Neural dynamics of inflectional processing in speech comprehension: Combined MEG-EEG evidence

Caroline Whiting

Alexandra Woolgar, Li Su, Elisabeth Fonteneau, William Marslen-Wilson

Department of Experimental Psychology, University of Cambridge

MRC Cognition & Brain Sciences Unit, Cambridge

MRC | Cognition and Brain Sciences Unit

UNIVERSITY OF CAMBRIDGE

Speech Comprehension

- Spatial and temporal dynamics of accessing inflected forms through spoken input
- What are the processing streams that support comprehension of morphologically simple and complex forms
  - Left-lateralised fronto-temporal network (Binder et al., 2000; Marslen-Wilson & Tyler, 2007)
- How does neural activity in this network evolve over time, how is it modulated by the properties of the speech input

- Does combination of stem and suffix (*walk* + *–ed*) trigger differential processes
  - Additional analysis involved in parsing into stem + suffix
  - When and where are phonological cues to inflectional suffix identified
- Regions that are sensitive to the presence of a grammatical suffix

Aims of the Study

- Examine how addition of inflectional suffix modulates engagement of language network
  - Predict shift from bilateral fronto-temporal to increasing left-hemisphere engagement for morphologically complex forms

- Application of multivariate analysis to make more specific predictions about critical linguistic dimensions over time
  - Representational Similarity Analysis (RSA)
- How different brain regions respond to different properties of the input

- Use of combined MEG+EEG to track speech comprehension
  - Increased temporal resolution through combined MEG+EEG at source level
  - Speed of language comprehension encourages use of techniques that can accurately measure on millisecond time scale

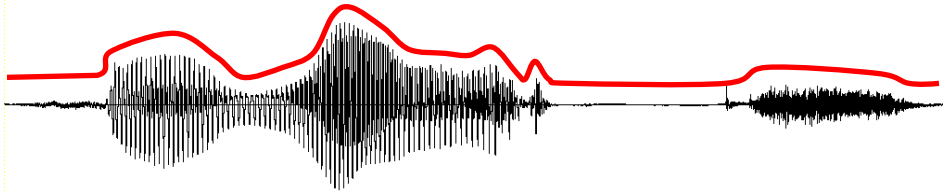
Experimental Design

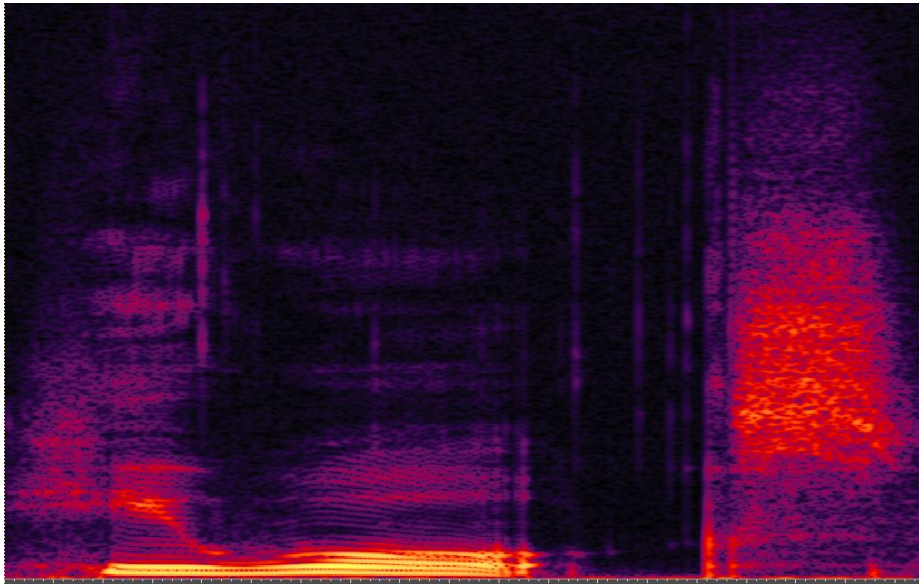
Regular	Irregular
I walk	I fall
He walks	He falls
He walked	He fell

- 10 regular, 10 irregular verbs
- 12 repetitions of each item (stable estimate for each word for items analysis)
- Acoustic baseline (Musical Rain) matched to each item, derived by jittering formants in each sound file
  - MR shares acoustic properties of speech but cannot be interpreted as speech
- 20 participants, right-handed, native English speakers
- Occasional (10%) one-back semantic completion task
- Trigger point at pronoun (onset of sound file) and onset of affix

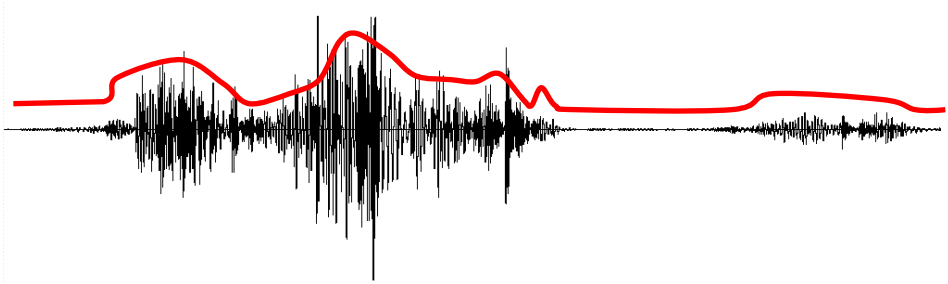
Stimuli

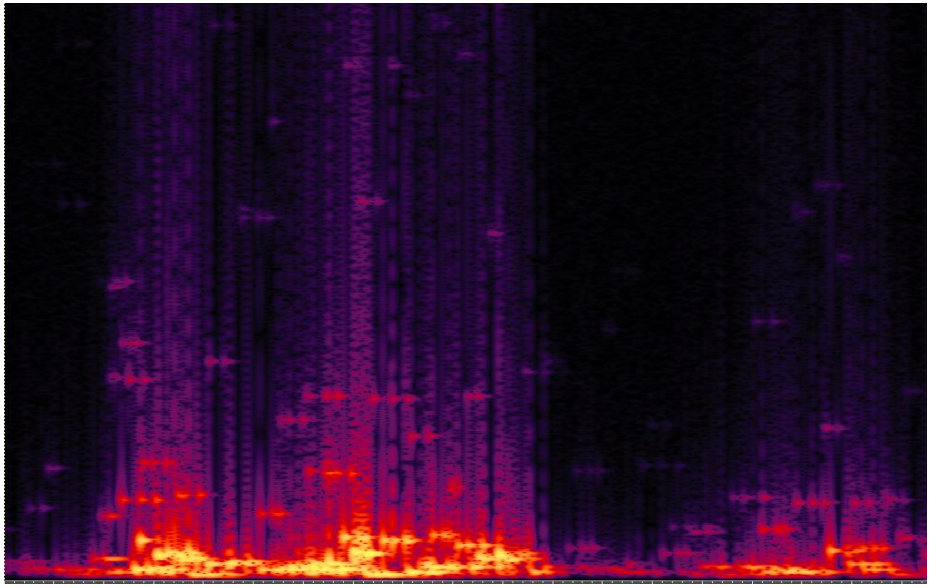
"He walks"





Matched Musical Rain





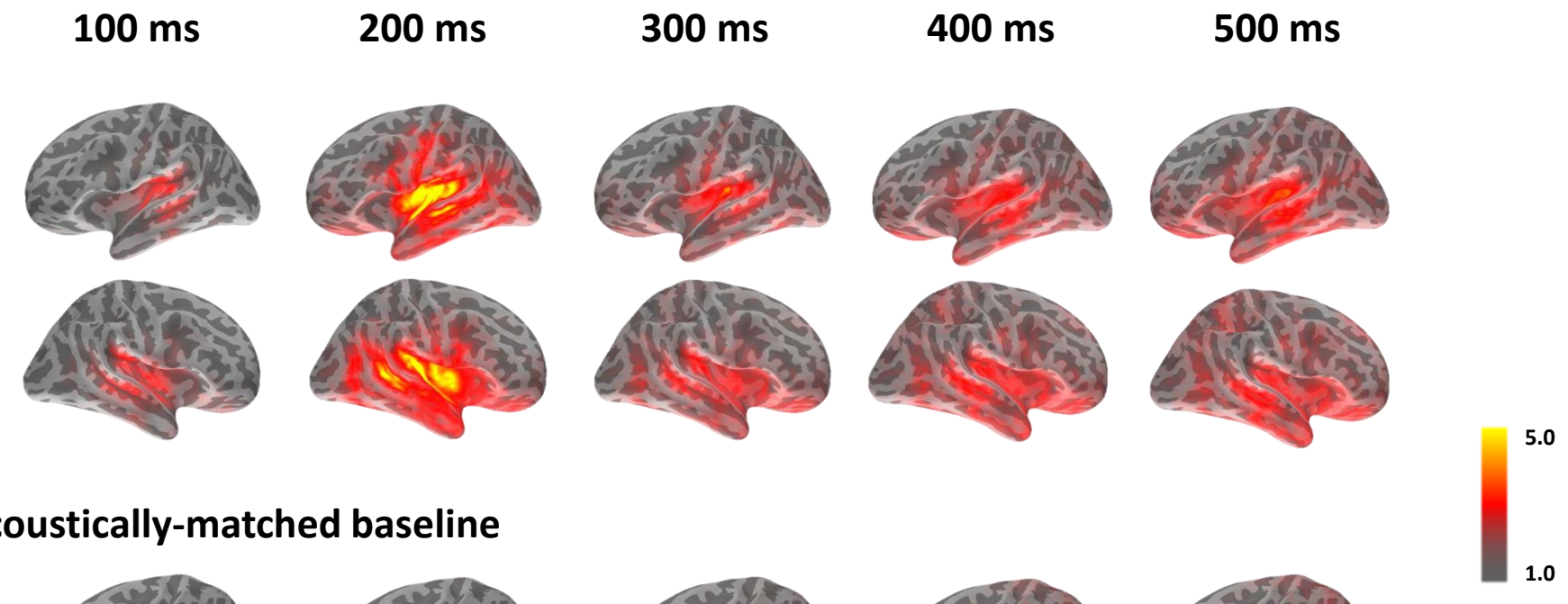
MEG-EEG analysis

- Concurrent MEG-EEG data acquired on 306-channel Vectorview system with 70-channel EEG
- Time windows of interest: -100 to 500 ms from onset of pronoun; -300 to 200 ms from onset of affix

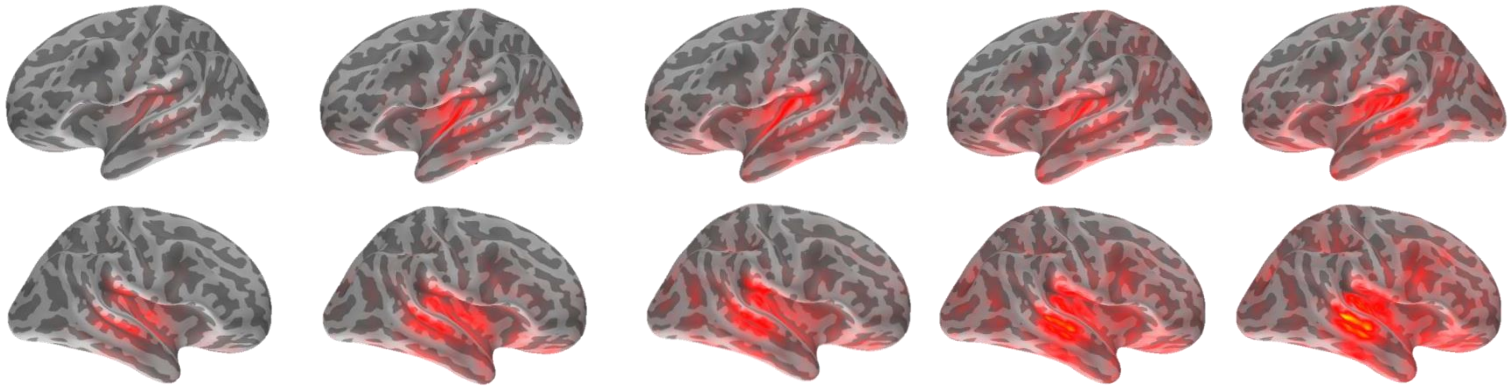
- Source reconstruction computed using L2 minimum-norm estimation (MNE) with three-layer boundary element model
- Combined MEG+EEG source solution
- Regions of interest defined anatomically in FreeSurfer
  - Frontal and temporal regions bilaterally

Average source-level activity

“I walk”

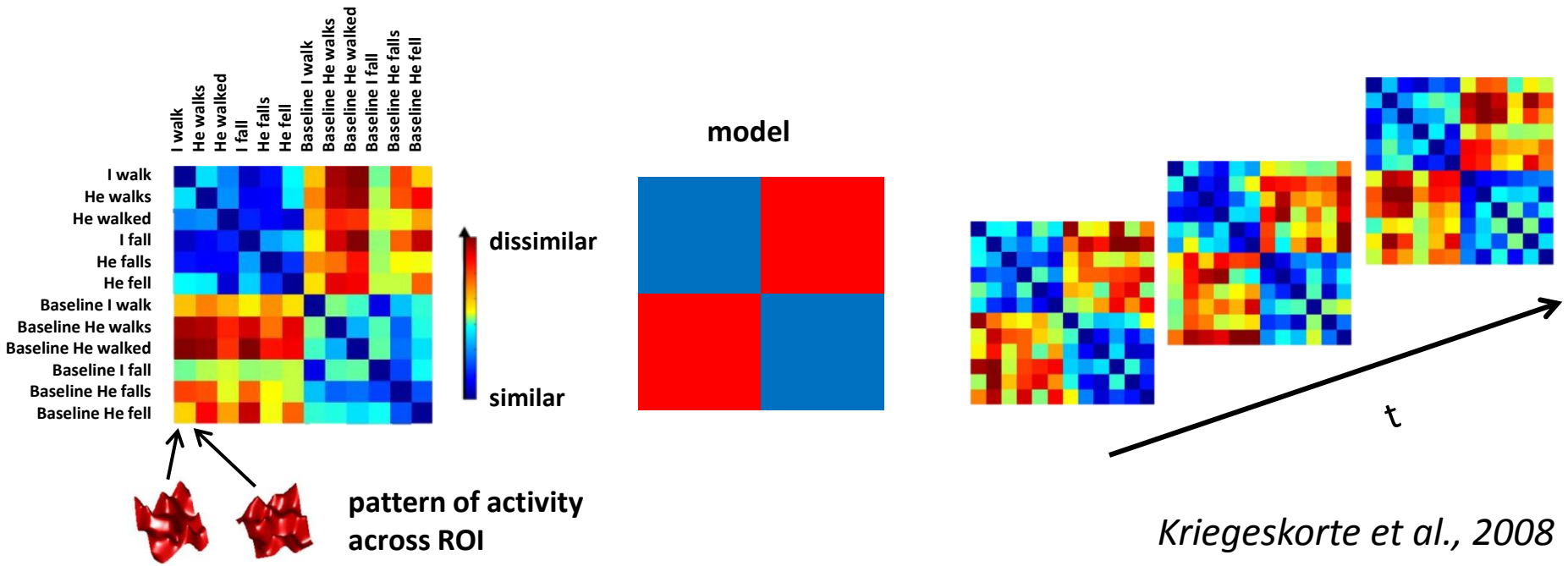


Acoustically-matched baseline



Representational Similarity Analysis (RSA)

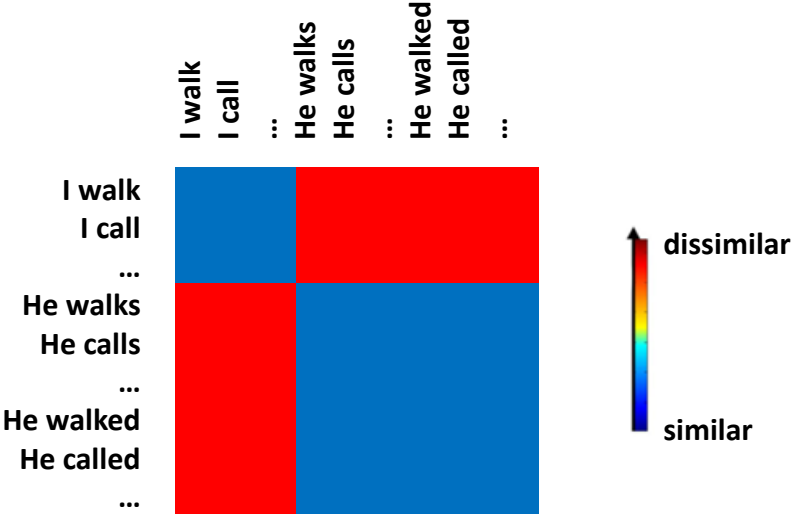
- Information carried by patterns of activity rather than overall activation in a given region
- Stimulus distinctions that are emphasised in a region at a particular time
- Allows inferences about the qualitative properties of the underlying processes

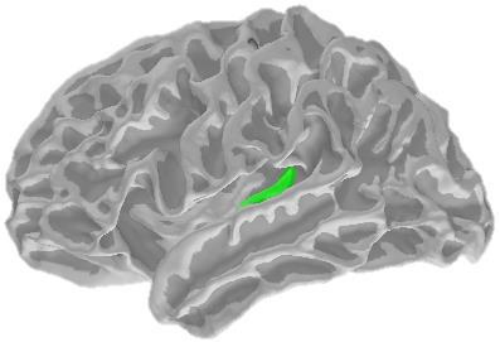


Kriegeskorte et al., 2008

Acoustic Model: Disambiguating Pronoun

- Acoustic differences between pronouns (*I*, *He*)
  - Voicing
  - Speech envelope (maintained in Musical Rain baseline)
- Early disambiguation, focused on primary auditory cortex (Tyler et al., 2013)
- 60 words, with same analysis run on Musical Rain





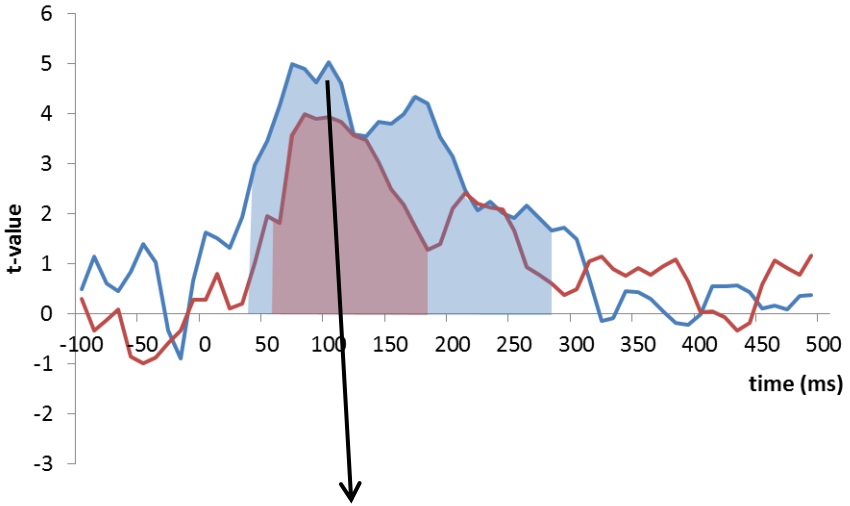
Heschl's Gyrus

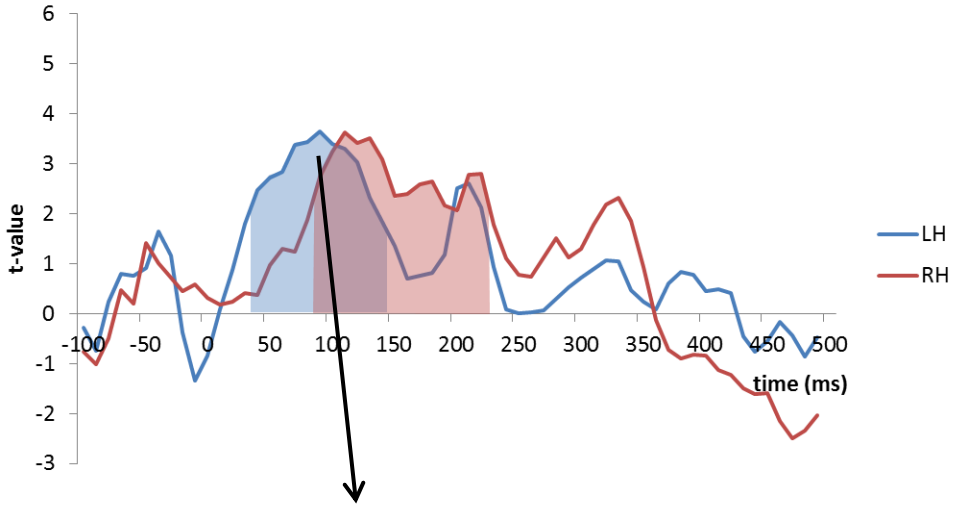
Acoustic Model

Words

Musical Rain

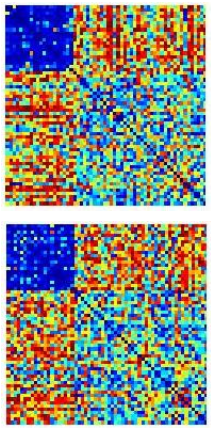
Heschl's Gyrus





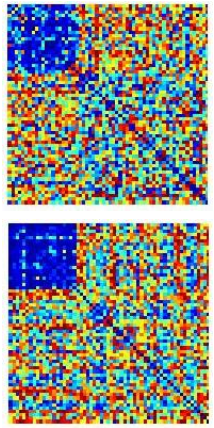
LH

RH



"I"

"He"

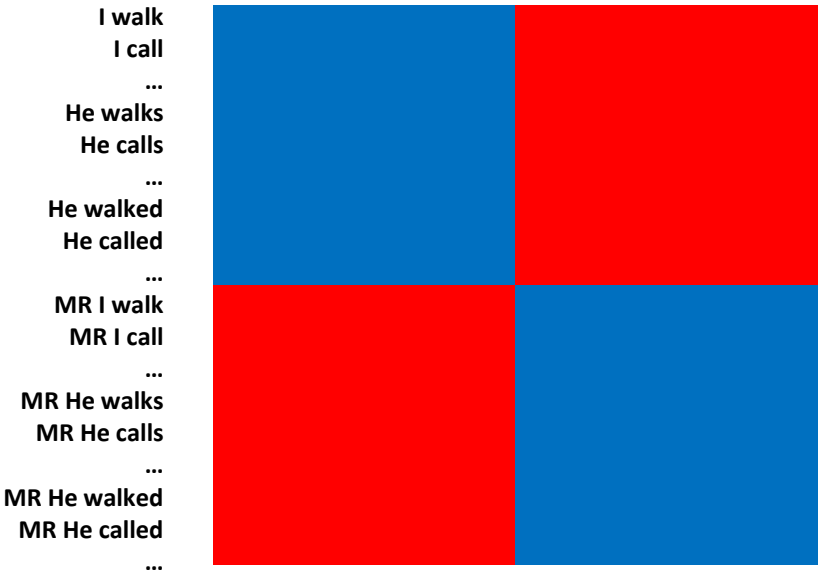


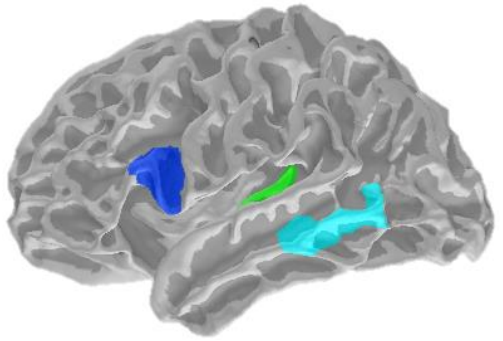
100 ms

100 ms

Speech Specificity Model

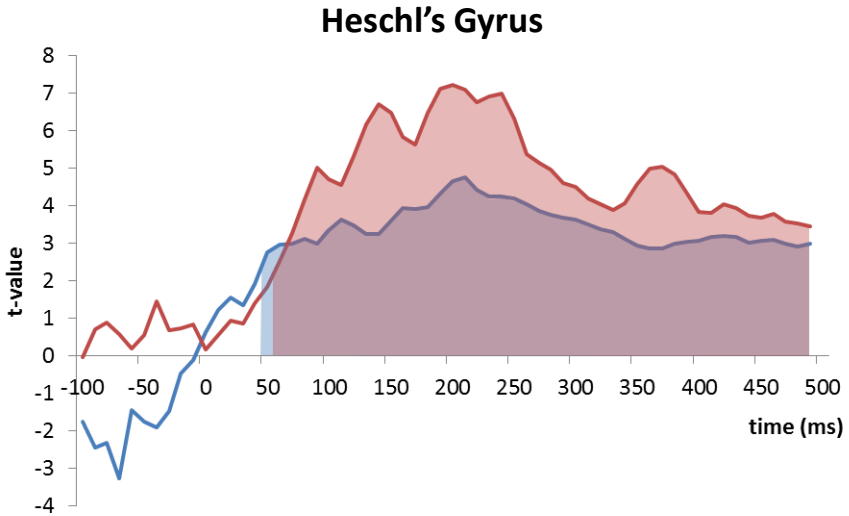
- What are the first regions to differentiate between speech (words) and non-speech (Musical Rain baseline)
  - Early engagement of primary auditory cortex
  - Also a critical dissociation for later stages of speech comprehension
- RSA reveals extensive bilateral fronto-temporal network

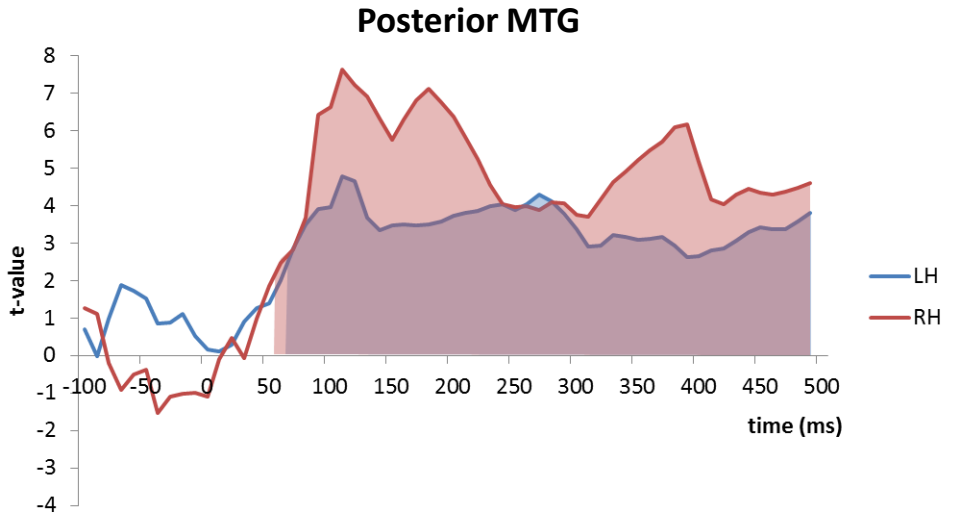


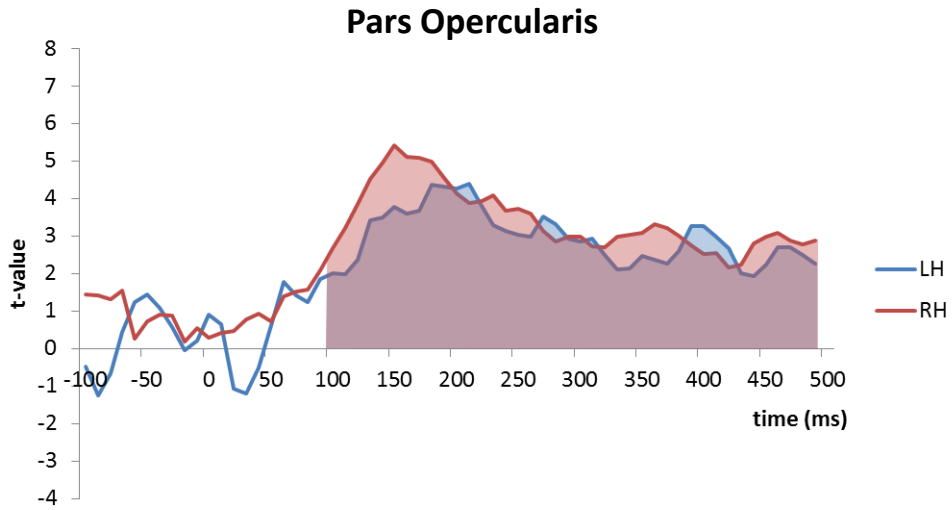


Heschl's Gyrus
Posterior Middle Temporal Gyrus
Pars Opercularis (BA 44)

Speech Specificity Model

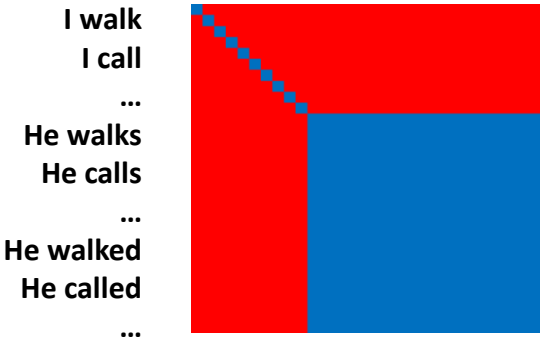


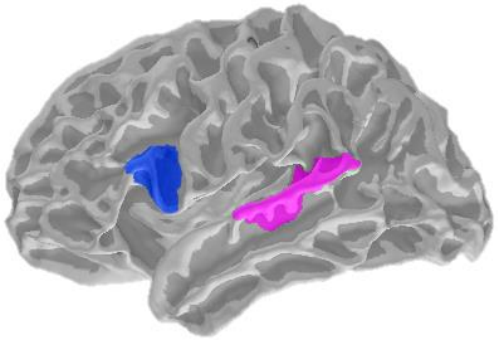




Affix Model

- Selective processing based on the presence of an inflectional suffix
- Engagement of left inferior frontal gyrus during grammatical processing (Bozic et al., 2010, Lehtonen et al., 2006, Marslen-Wilson & Tyler, 2007)
- Analysis aligned to release of suffix (*-s*, *-ed*)
- Control for length effect by running model on Musical Rain baseline (matched to each word)

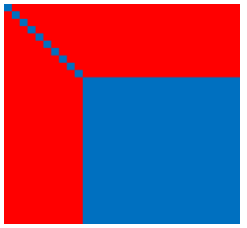




Posterior Superior Temporal Gyrus

Pars Opercularis (BA 44)

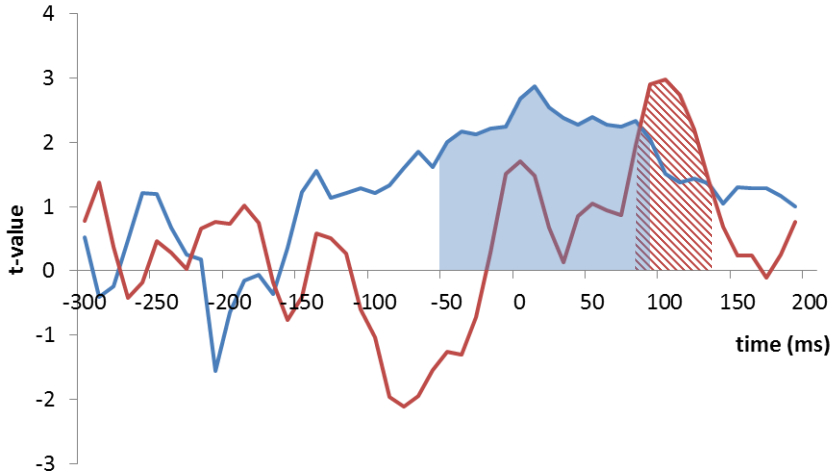
Affix Model

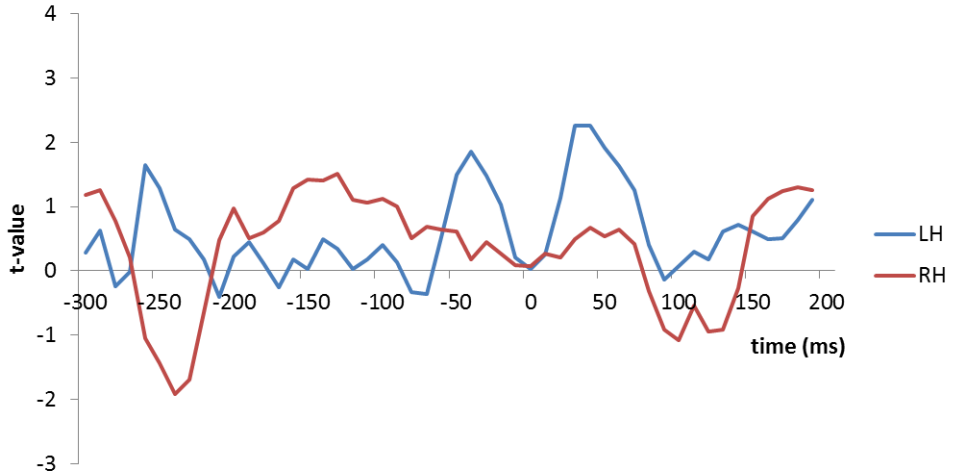


Words

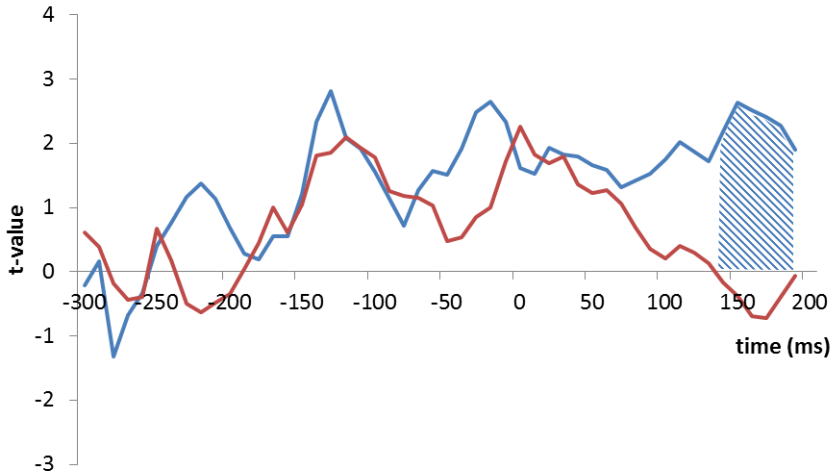
Musical Rain

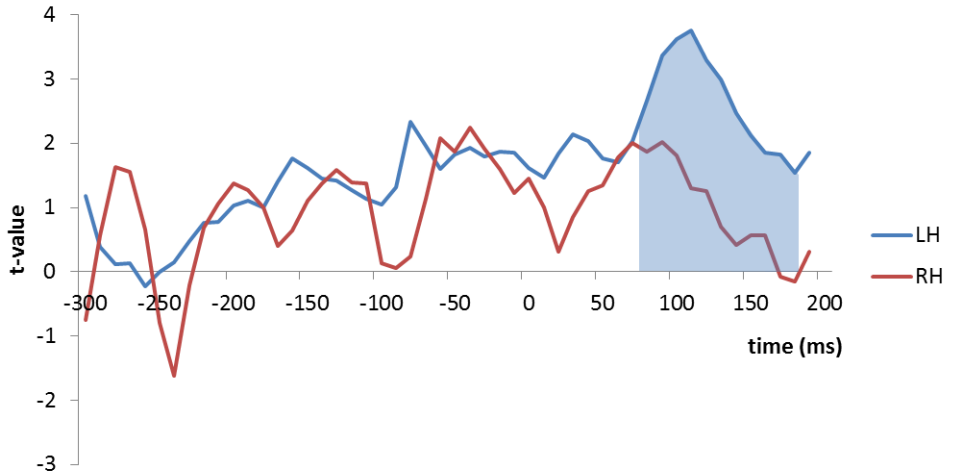
Pars Opercularis (BA 44)





Posterior Superior Temporal Gyrus





Conclusions

- Early dissociation based on low-level acoustic differences appeared by 50 ms in primary auditory cortex bilaterally, peaking at 100 ms
- Difference between speech and non-speech engages extensive bilateral frontal and temporal regions, peaking between 100-200 ms
- Processes within left IFG (BA 44) sensitive to the presence of an inflectional affix, not significant in Musical Rain baseline
  - Timing centred around onset of suffix

- Multivariate RSA provides detailed dissociations of linguistic processing dimensions across both space and time
- Allows us to construct a broader picture of the spatiotemporal dynamics of speech comprehension

Thank you


MRC
Cognition and
Brain Sciences Unit


UNIVERSITY OF
CAMBRIDGE


NeuroLex
/njʊərəlɛks/