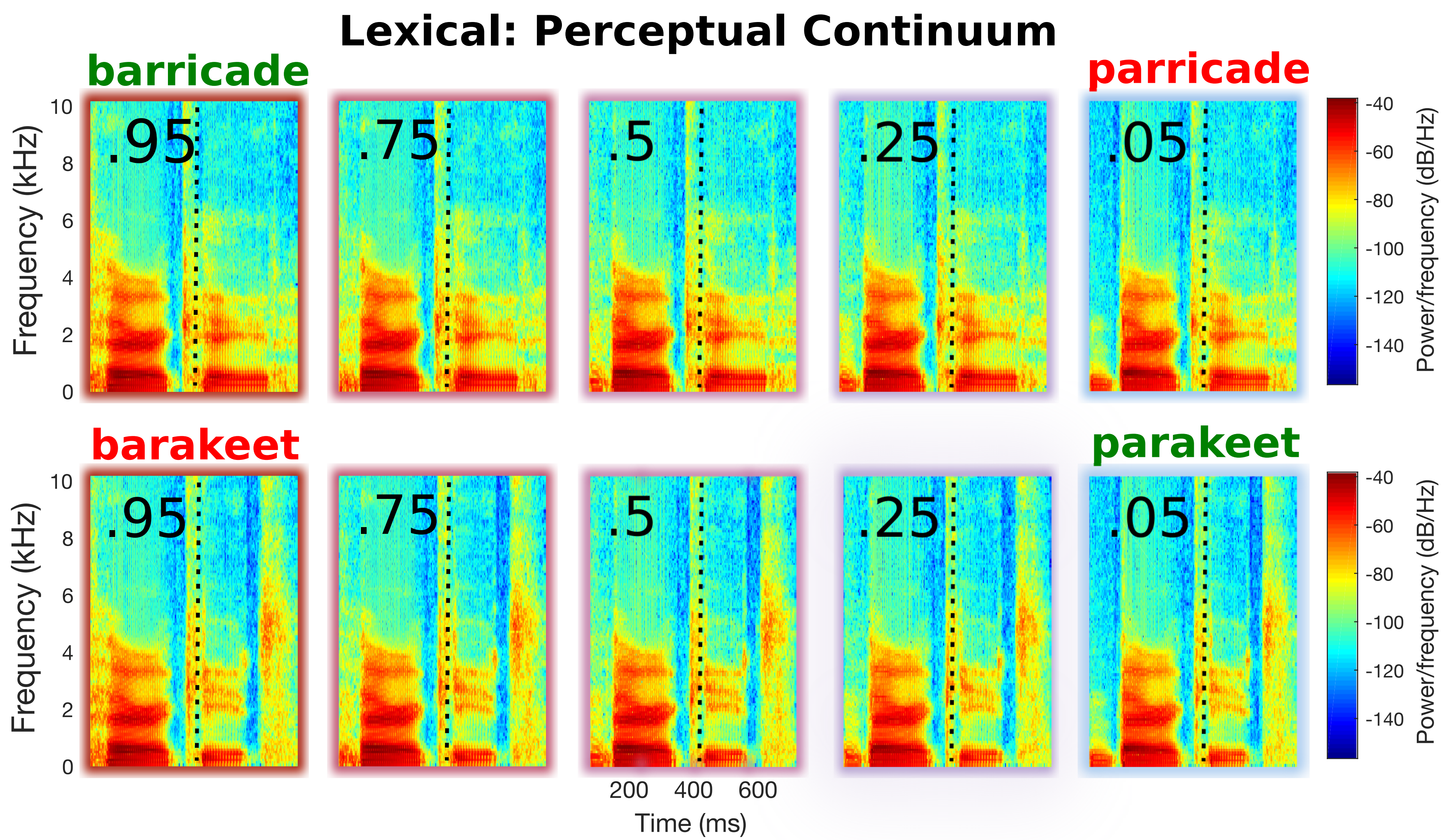


Design & Materials

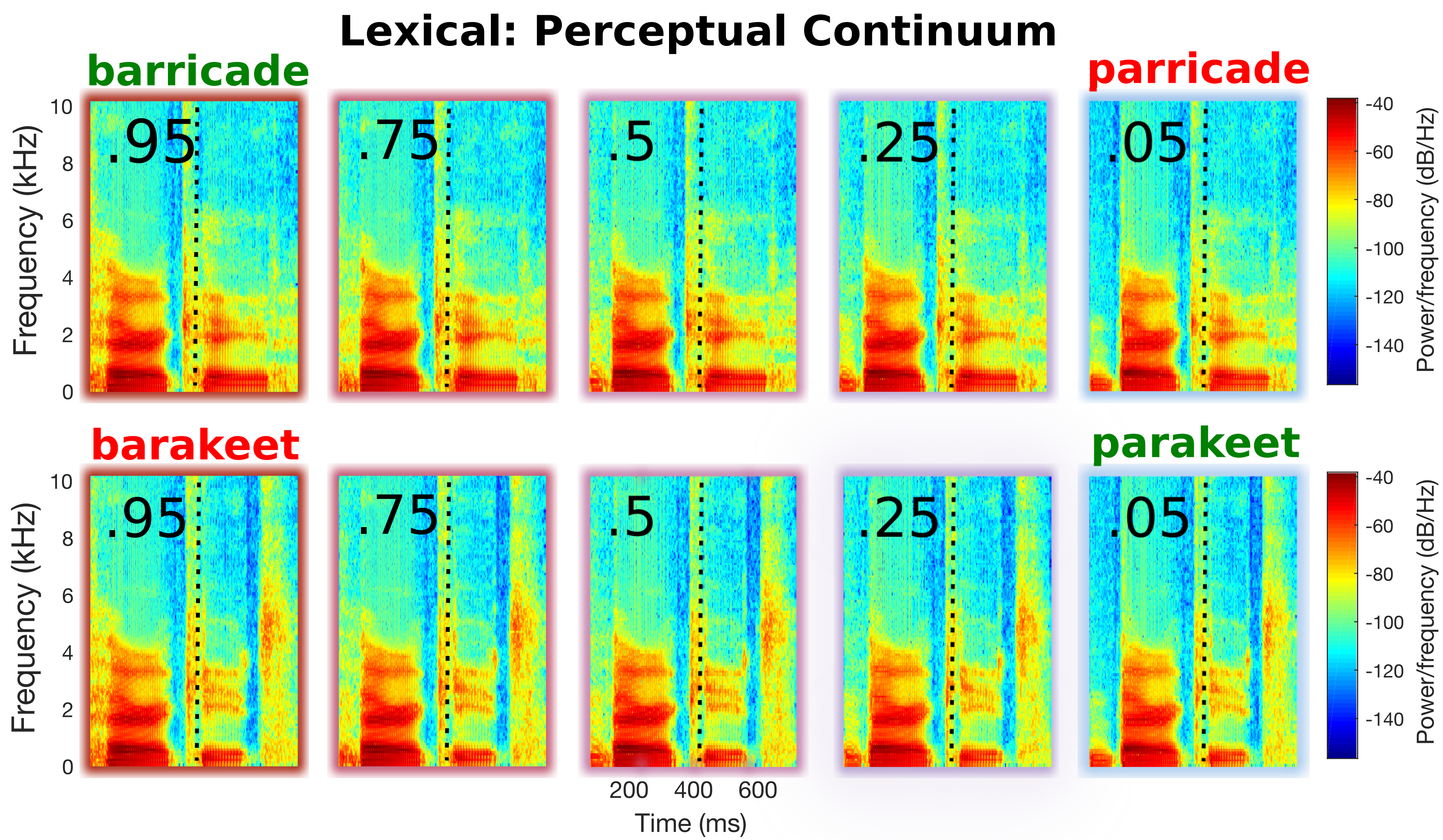


p p b b b

Design & Materials



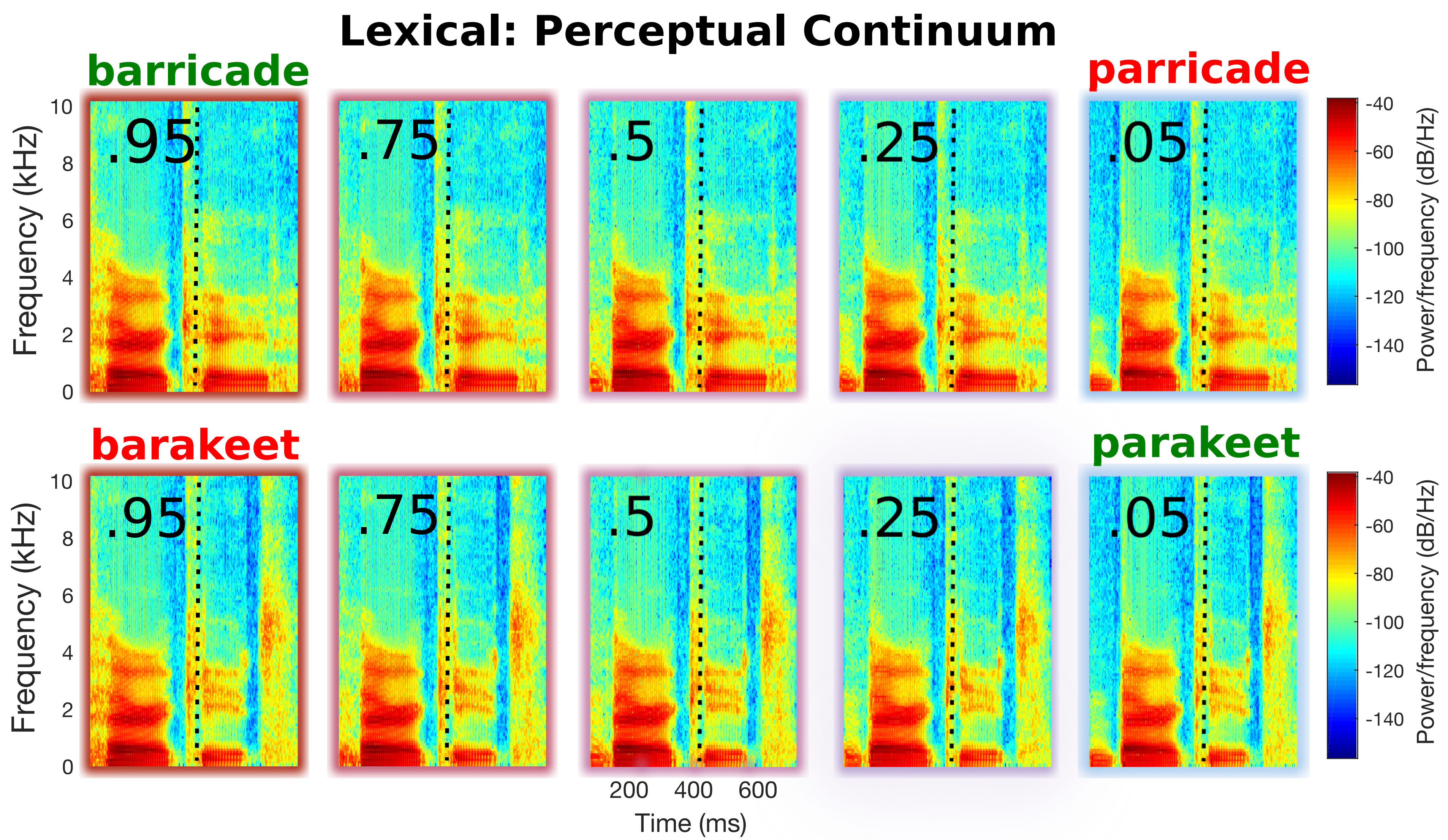
Design & Materials



- Point of Disambiguation (POD) ranged 3-8 phonemes / 150-750 ms

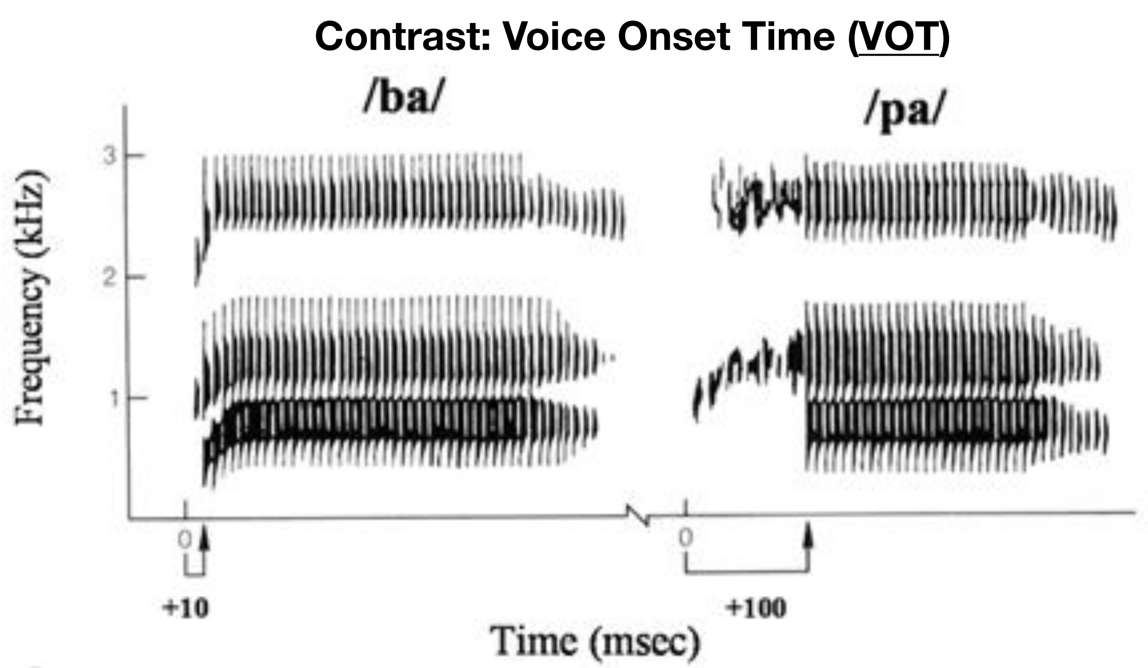
p p b b b

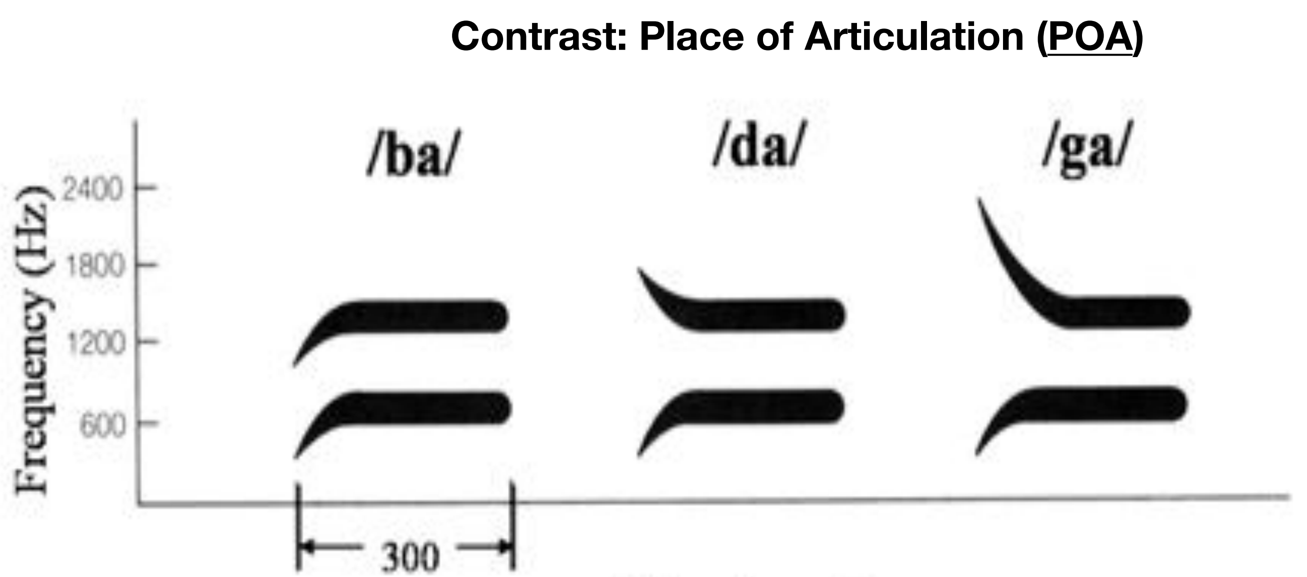
Design & Materials



- Point of Disambiguation (POD) ranged 3-8 phonemes / 150-750 ms
- VOT (31 pairs) {p-b, t-d, k-g} and POA (22 pairs) {t-k, p-t}

Design & Materials





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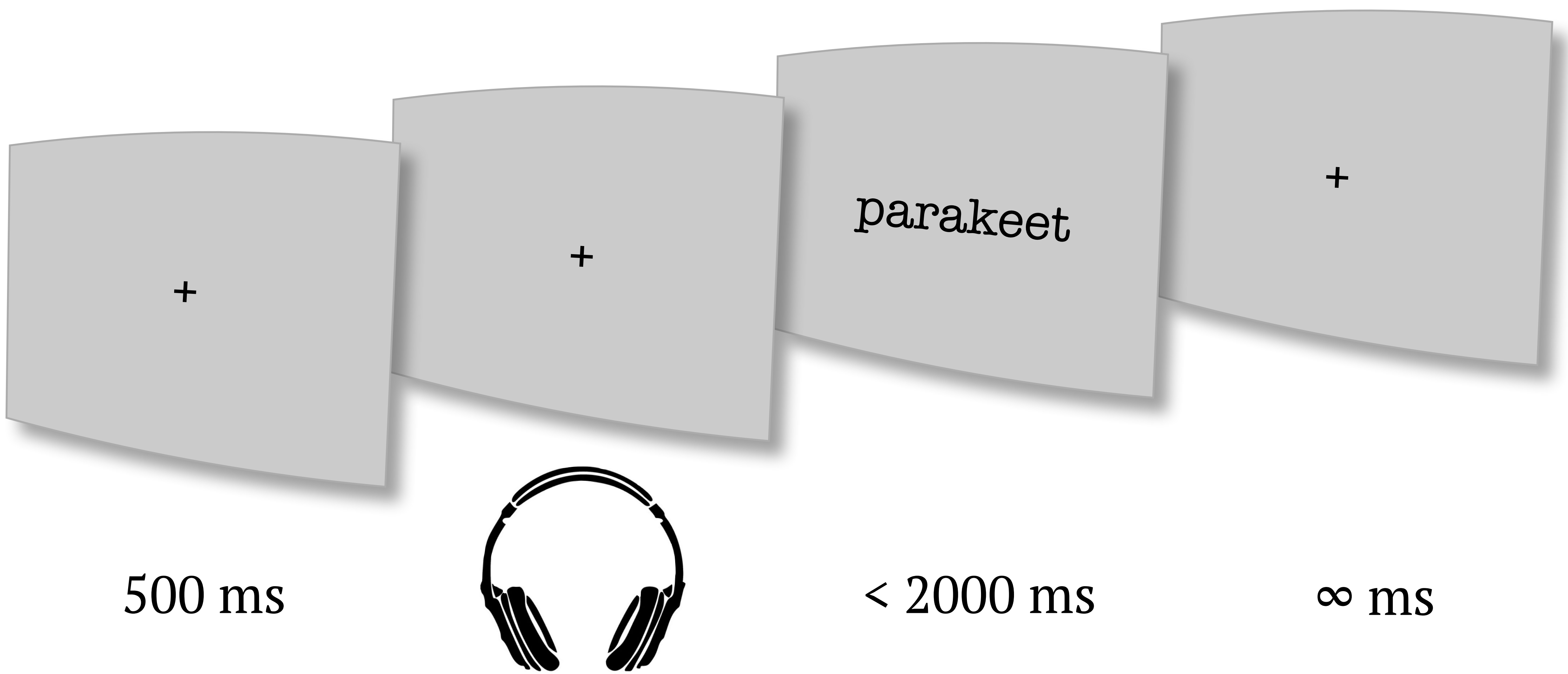
Design & Materials

Design & Materials

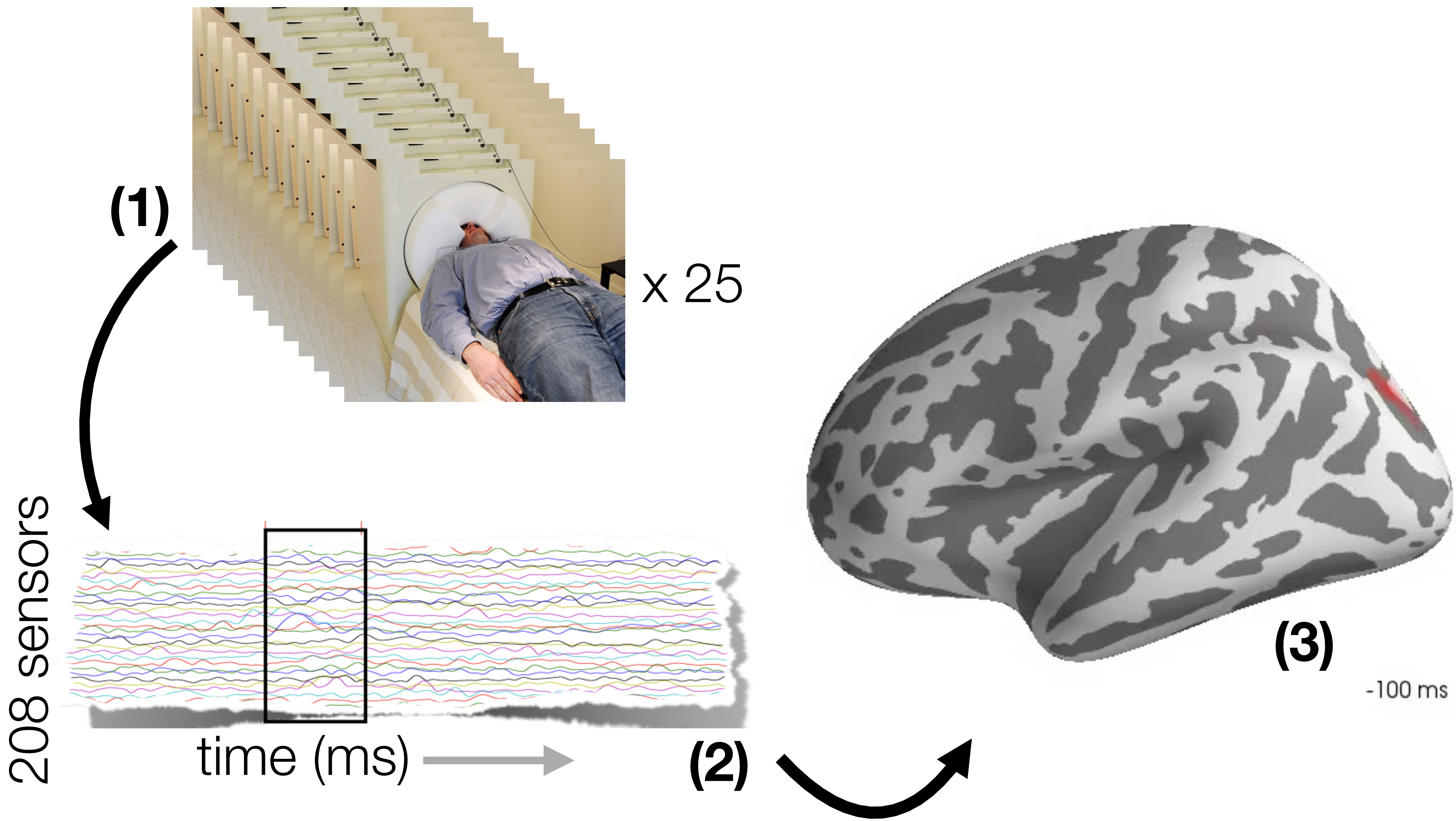


Procedure & Analysis

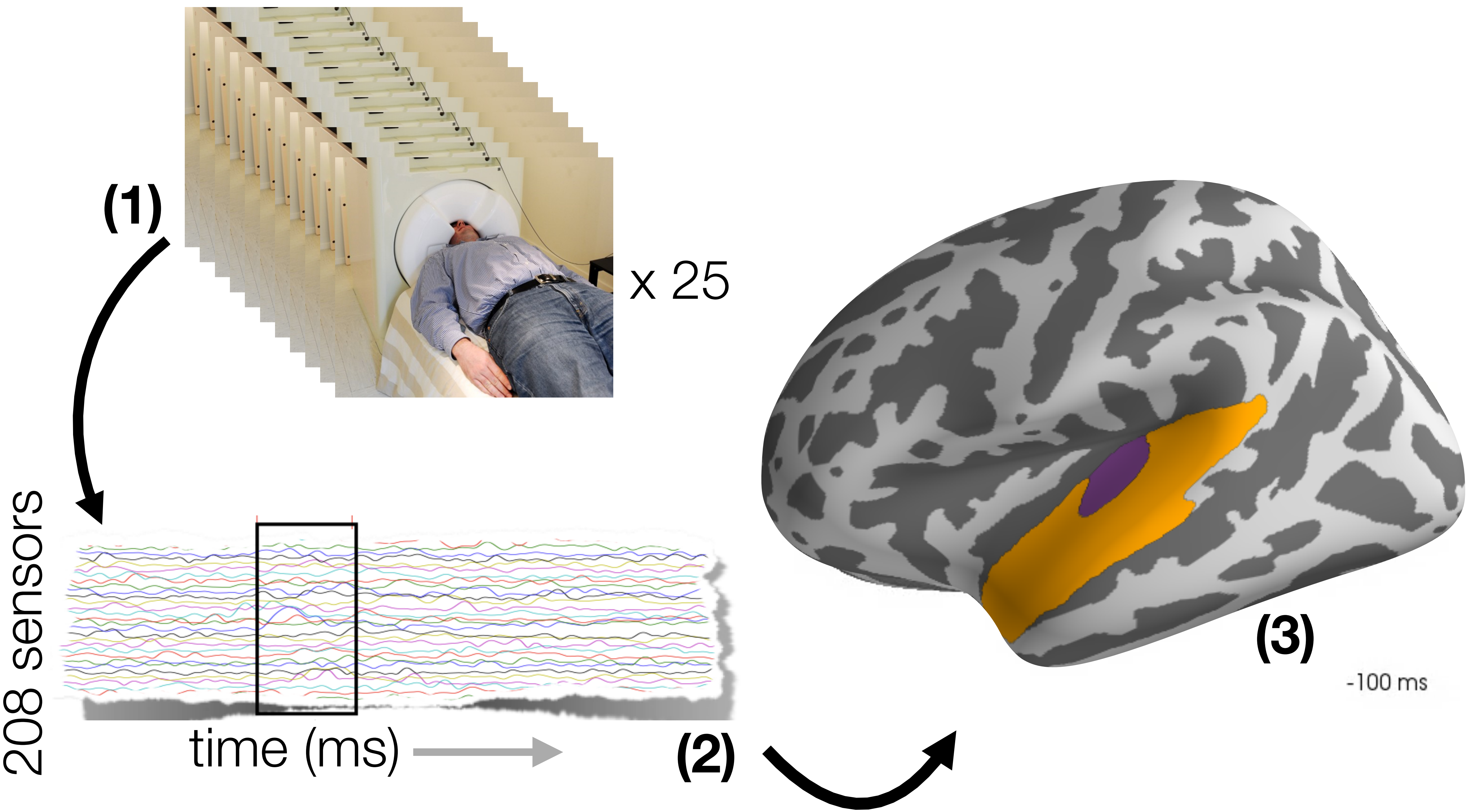
Procedure & Analysis

x 25

Procedure & Analysis

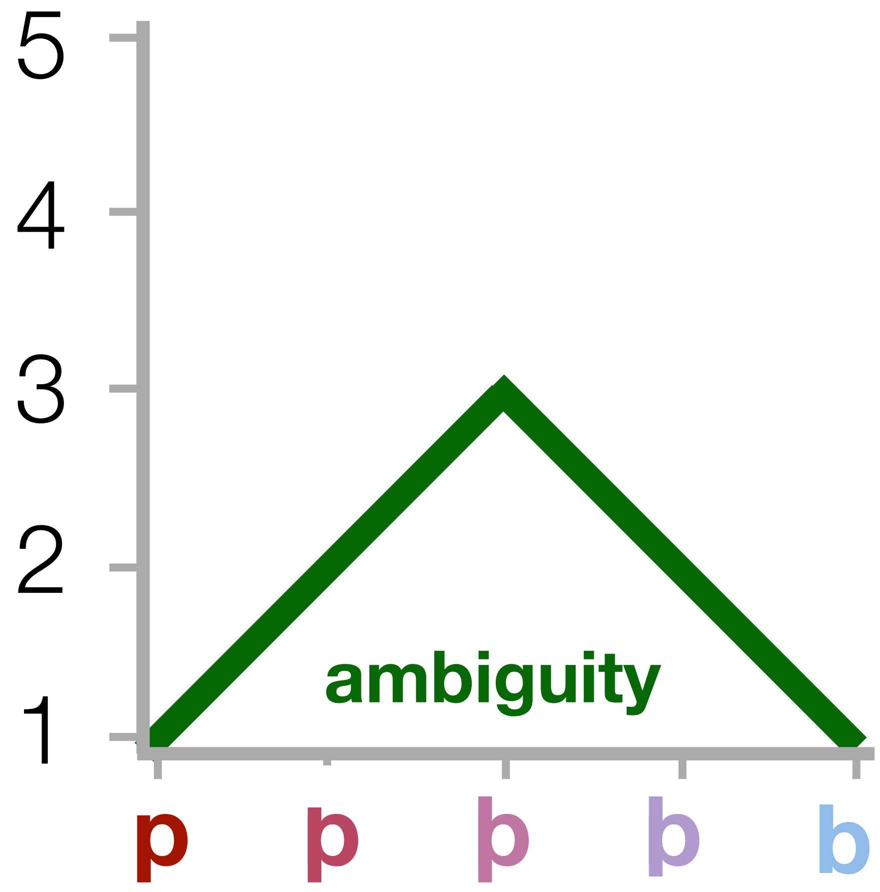


Procedure & Analysis

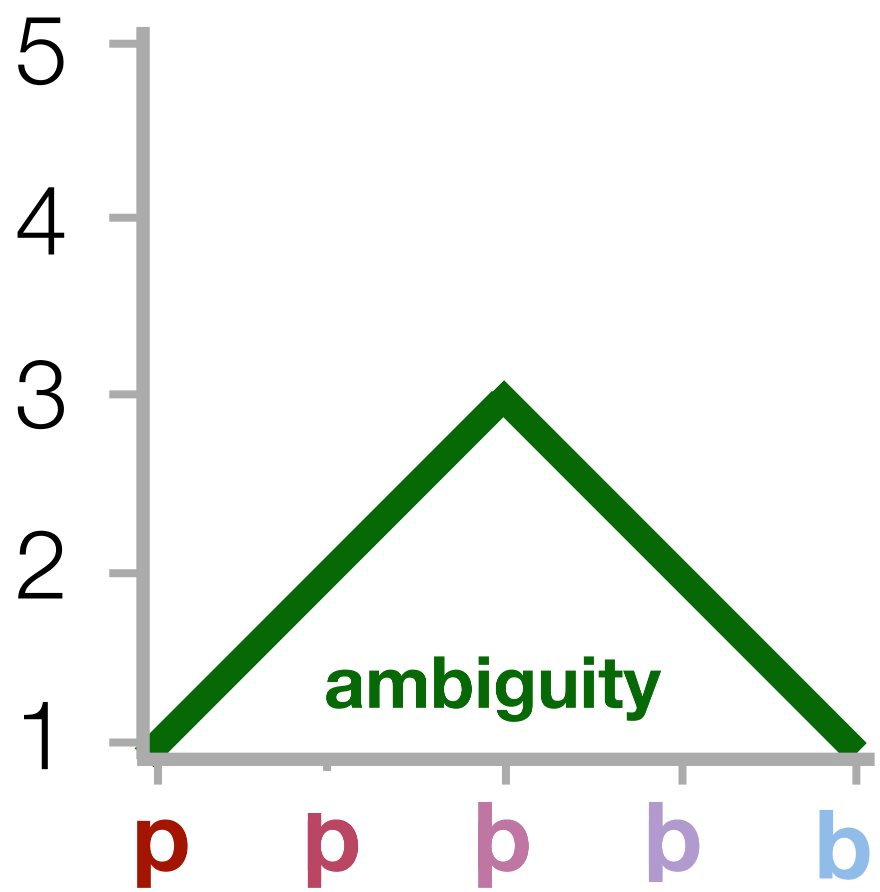


Three Experimental Variables

Three Experimental Variables

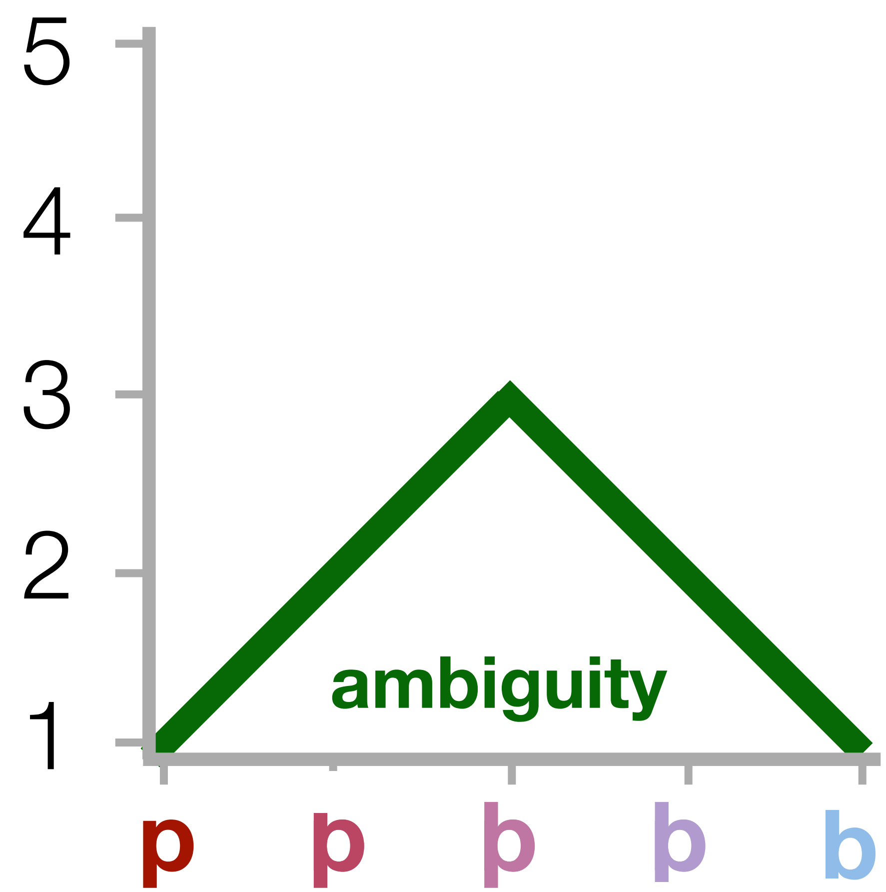


Three Experimental Variables



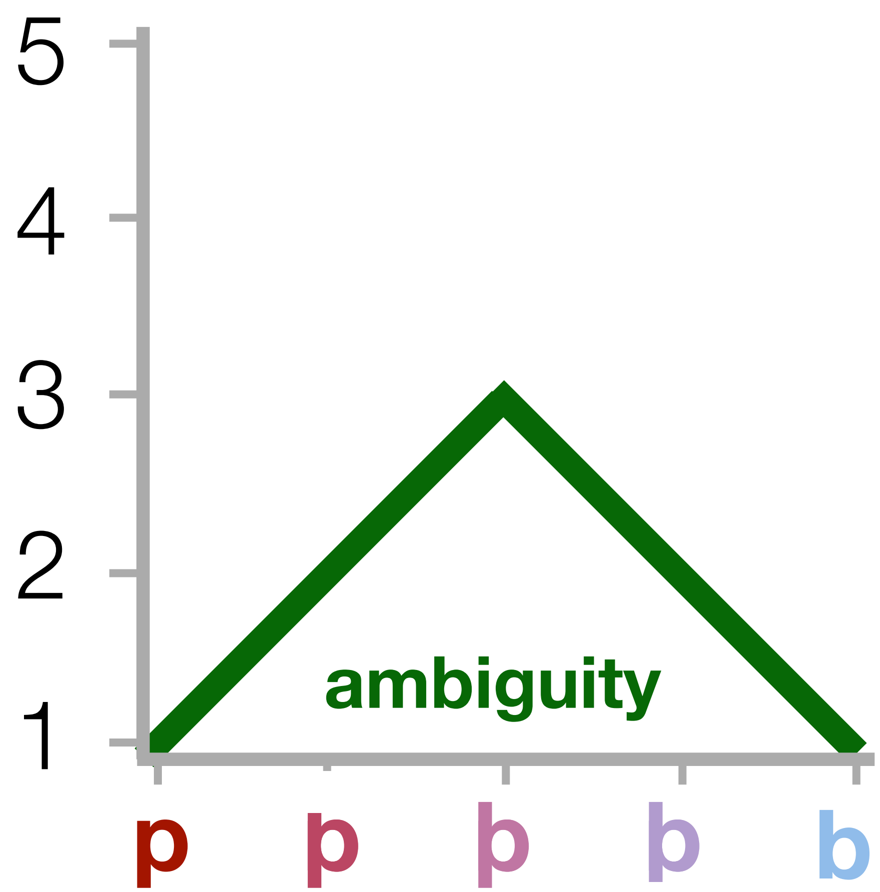
p p	b b
t t	d d
k k	g g

Three Experimental Variables



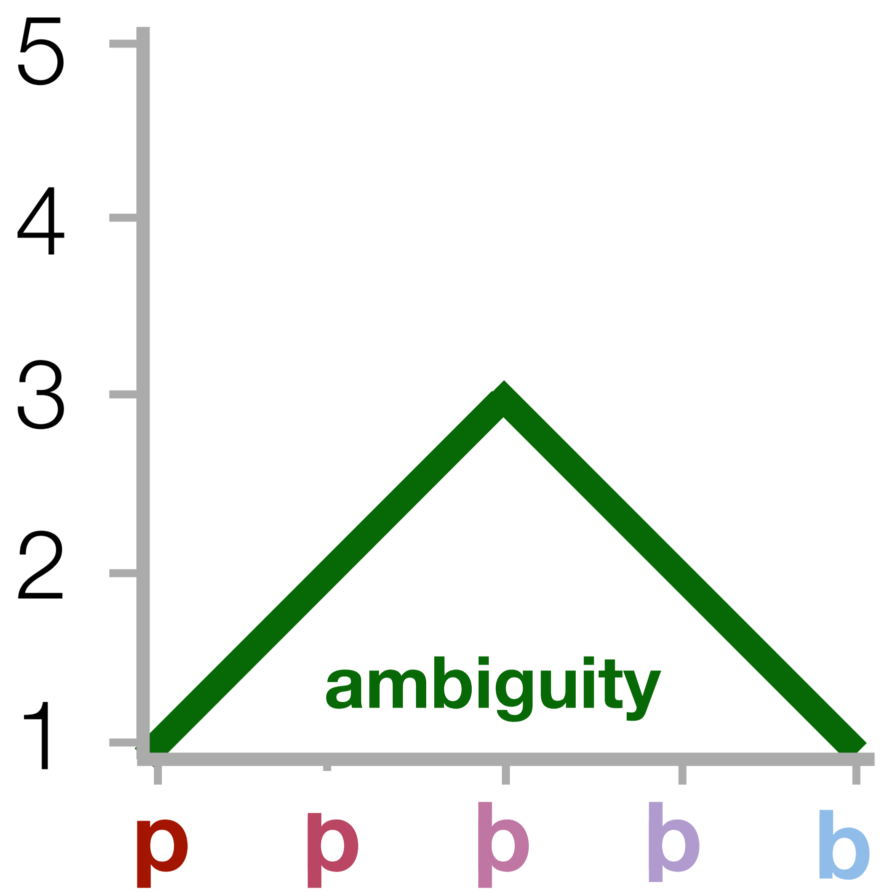
voiceless	voiced	
p p	b b	bilabial
t t	d d	labio-dental
k k	g g	velar

Three Experimental Variables



	VOT		
	voiceless	**voiced**	
	p p	**b b**	**bilabial**
	t t	**d d**	**labio-dental**
	k k	**g g**	**velar**

Three Experimental Variables



VOT

voiceless	voiced	
p p	b b	bilabial
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POA

Today's Questions

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

Today's Questions

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

Sensitivity to phonetic features ~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

Ambiguity at Onset

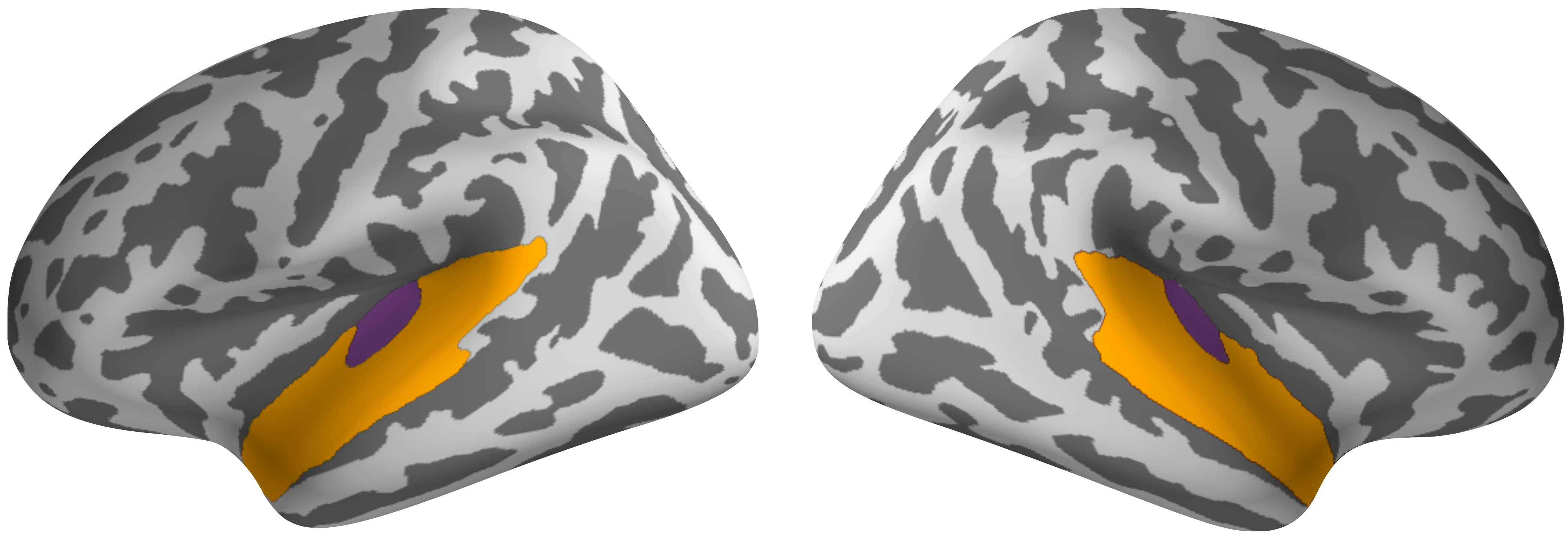
p p b b b

Ambiguity at Onset

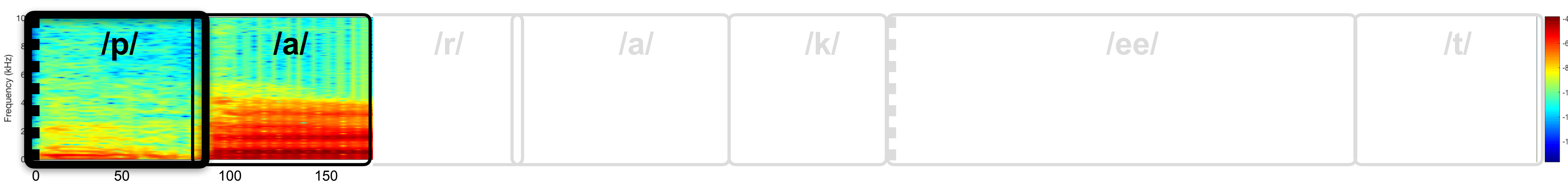
Ambiguity at Onset

p p b b b

Ambiguity at Onset



- Time-window: 0-200 ms after word onset
- Region: **Heschl's gyrus** & **superior temporal gyrus** bilaterally



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Ambiguity at Onset

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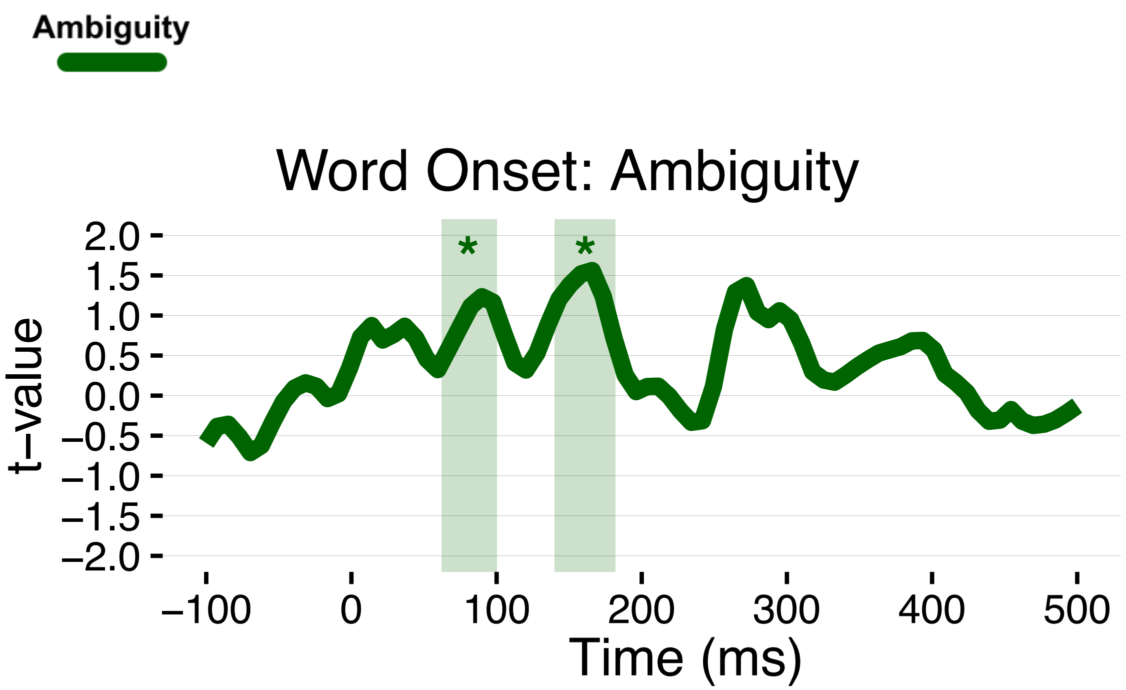
Ambiguity at Onset

Ambiguity

p p b b b

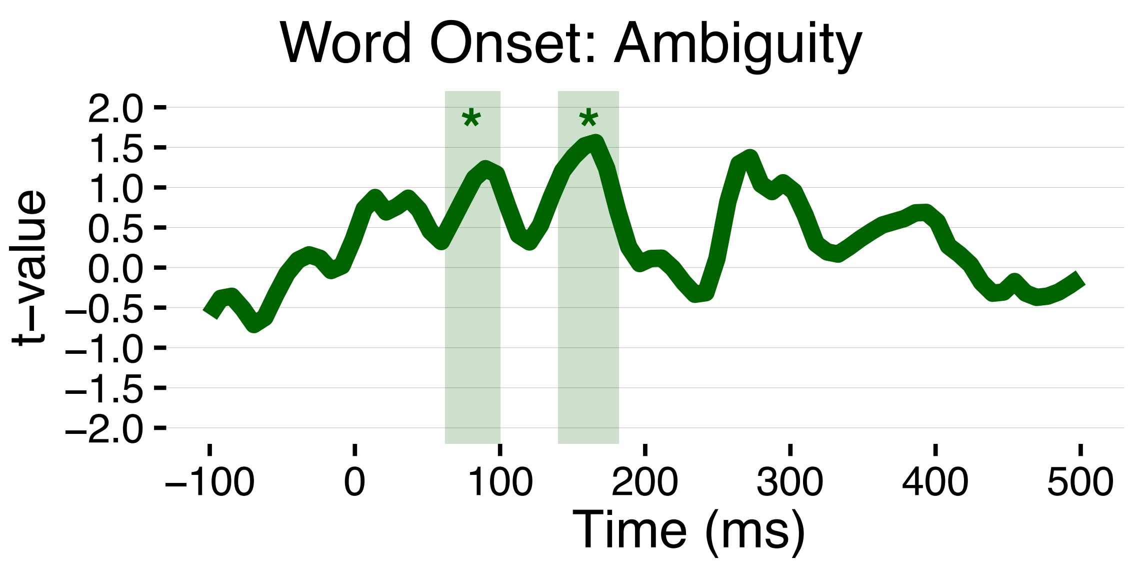
Ambiguity at Onset

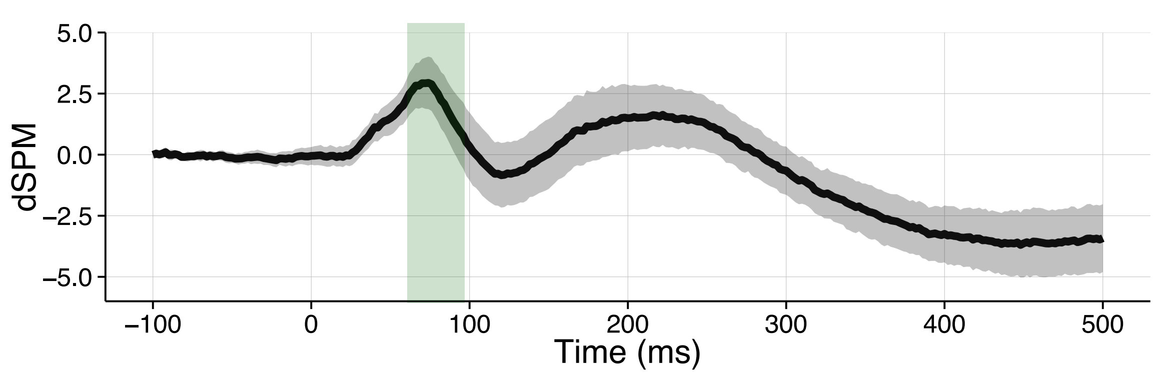


p p b b b

Ambiguity at Onset

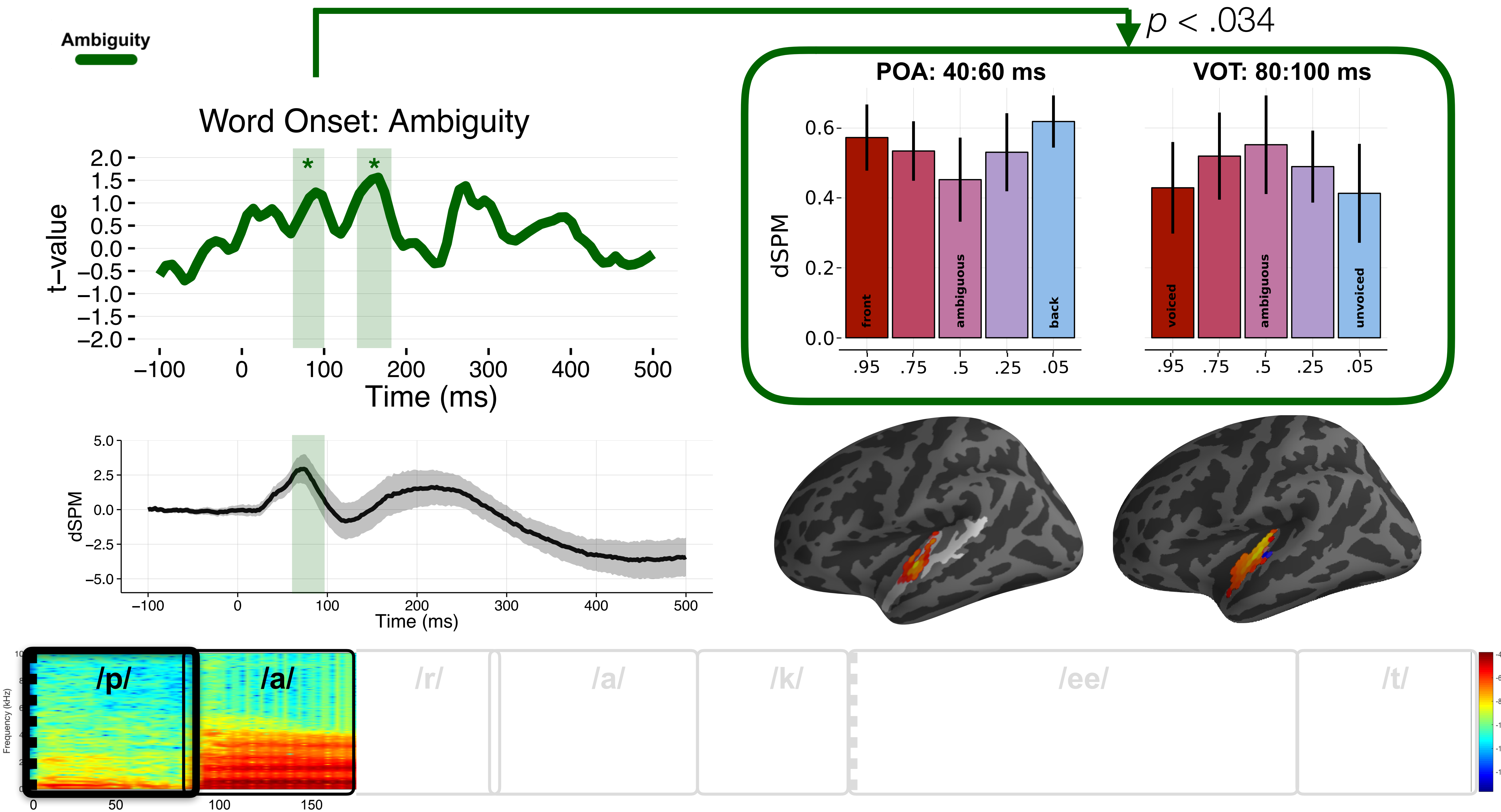
Ambiguity





p p b b b

Ambiguity at Onset



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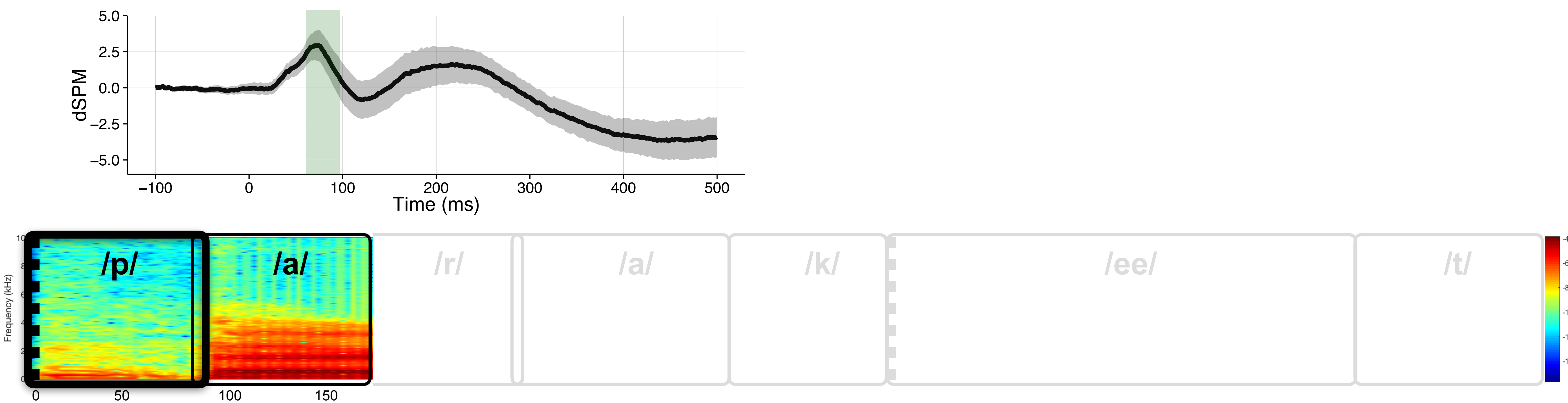
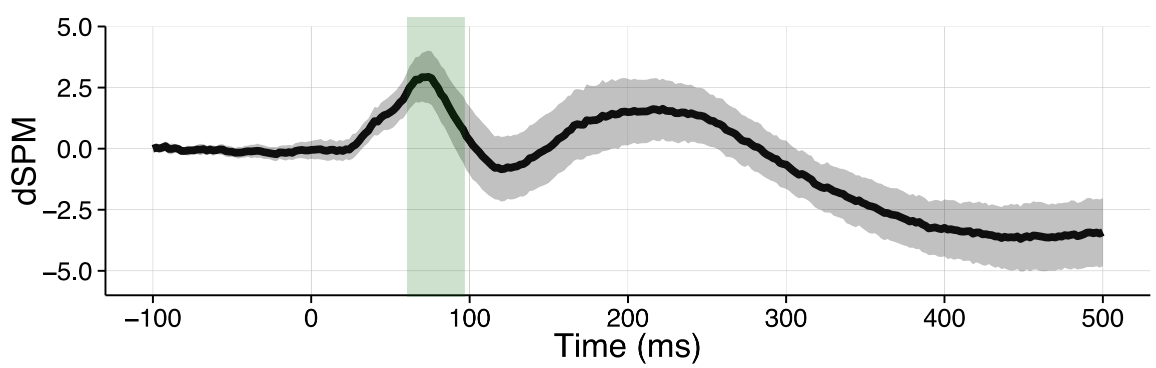


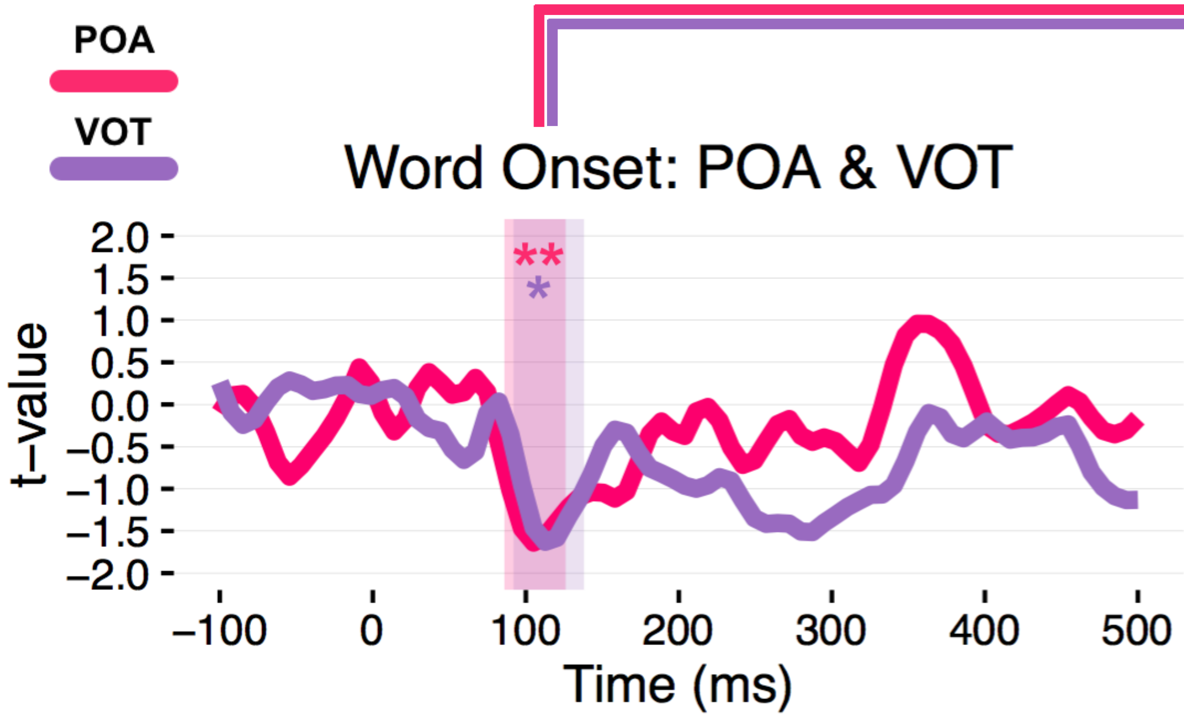
Ambiguity at Onset

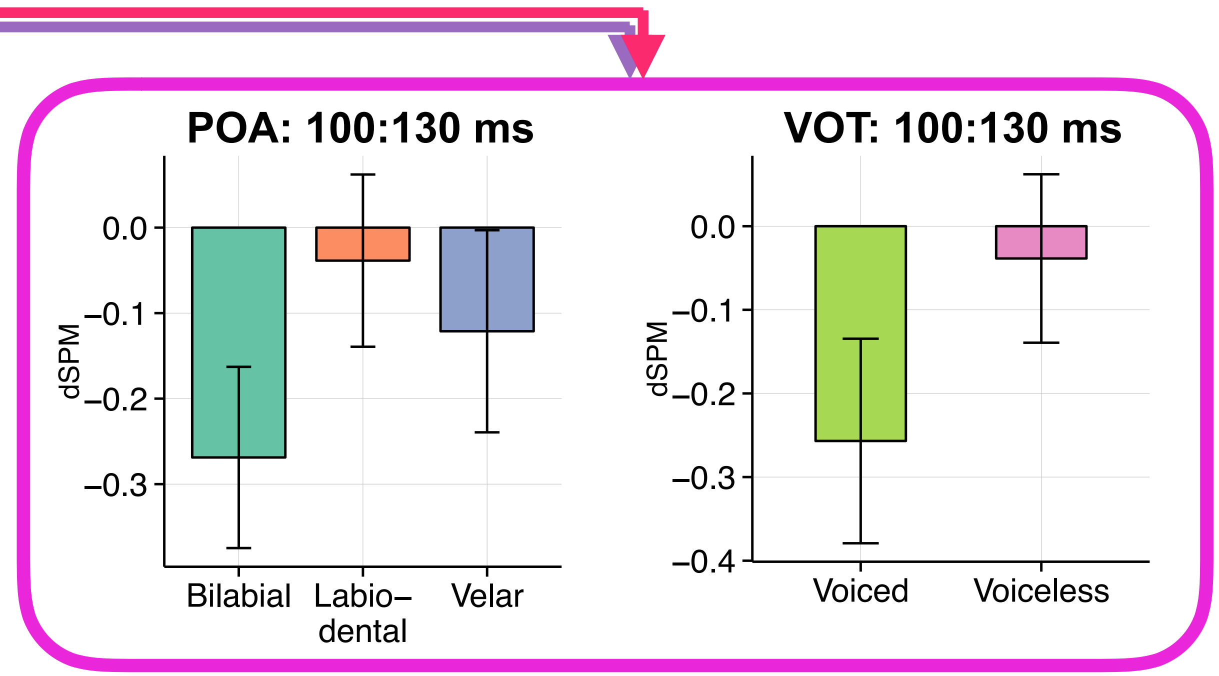
POA

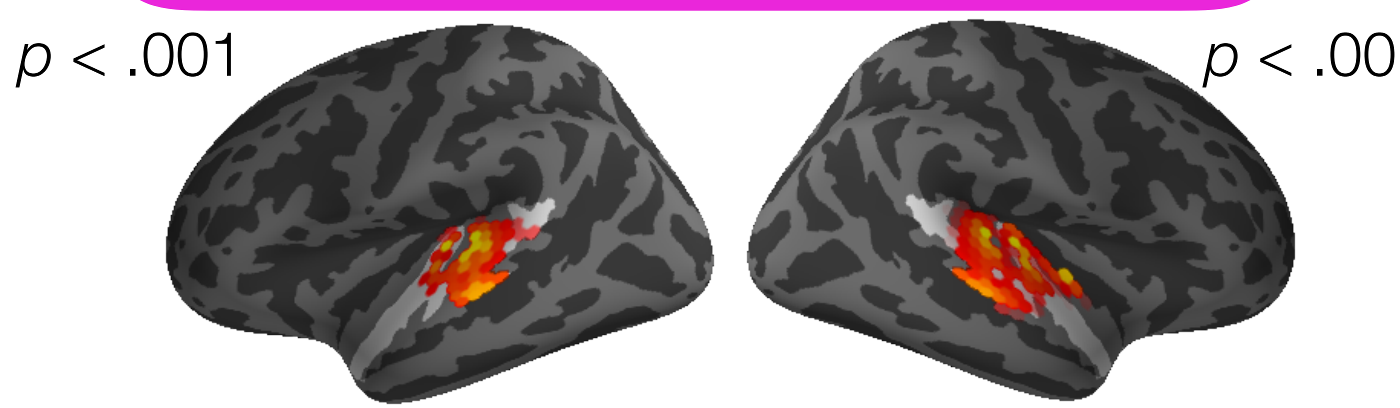
VOT

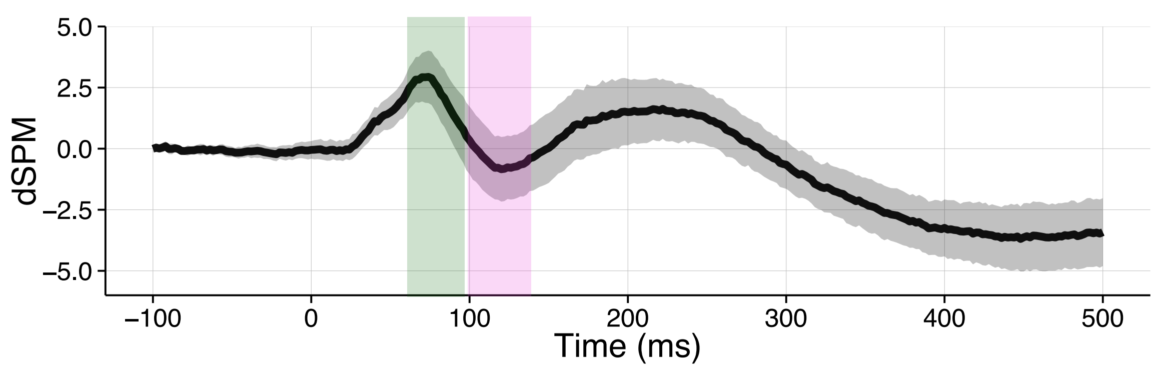


Ambiguity at Onset









Interim Conclusion

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b a r a k **ee** t

Interim Conclusion

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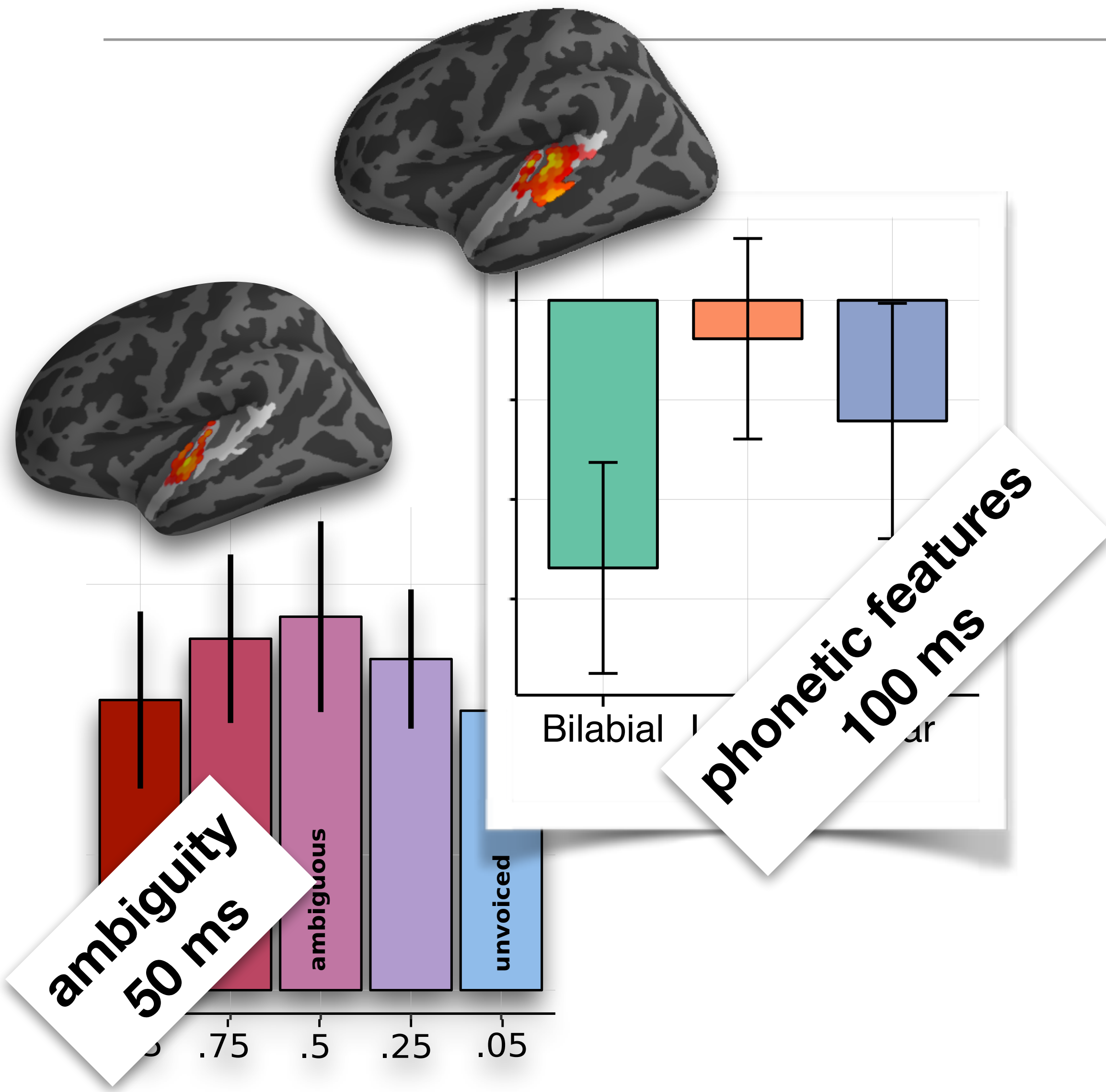
Interim Conclusion



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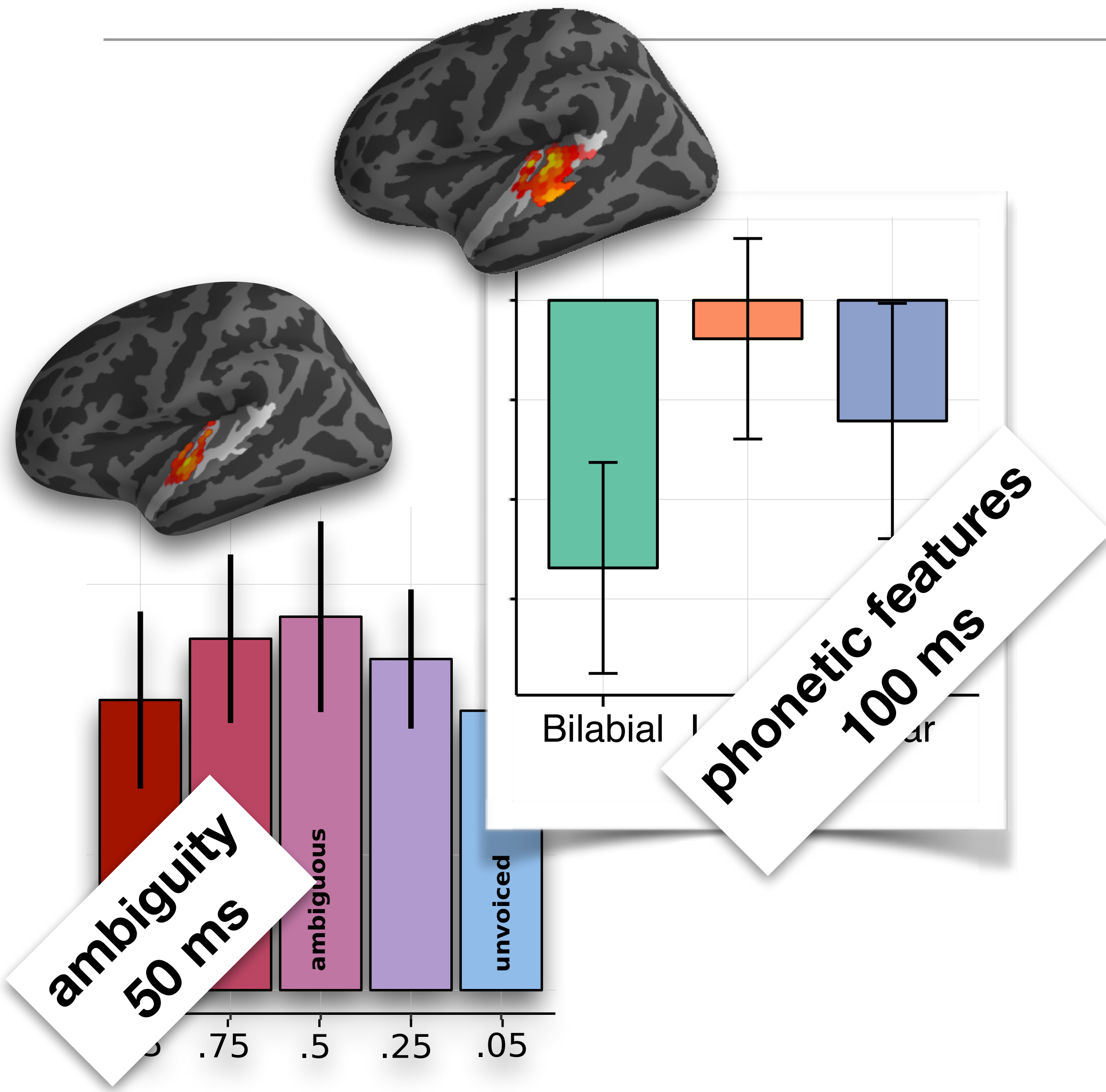
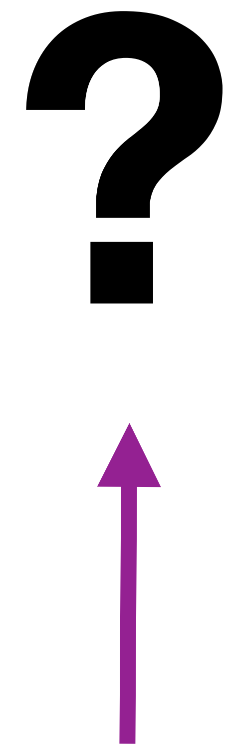
Interim Conclusion





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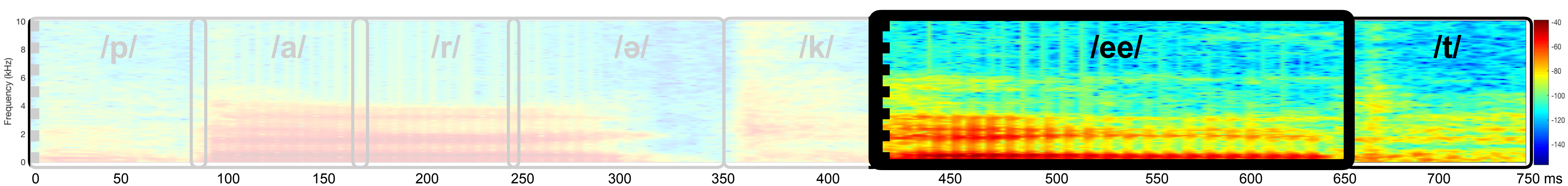
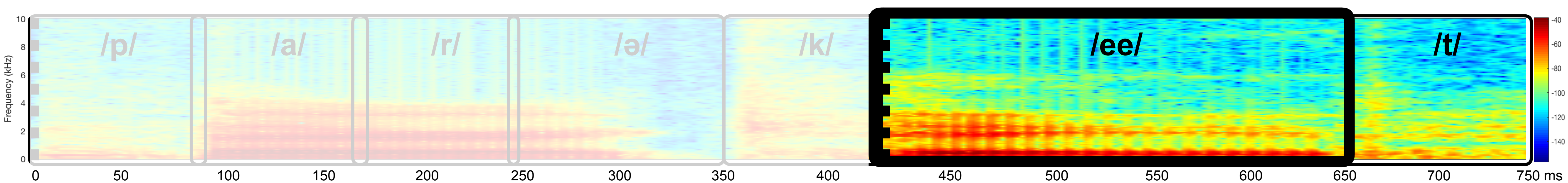
Today's Questions

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

Ambiguity at POD

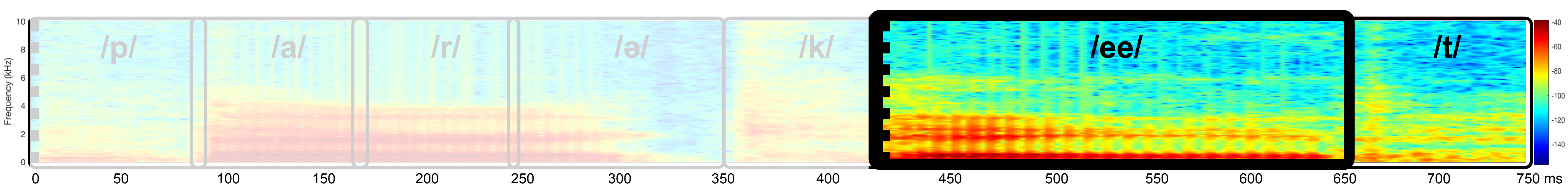


Ambiguity at POD



Ambiguity at POD

- Time-window: 0-200 ms after POD onset
- Region: **Heschl's gyrus** & **superior temporal gyrus** bilaterally



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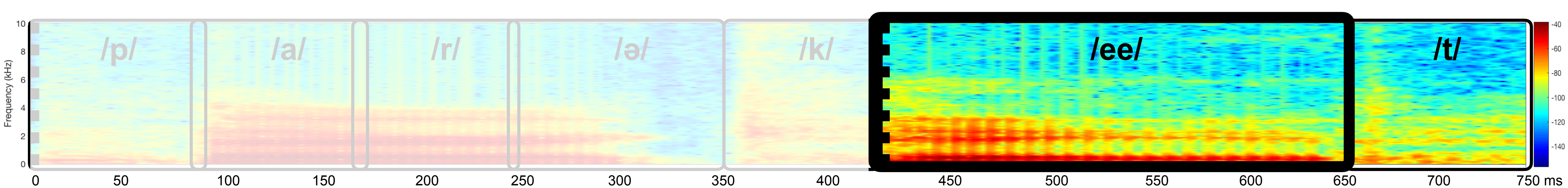

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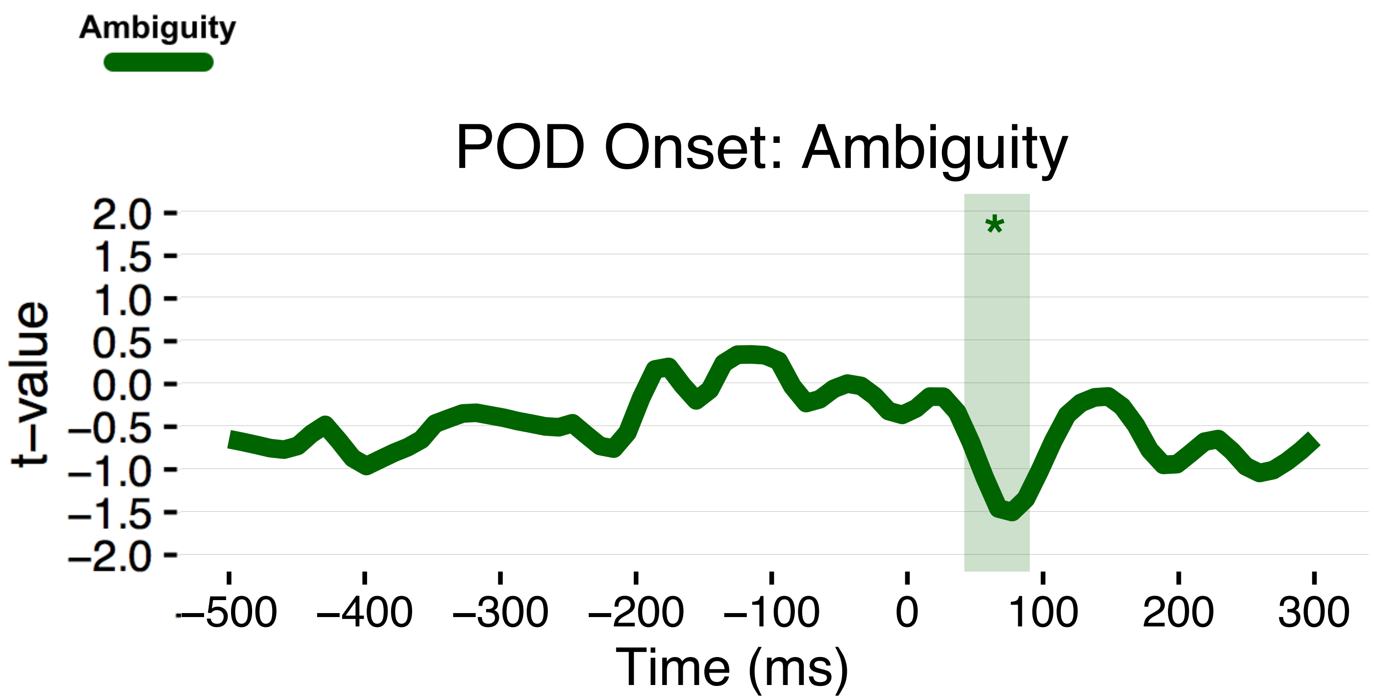

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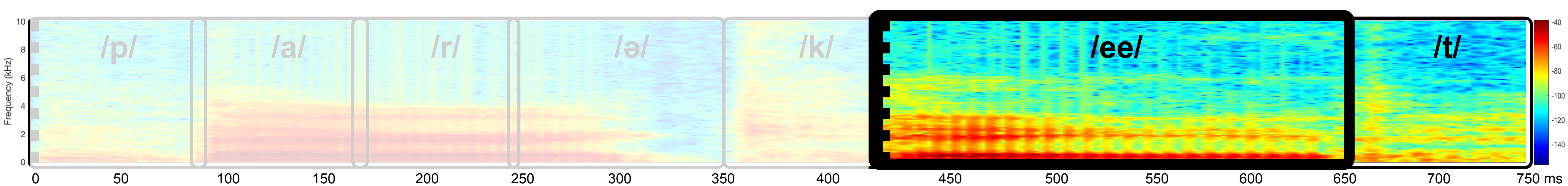

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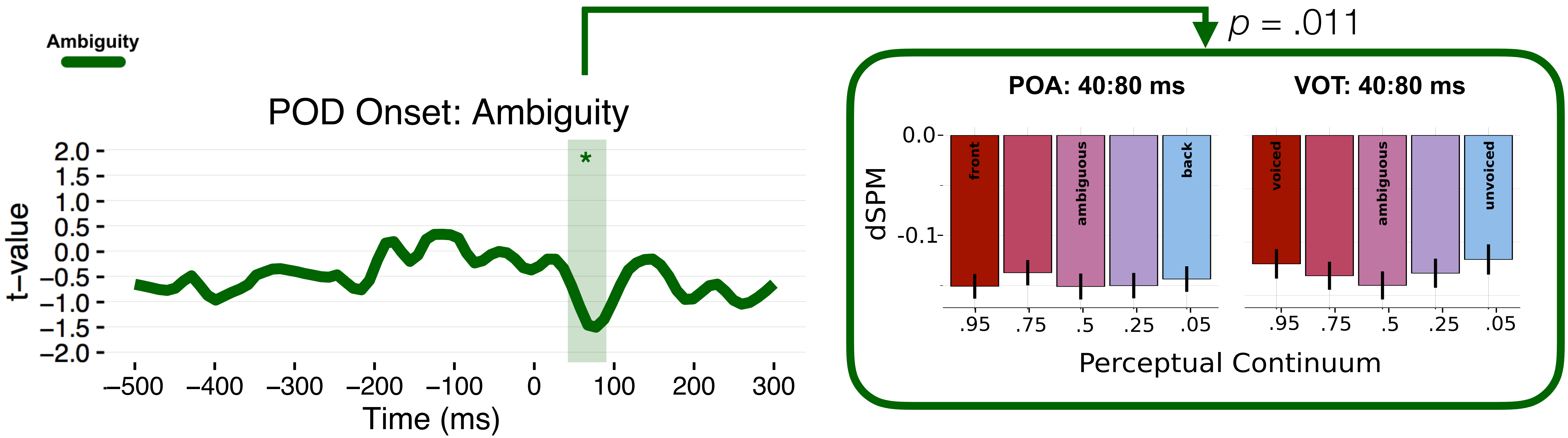

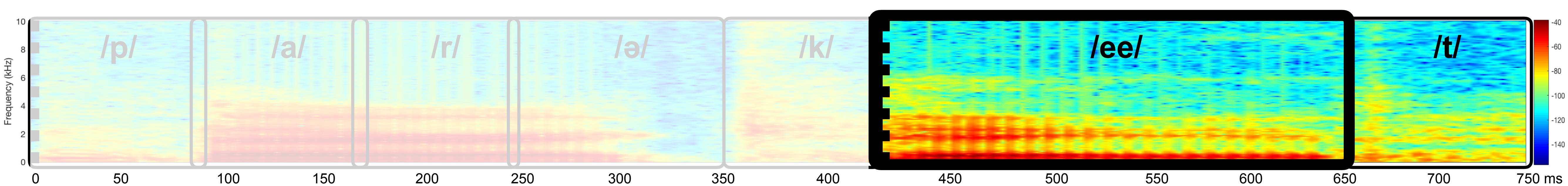

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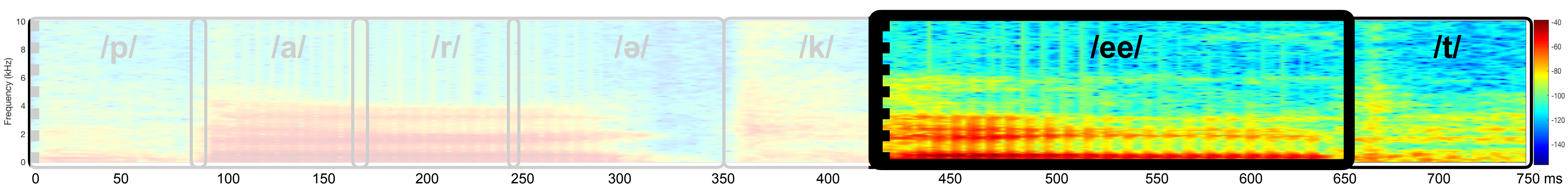

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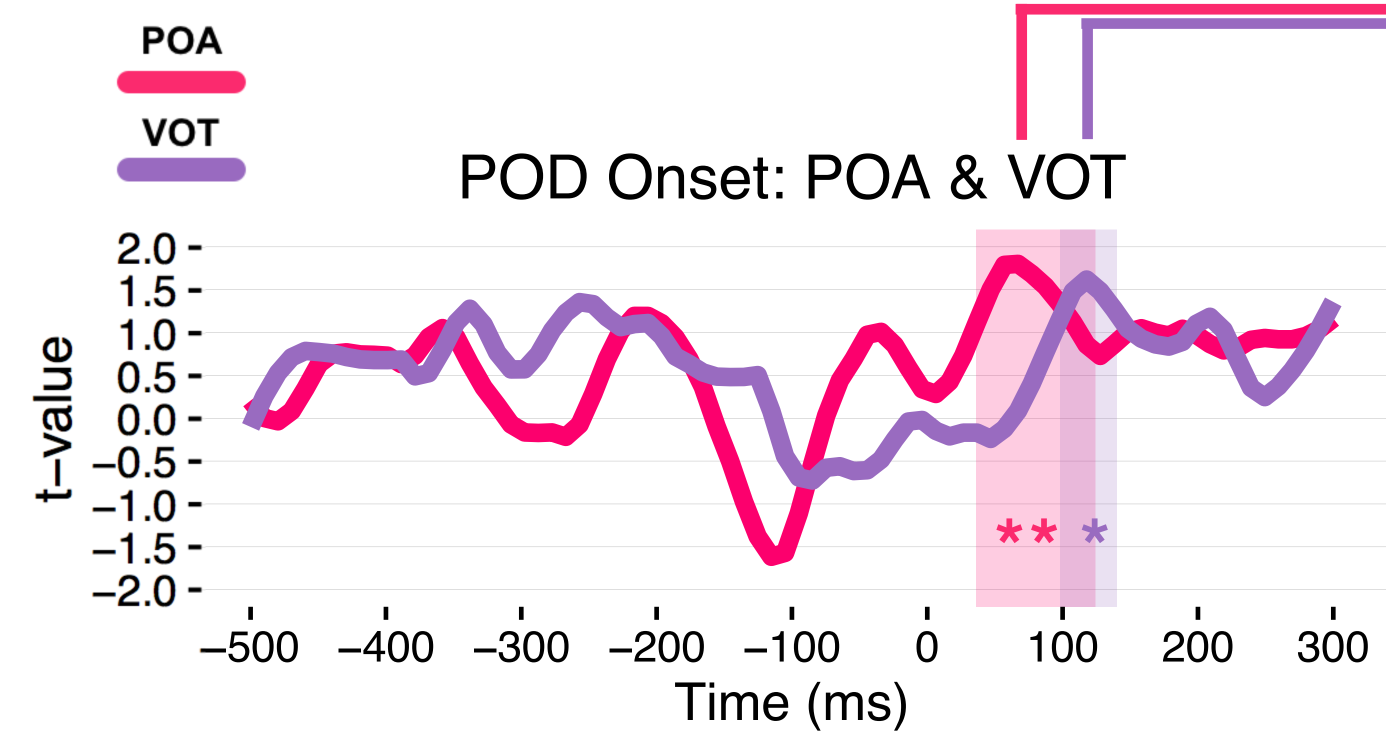
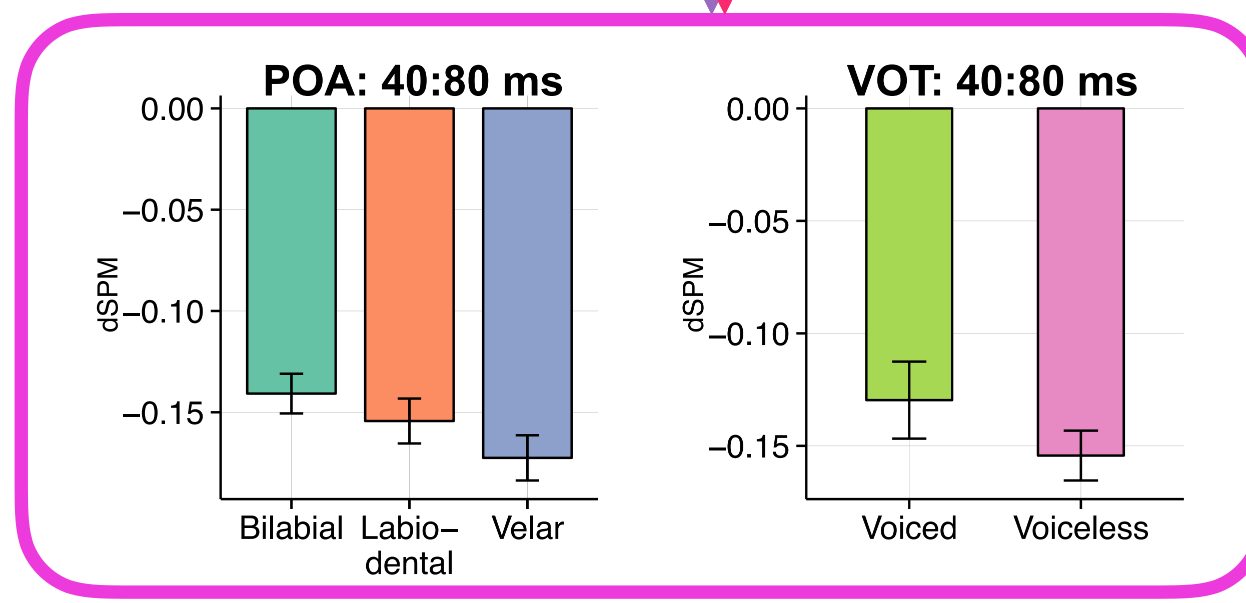
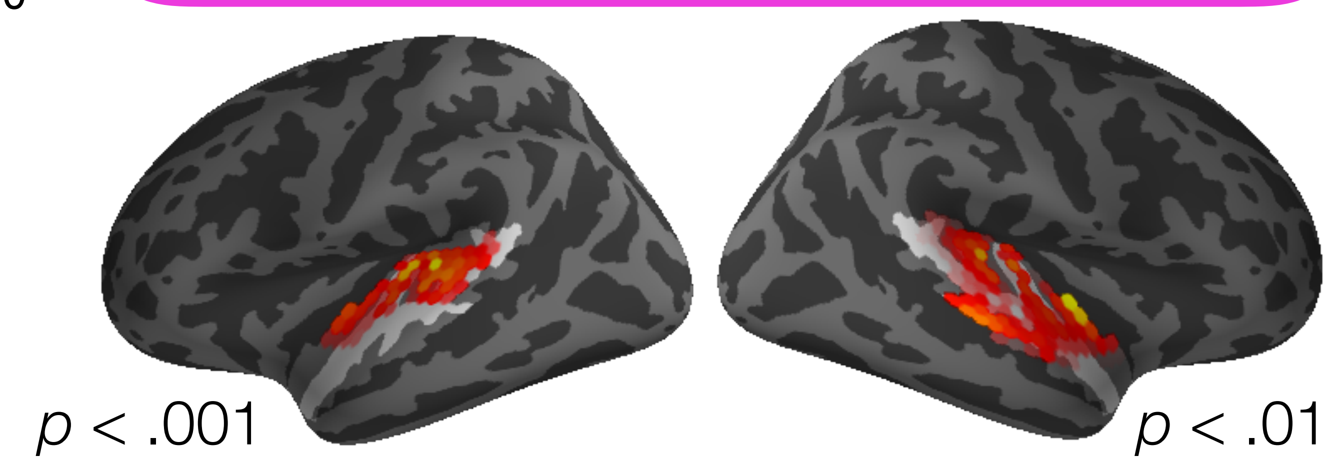
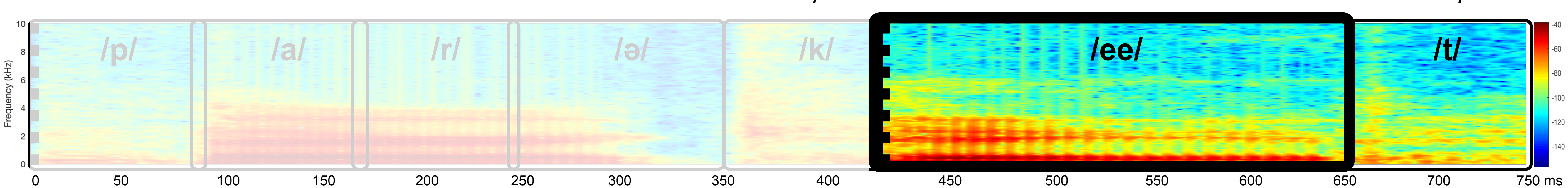
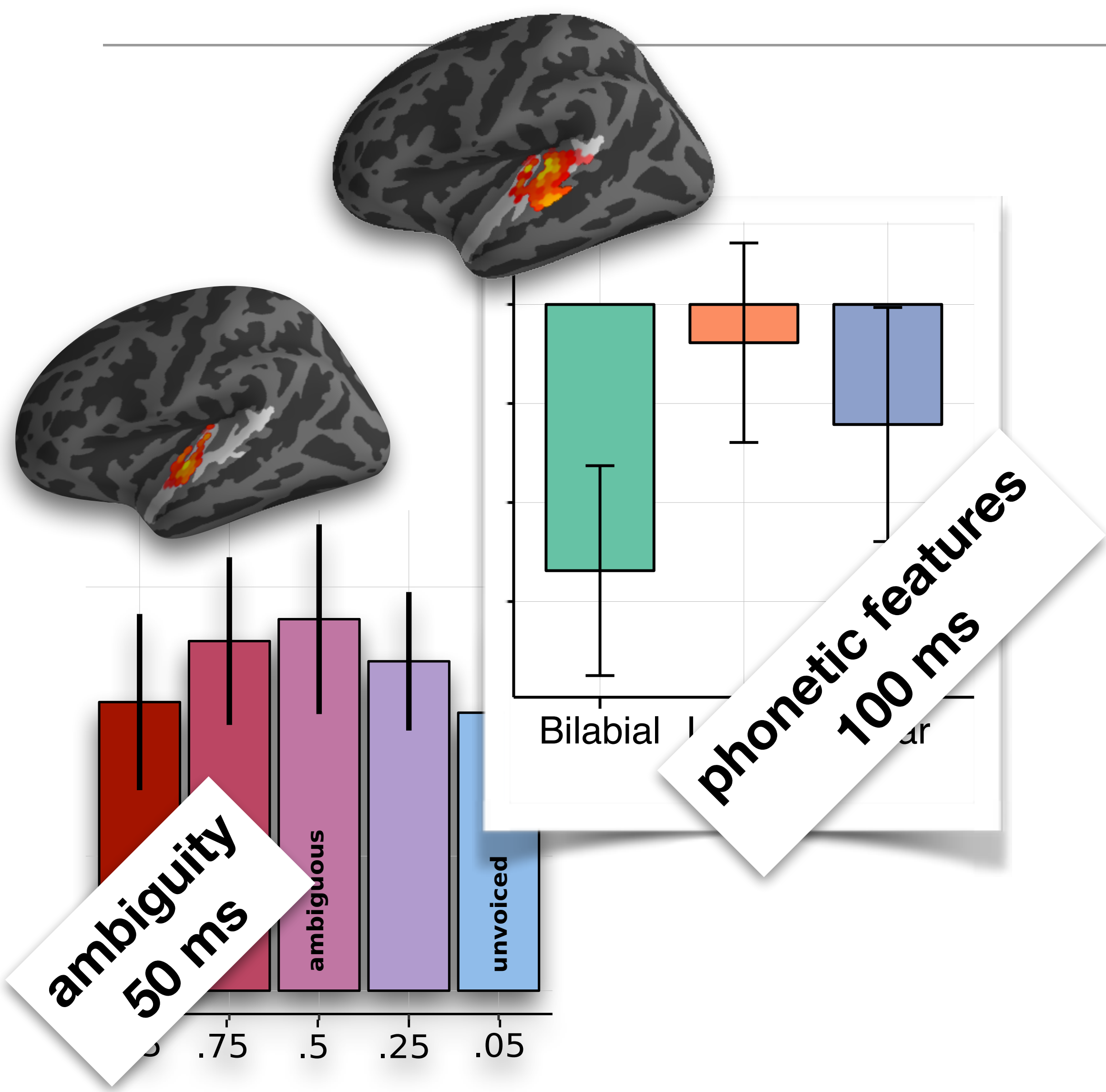








Interim Conclusion



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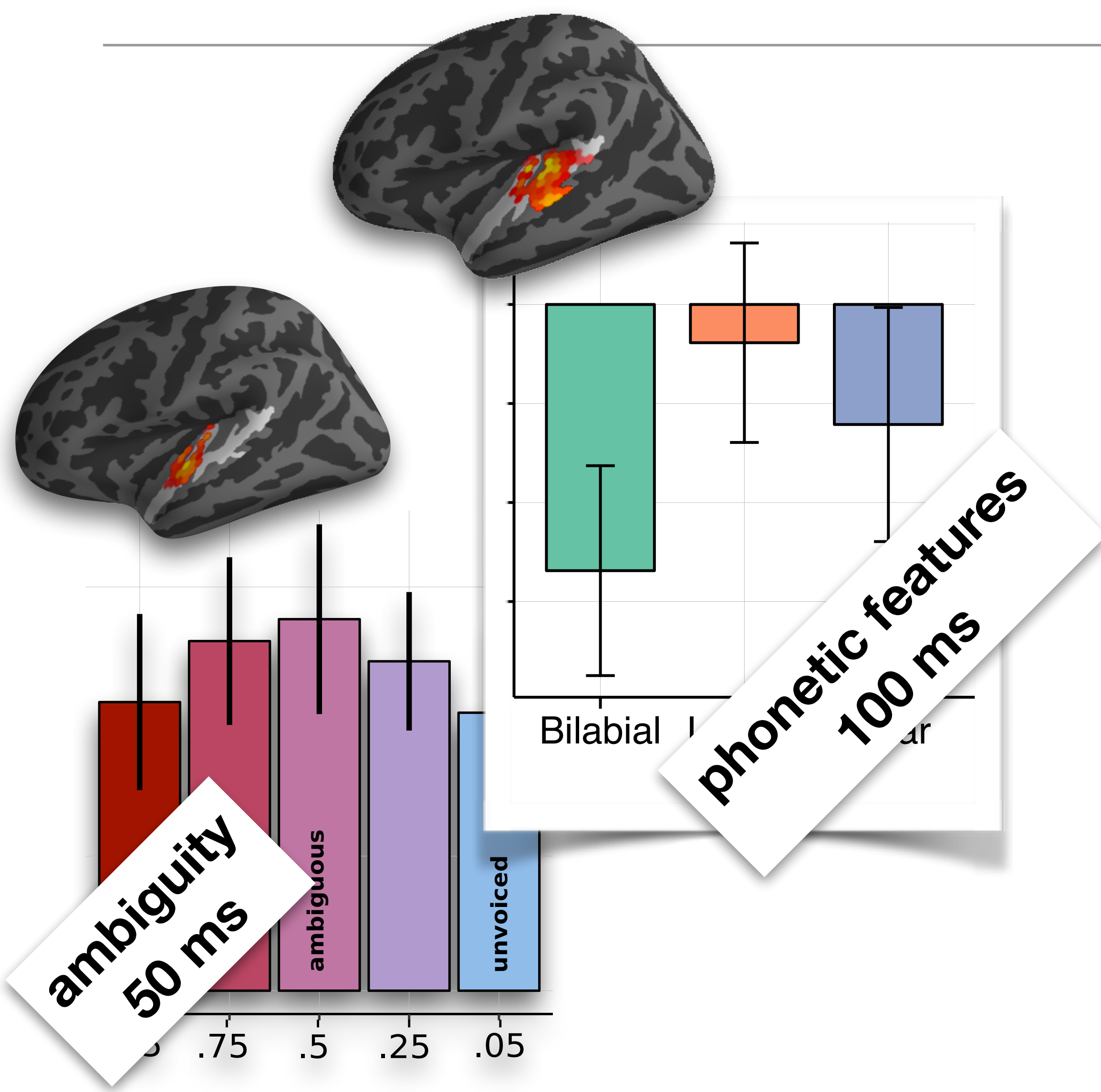
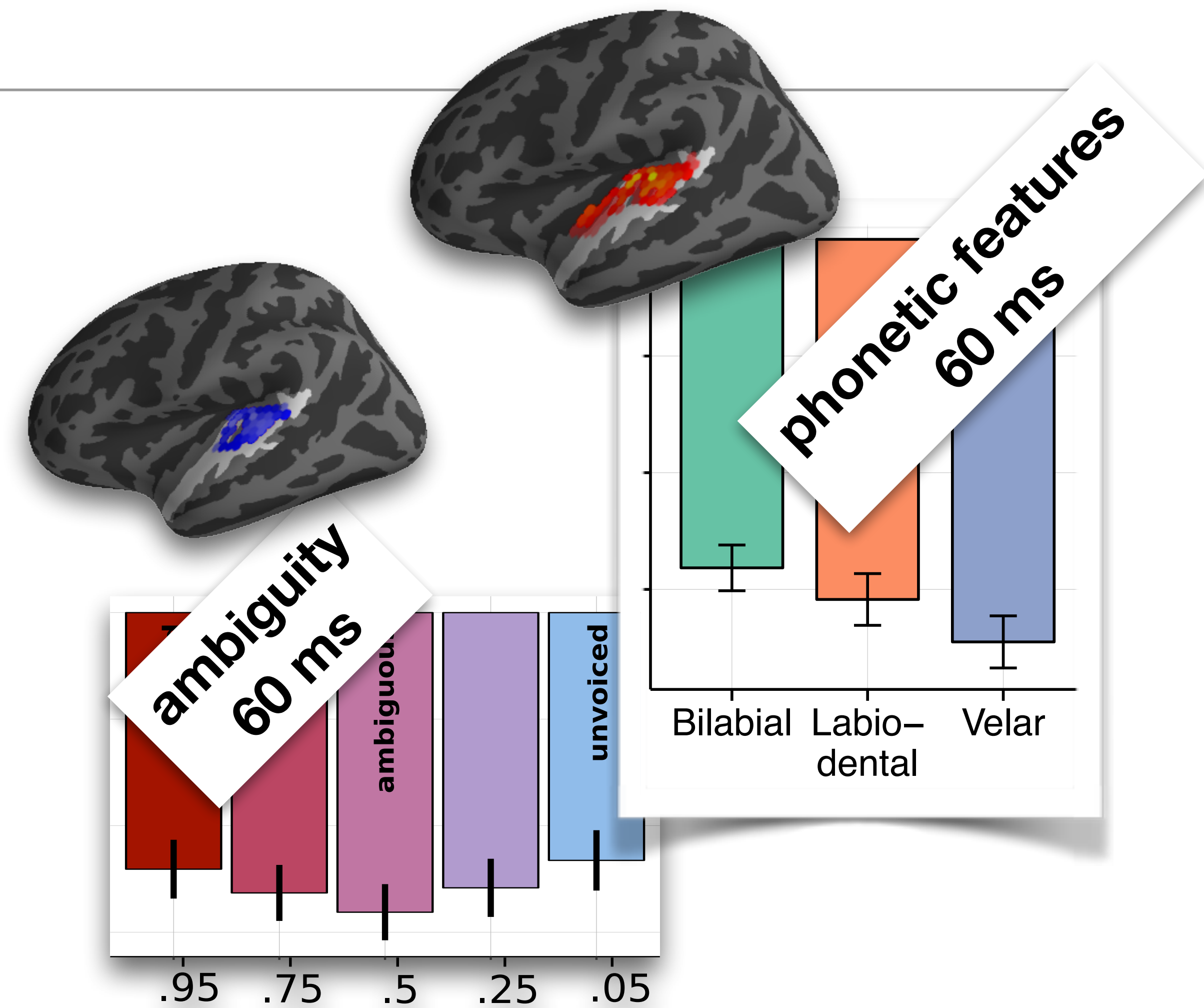
Interim Conclusion





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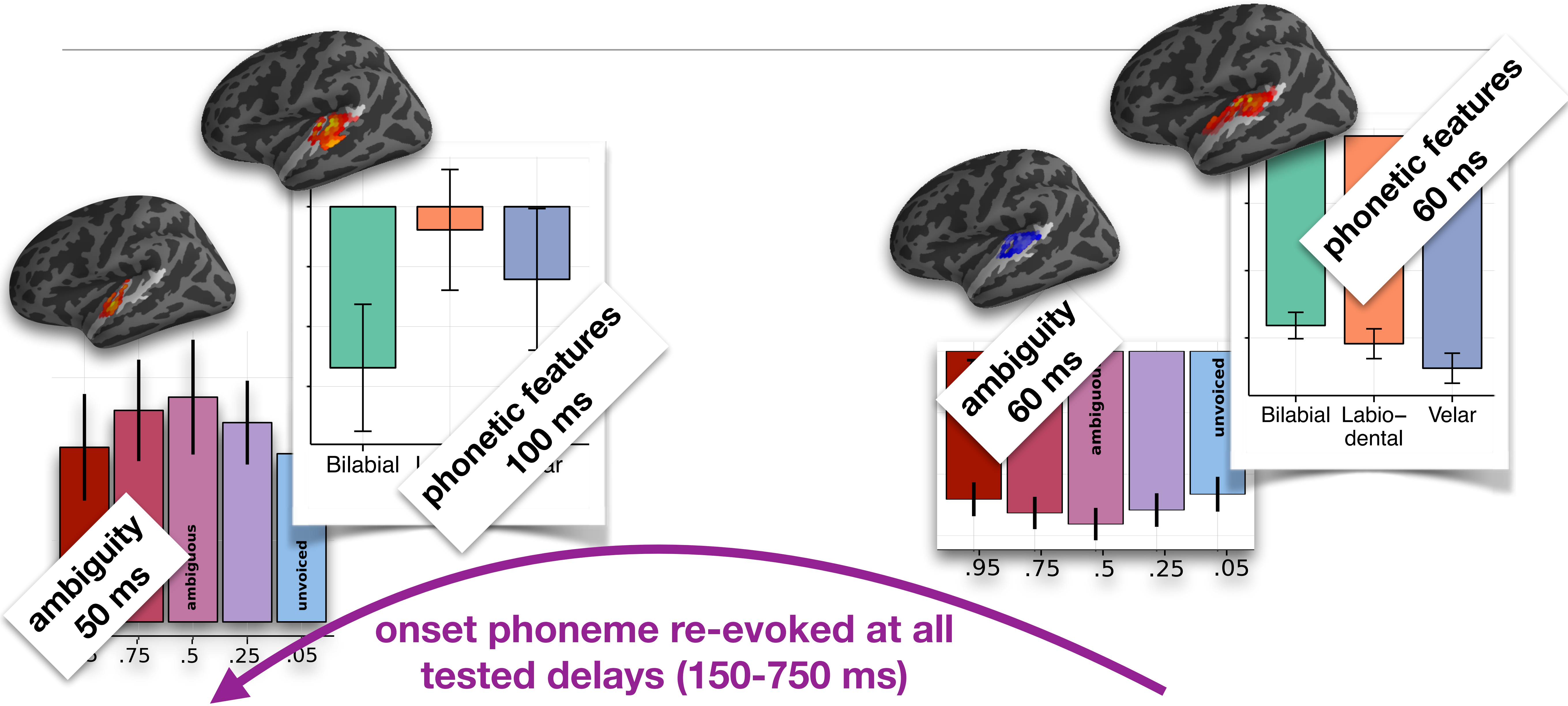

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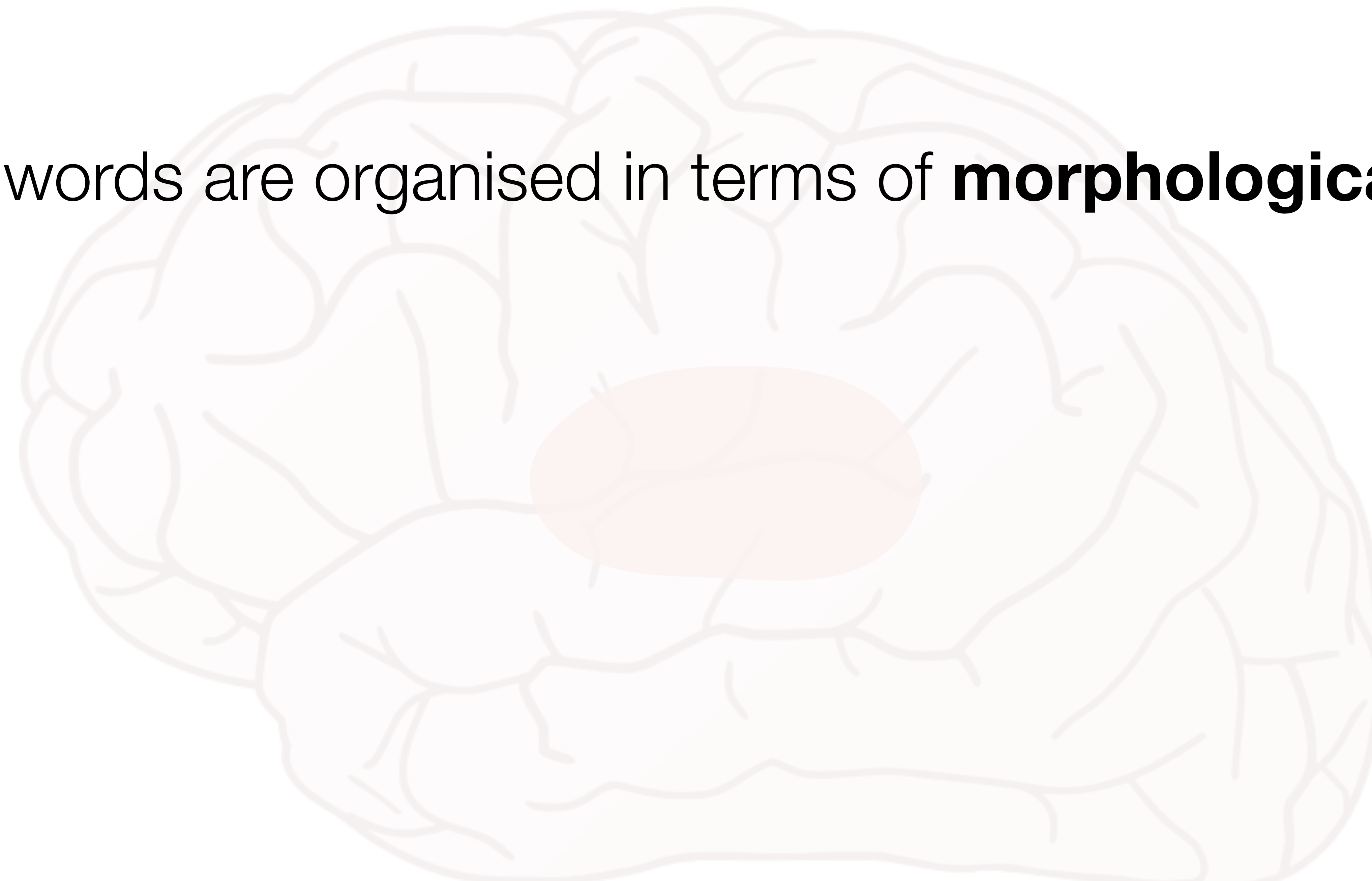
Today's questions

- How is language **organised** in the brain?
- What **computations** does the brain perform to process speech?

Take Home Messages

Take Home Messages

- words are organised in terms of **morphological** units



Take Home Messages

- words are organised in terms of **morphological** units
- auditory cortex is sensitive to **phoneme ambiguity** very early during processing

Take Home Messages

- words are organised in terms of **morphological** units
- auditory cortex is sensitive to **phoneme ambiguity** very early during processing
- **“auto-correct” process** is implemented by updating interpretations when more information is provided

laura.gwilliams@nyu.edu
@GwilliamsL

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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Funding: G1001 Abu Dhabi Institute

Thank you!

laura.gwilliams@nyu.edu
@GwilliamsL

NEW YORK UNIVERSITY