Imperial College London

Talk: Leuven University

14/01/2020

# Cortical tracking of linguistic features in continuous EEG

Hugo Weissbart

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# Neuroanatomy of Language processing



Wernicke, 1874

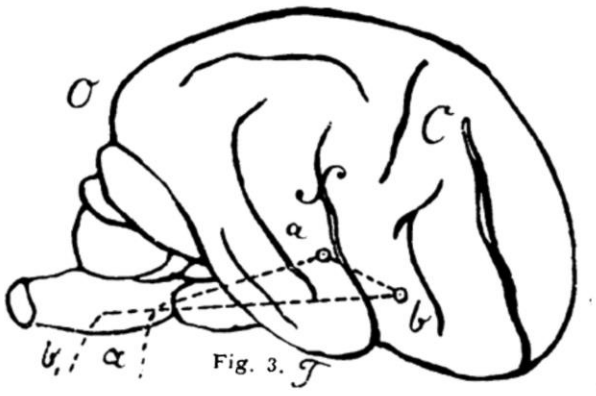
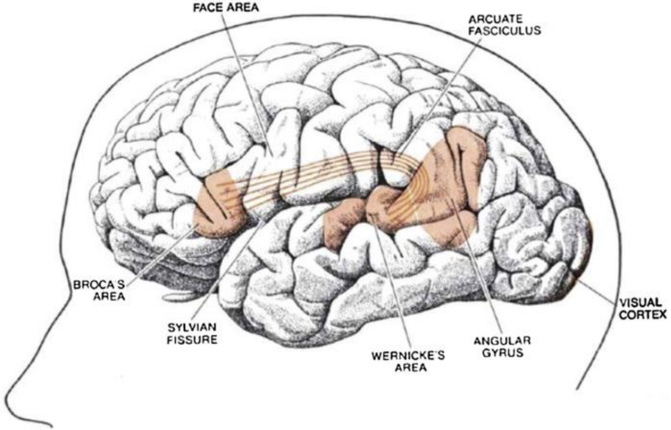



Fig. 3 [The speech areas and their connections. The "a" near the Sylvian fissure should have been designated "a₁".]

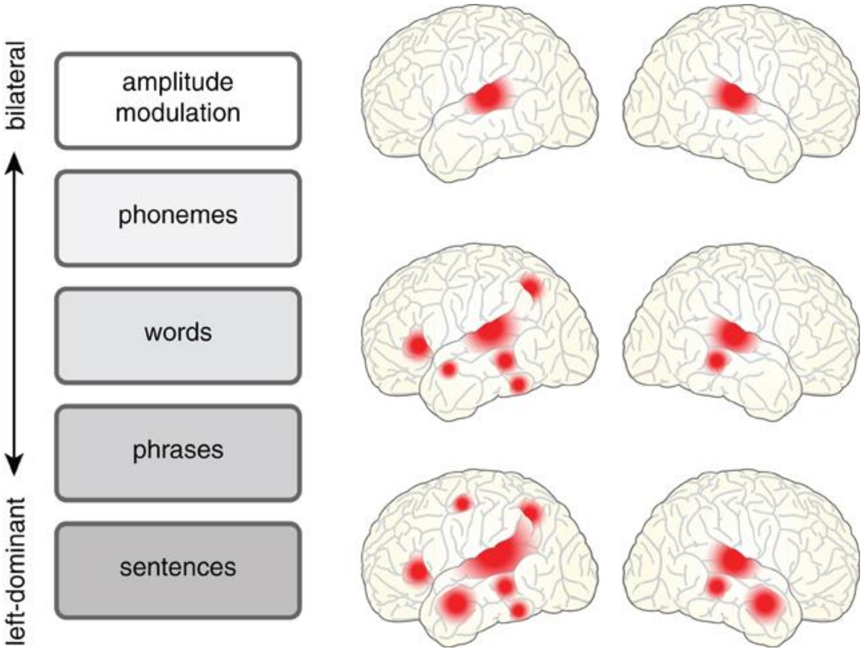
Geschwind, 1972




Tremblay & Dick, *Brain and Language*, ***2016***

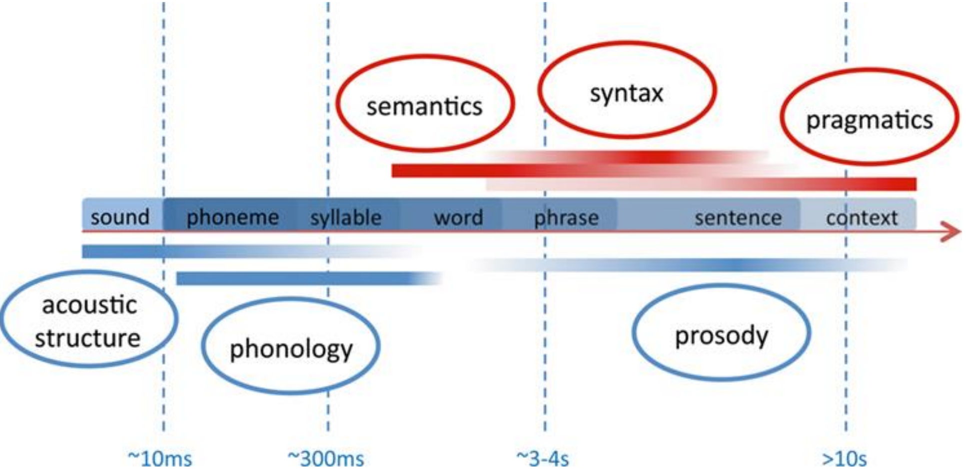
# Neuroanatomy of Speech processing

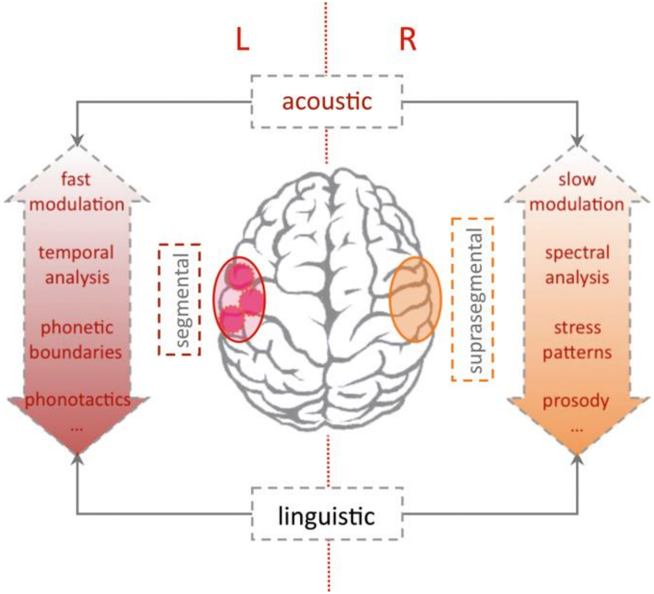





J. Peele, *Frontiers in Human Neurosci.*, **2012**

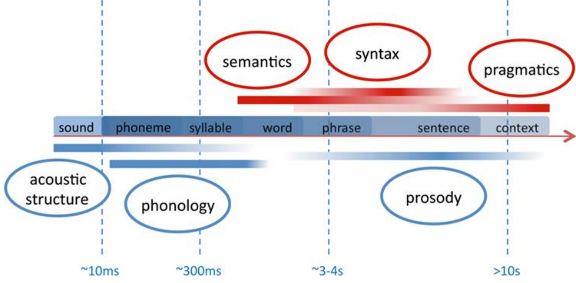
# Timescales in Speech

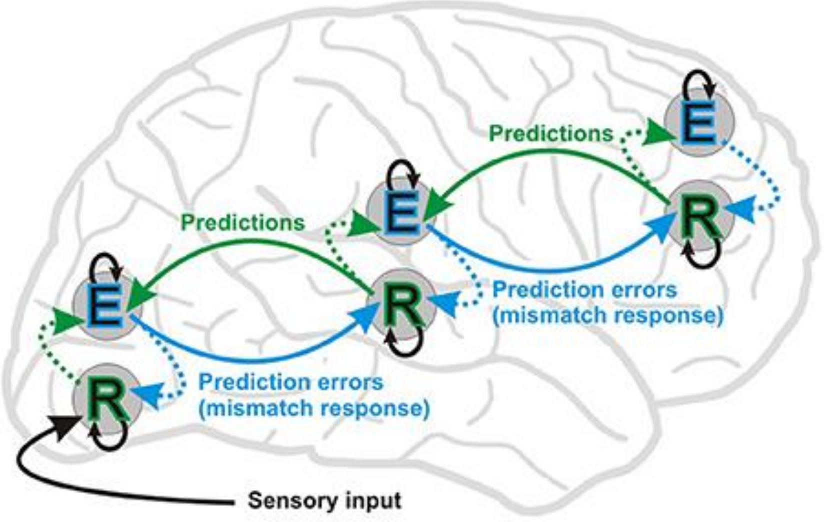


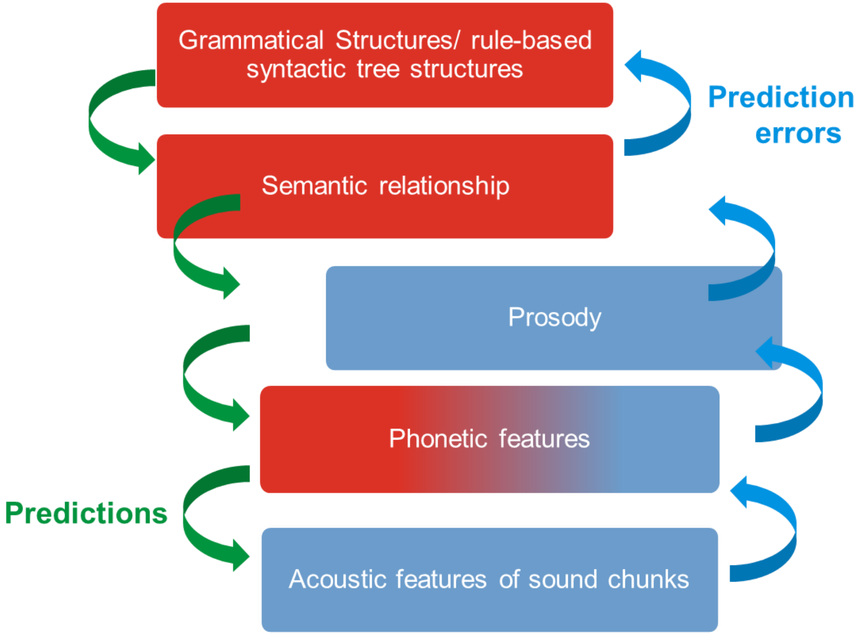

O. Hellmuth et. al., *Frontiers in Neuroenergetics* , **2010**

# Predictive Coding for Language Perception



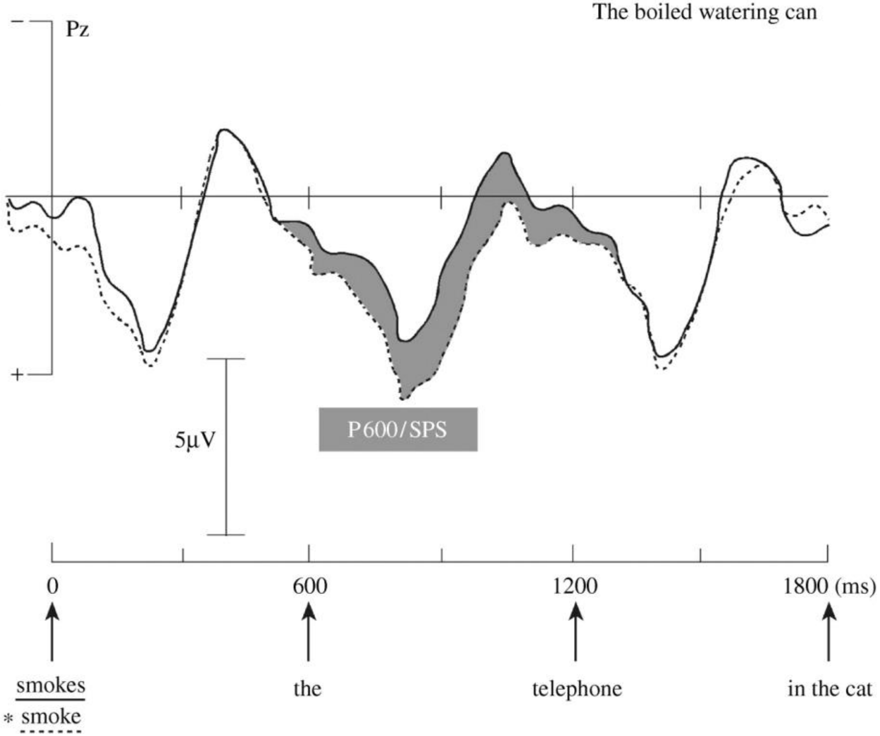

Stefanics, Kremláček & Czigler, 2014, Front.Hum.Neurosci.



# Linguists’ ERP components:

- Modulation of the N400 amplitude as a result of a manipulation of the semantic fit with context

- A P600/SPS is elicited by a grammatical violation (here in number agreement between subject and verb)




Peter Hagoort Phil. Trans. R. Soc., 2008

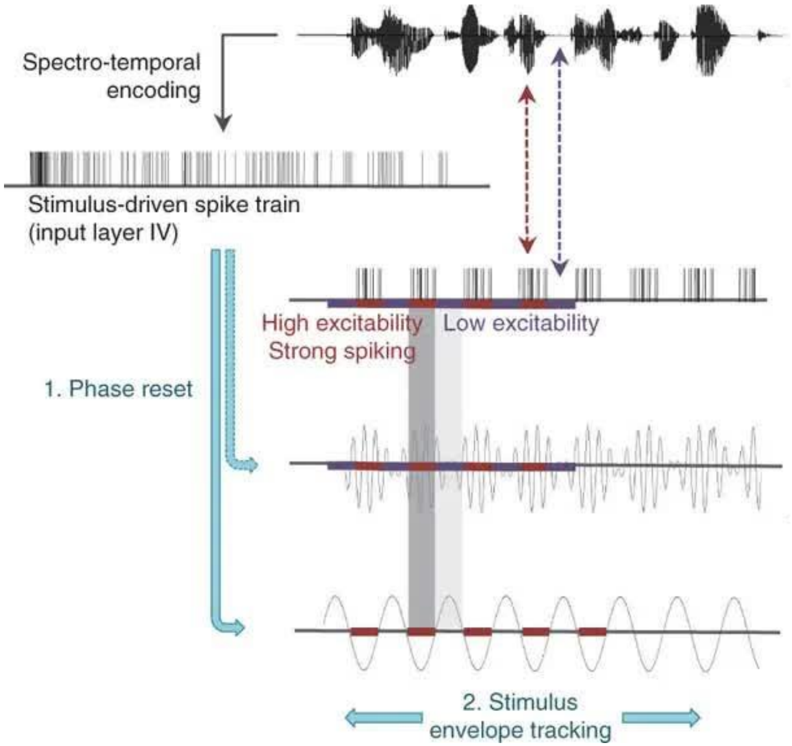
# Naturalistic Language Comprehension

- Listening to repetition of sentences, words, syllables or violations is far from a natural condition for speech comprehension

- Listening to a story you like allows to study speech in its ecologically valid context and helps to maintain the attention

# Cortical tracking of speech features

- Characterizing brain responses to continuous speech:
  - Speech acoustic (Ding and Simon, 2014)
  - Phonemes (Di Liberto, 2015)
  - Sentence Structure (Ding et al. 2017)
  - Semantic similarity (Broderick et al., 2018)




Giraud, A. L., and Poeppel, D.., *Nat. Neurosci.* **2012**

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# Language Modelling with RNN

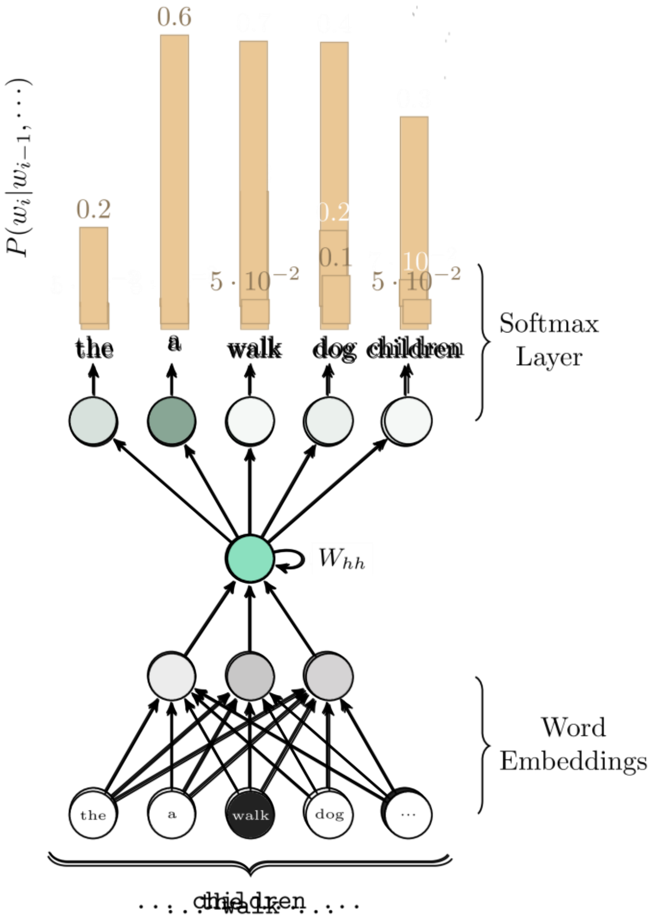
- The ***Surprisal*** is defined from a probability:

$$s_t = -\log[\, p(w_t | w_{t-1}, w_{t-2}, \dots, w_0)\, ]$$

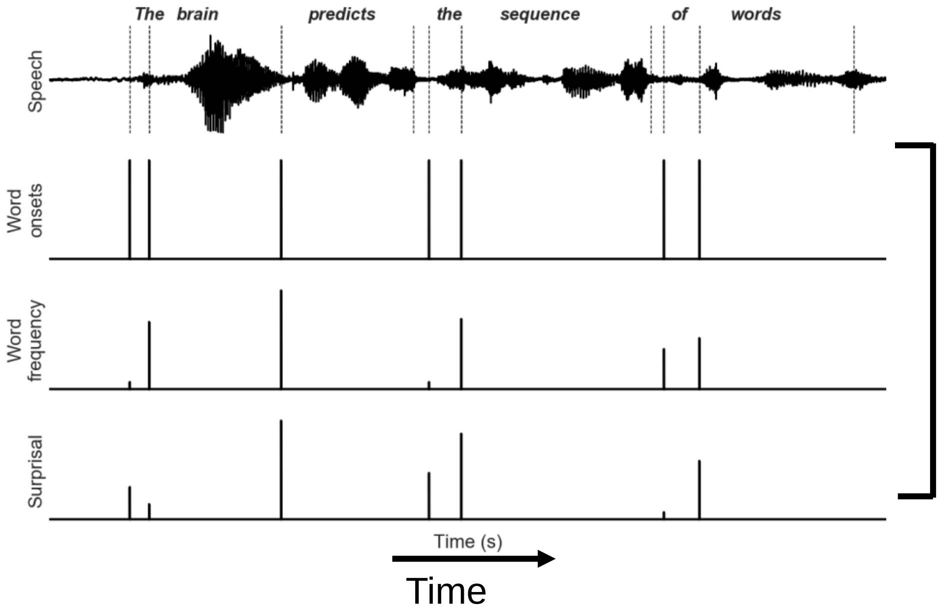
- Expectation of ***surprise*** across all words in a vocabulary is *Shannon* **Entropy**:

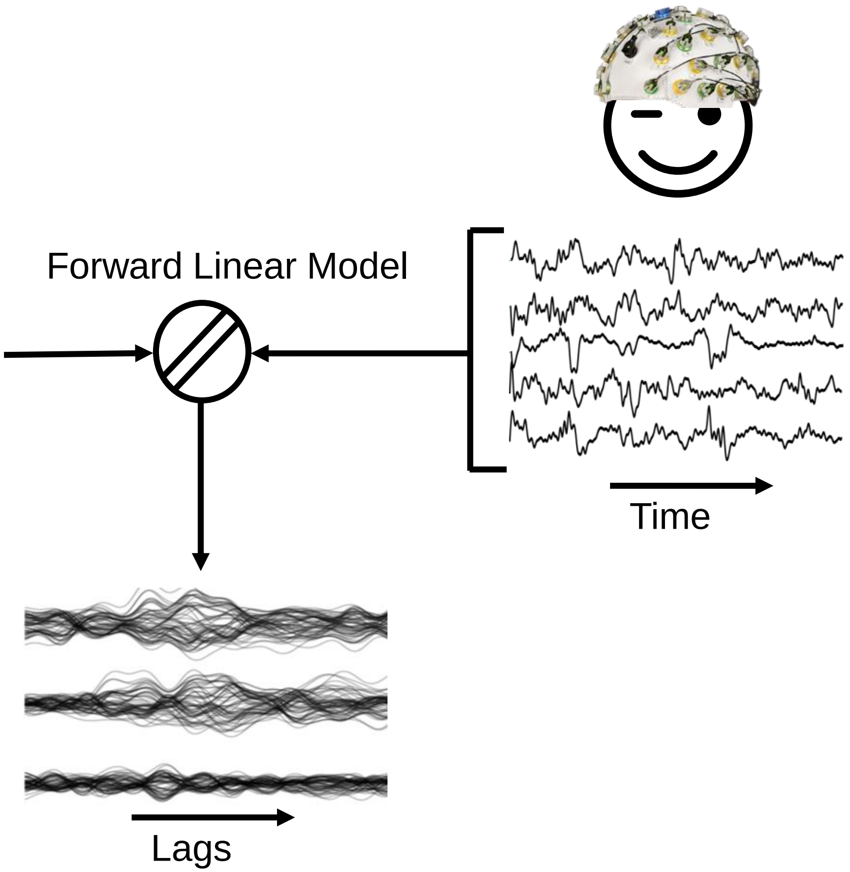
$$e_t = \mathbb{E}[s_t] = \sum s_t * p(w_t | \dots)$$

- Measures of *predictability* of words in their context and *uncertainty* about those predictions



# Methods

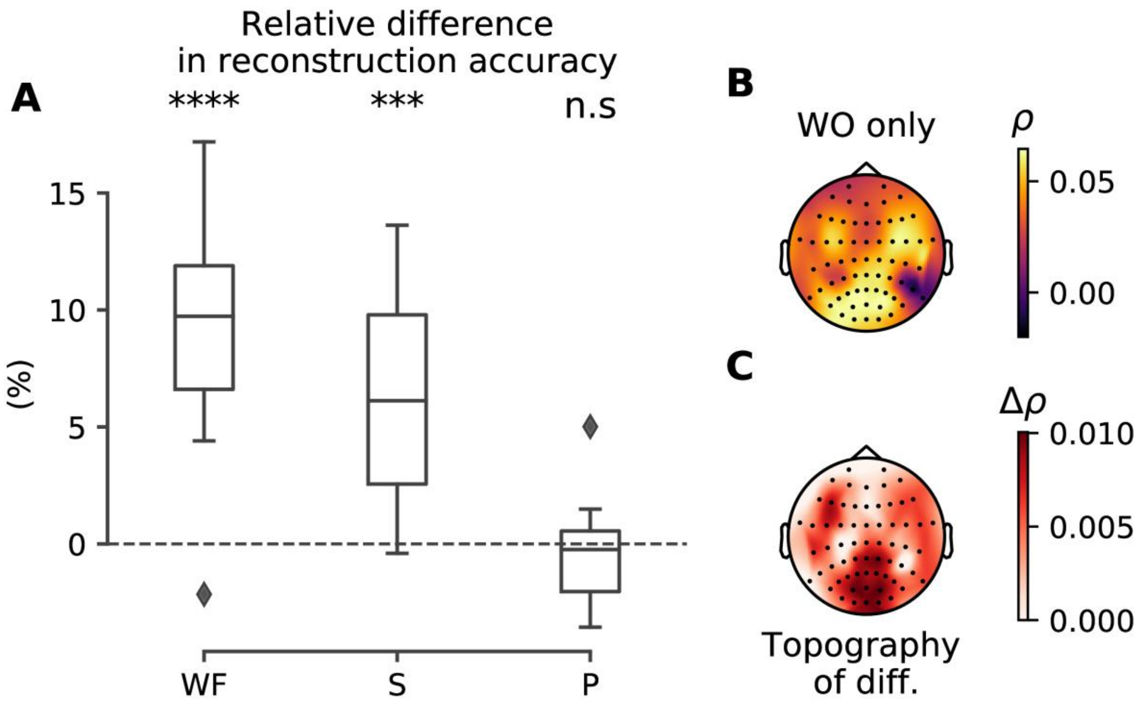



$$EEG_i(t) = \sum_{k,\tau} \beta_i^k(\tau) * s_k(t-\tau)$$

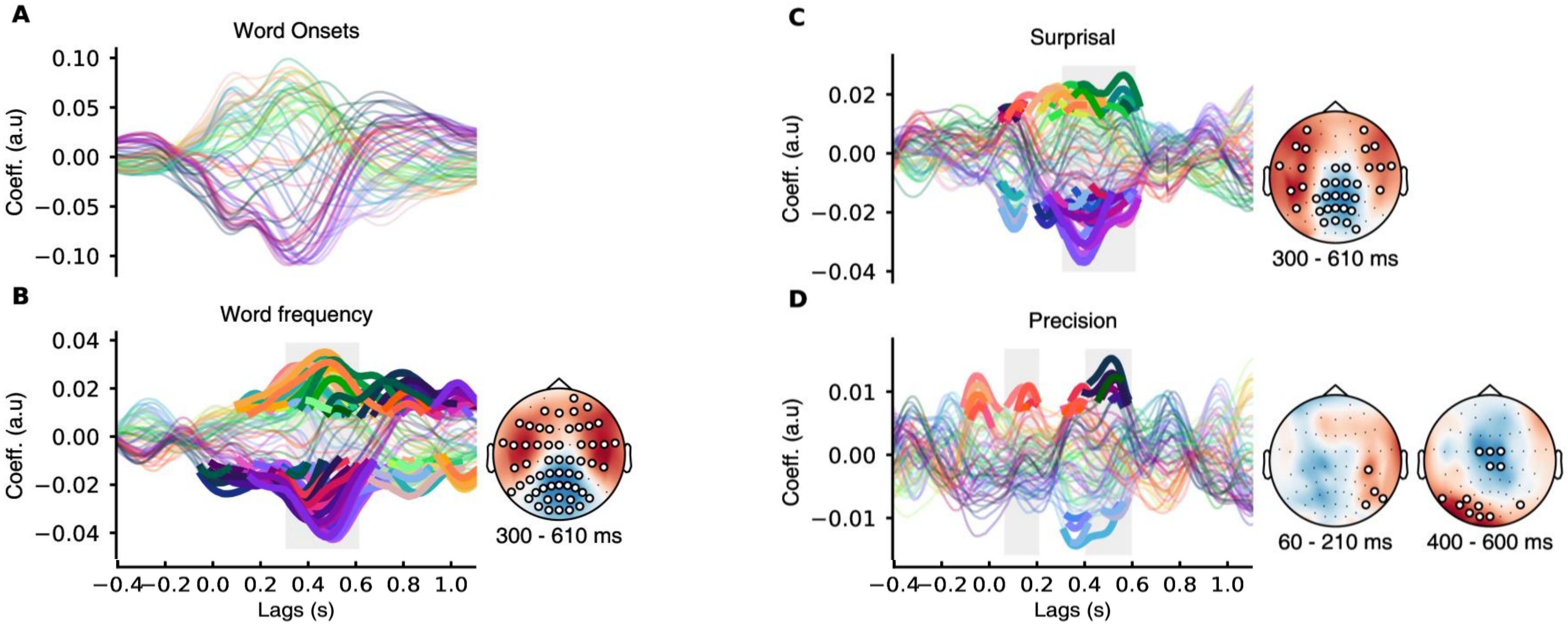
# Global Reconstruction





# TRF in the delta band

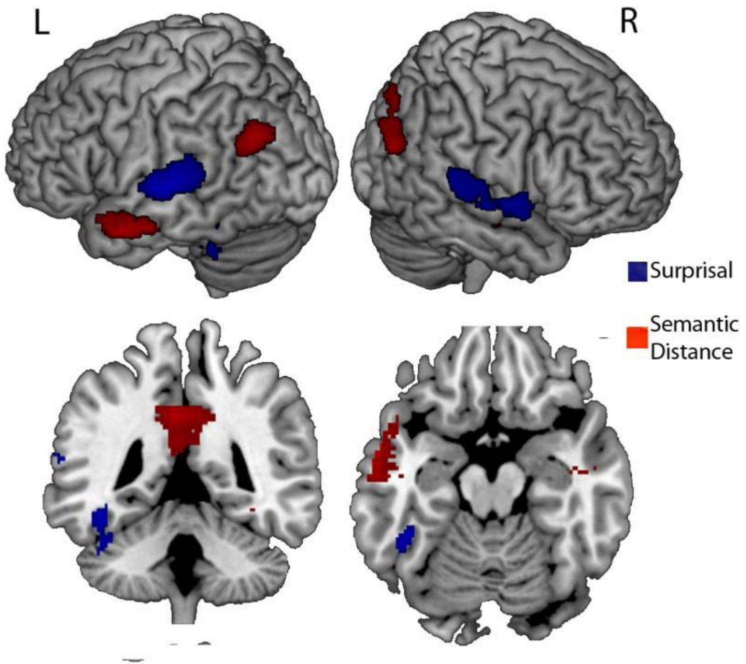




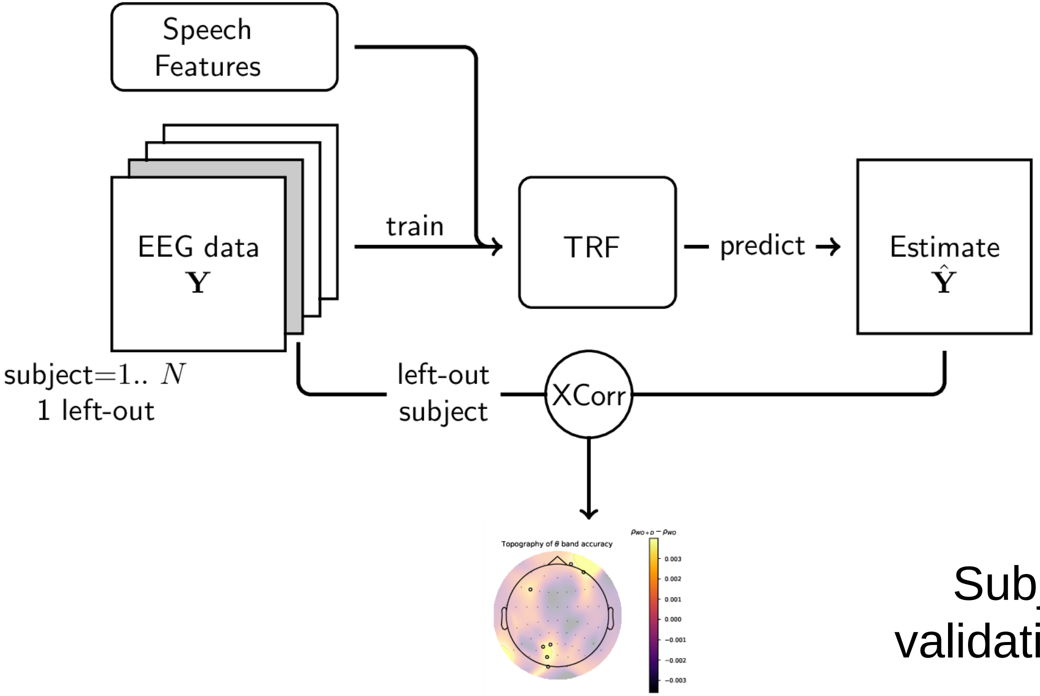
# Distinct neural sources for surprisal and semantic dissimilarity

Frank and Willems, 2017, in Language, Cognition and Neuroscience:

- Found similar TRF (using EEG data)
- But distinct sources when looking at fMRI data



# Prediction of neural data (reconstruction)

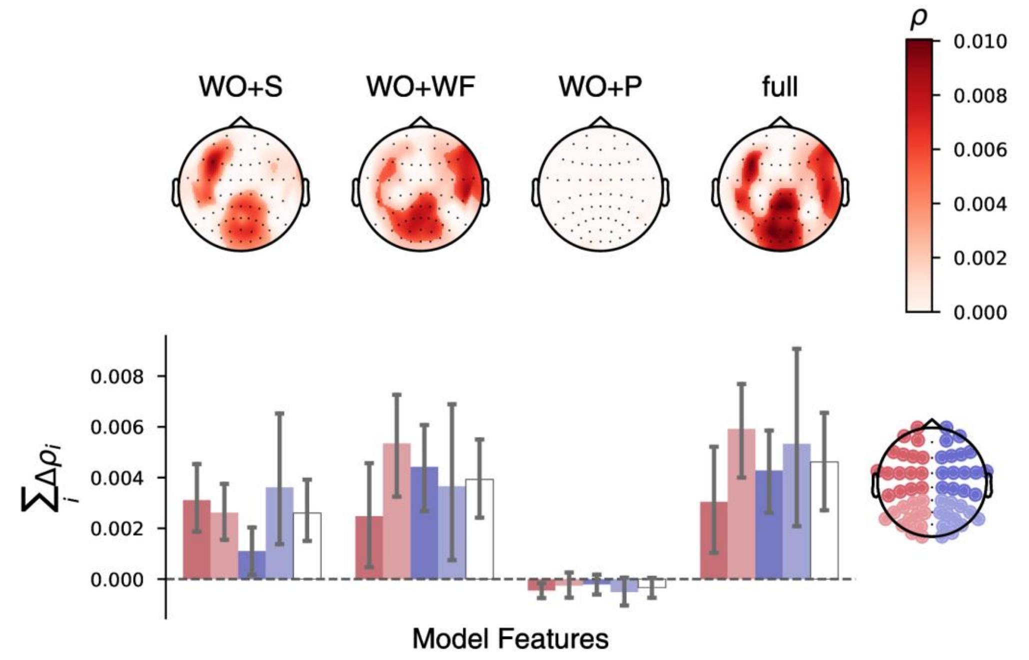


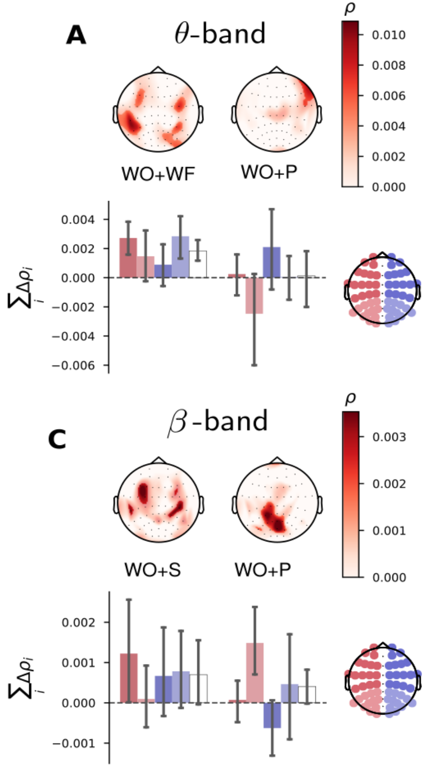

Subject-out cross-validation procedure:

# Reconstruction accuracies

**Cortical response to linguistic features**

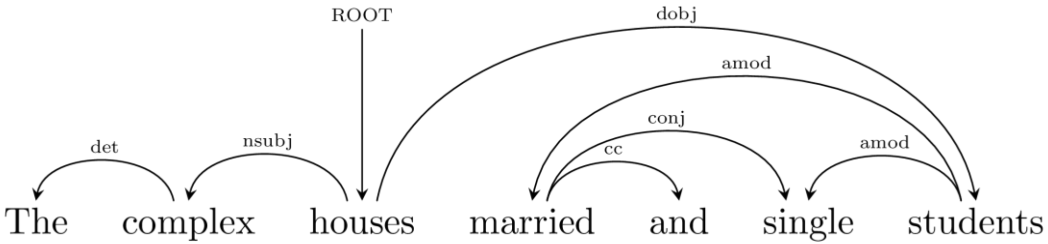
In different frequency band



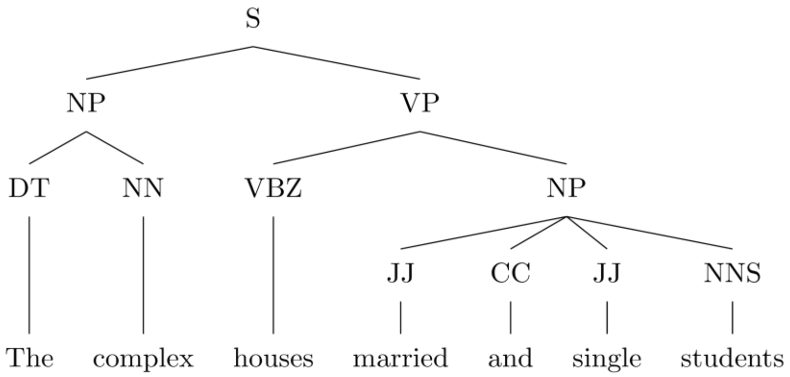



# Linguistic Tree Structures

- Example of a dependency-based tree



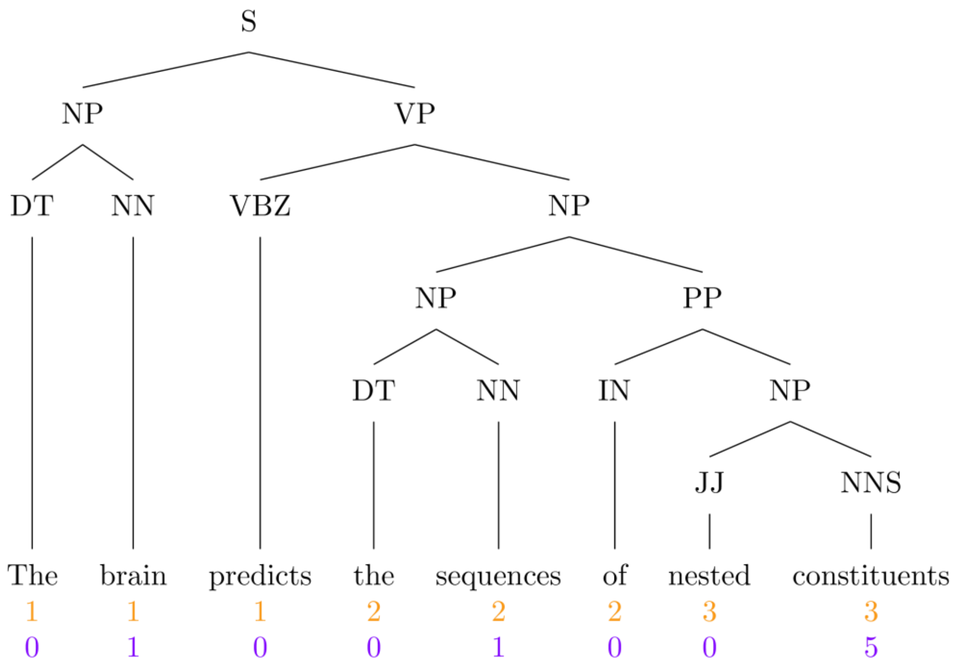

- Example of a constituency-based tree



# Features of Syntactic Tree structures

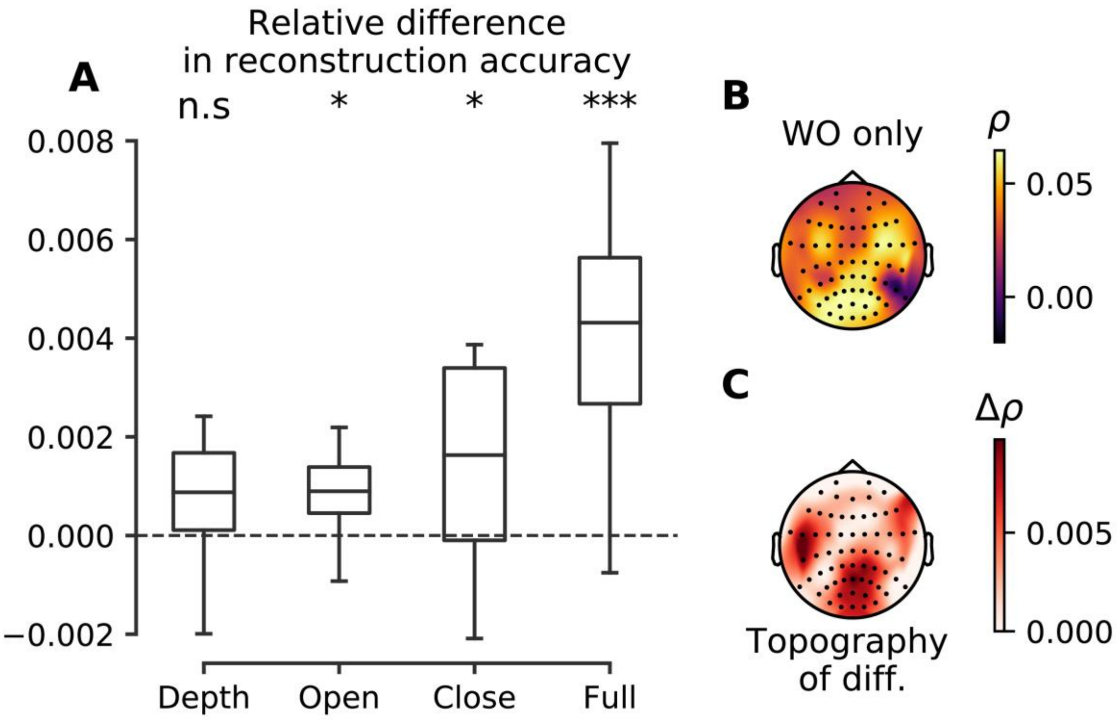
Counting the depth of each node,

The number of branches that a word closes, or opens



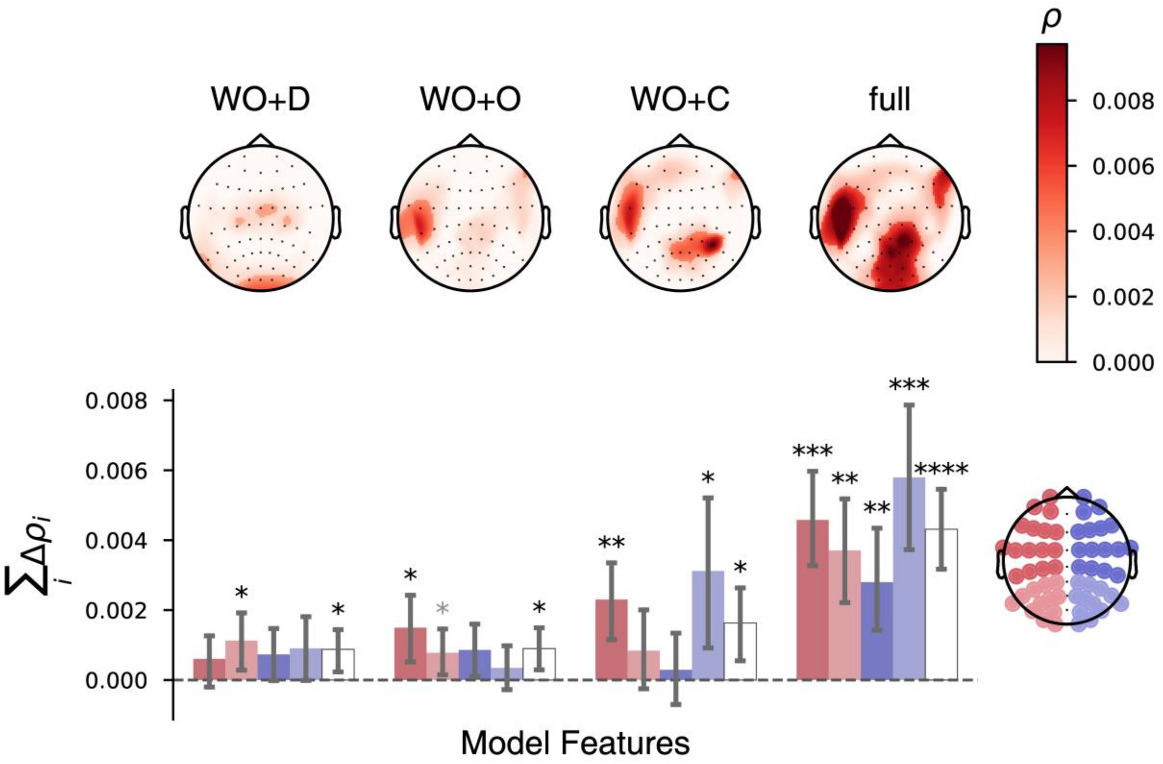
# Global Reconstruction accuracy

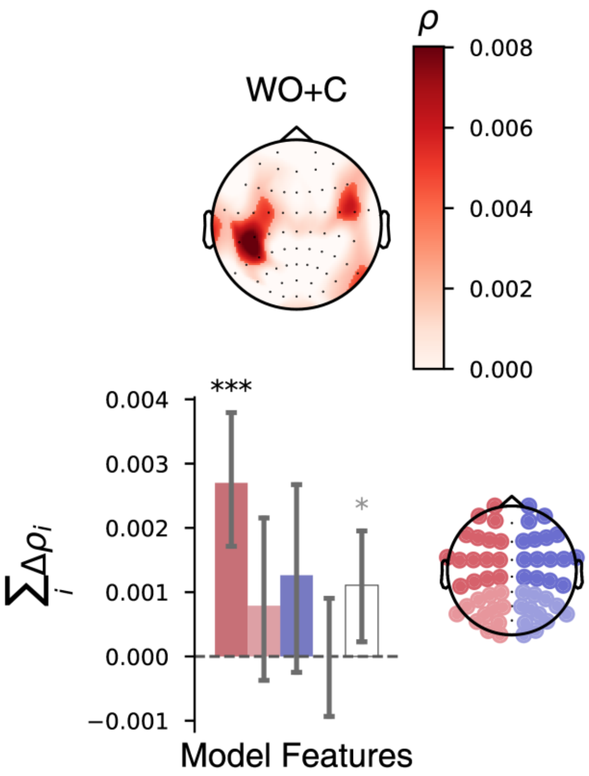




# Syntax




WO+D
WO+O
WO+C
full
ρ
0.008
0.006
0.004
0.002
0.000
$\sum_i \Delta\rho_i$
Model Features


WO+C
ρ
0.008
0.006
0.004
0.002
0.000
$\sum_i \Delta\rho_i$
0.004
0.003
0.002
0.001
0.000
−0.001
Model Features

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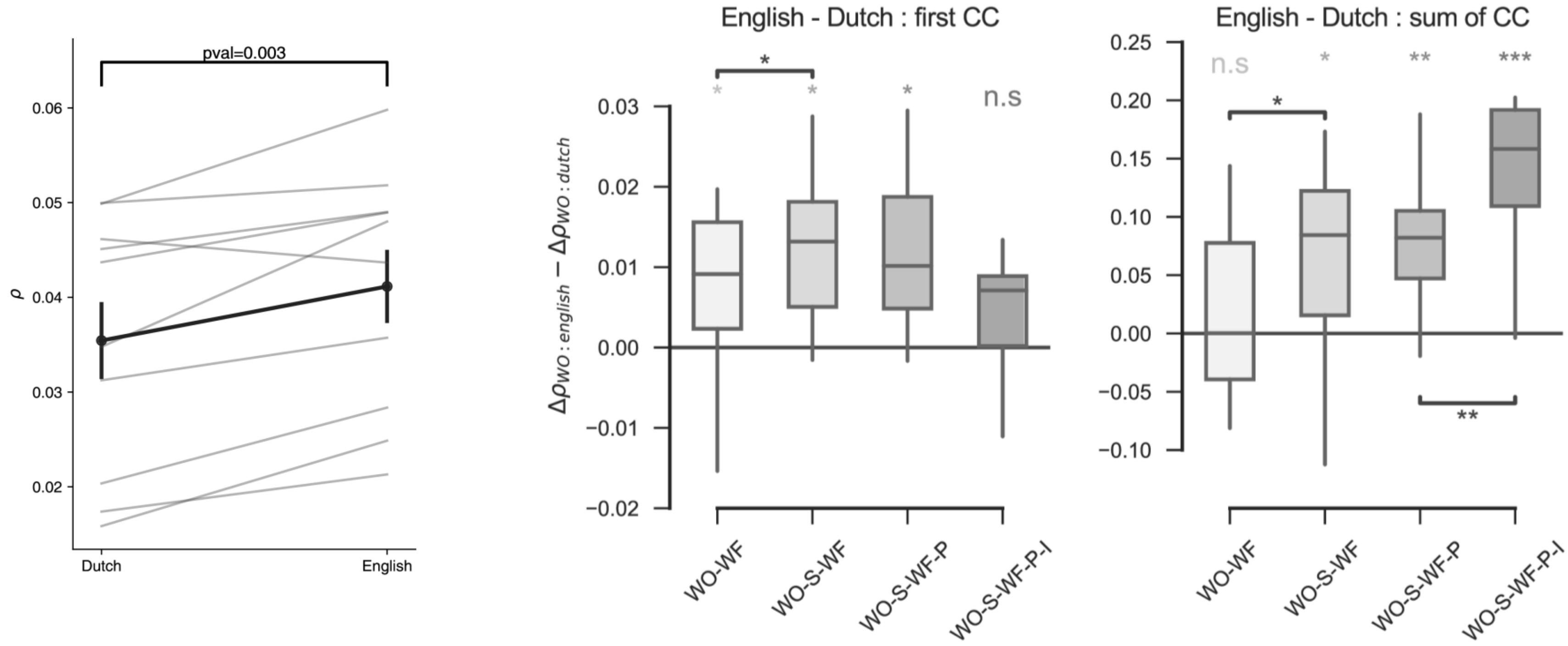
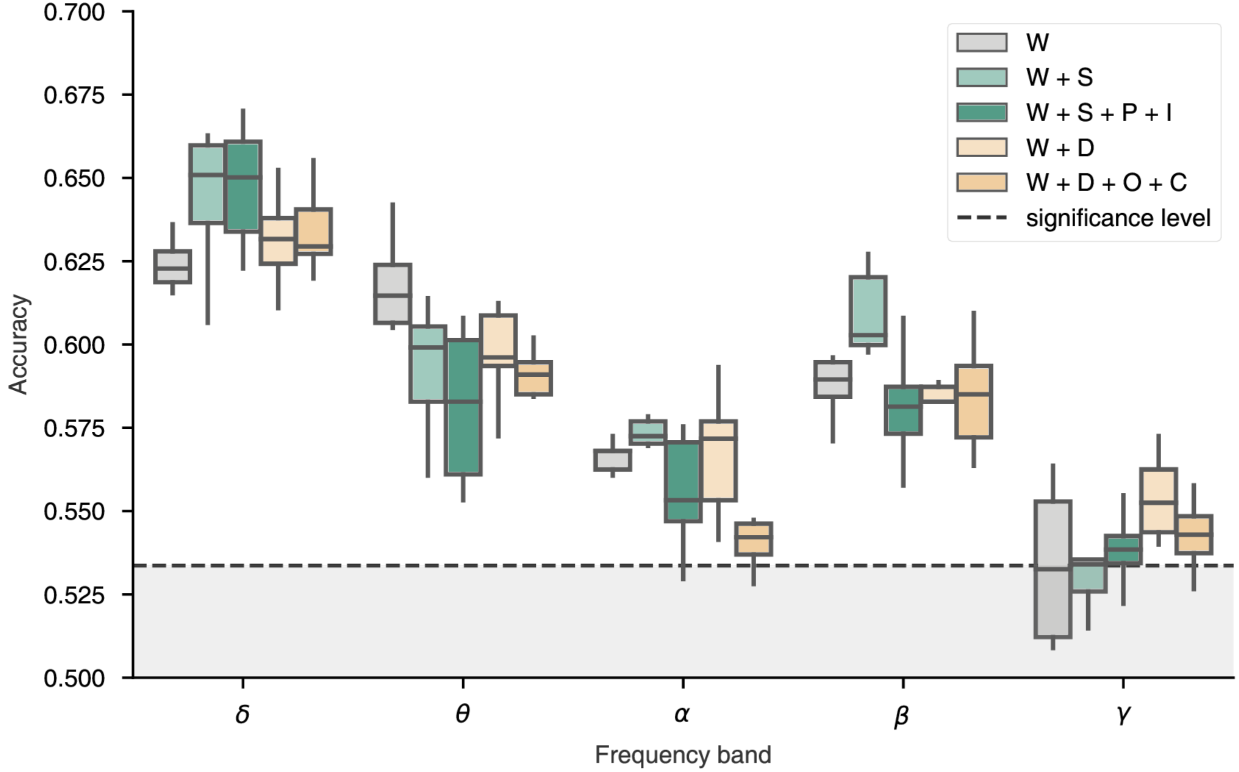
# CCA results



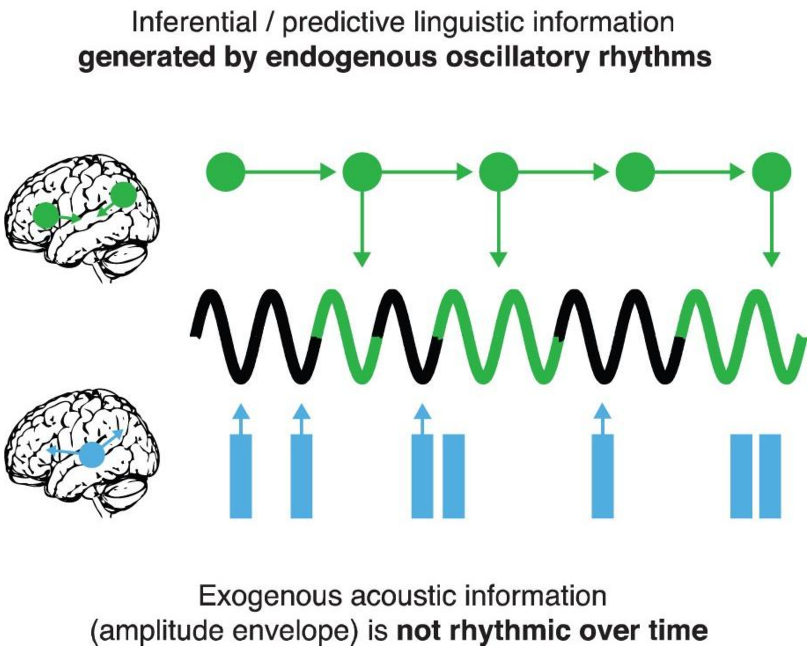

pval=0.003
0.06
0.05
0.04
0.03
0.02
ρ
Dutch
English
English - Dutch : first CC
*
n.s
0.03
0.02
0.01
0.00
−0.01
−0.02
Δρ_WO:english − Δρ_WO:dutch
WO-WF
WO-S-WF
WO-S-WF-P
WO-S-WF-P-I
English - Dutch : sum of CC
n.s
*
**
***
0.25
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
WO-WF
WO-S-WF
WO-S-WF-P
WO-S-WF-P-I

# Decoding comprehension from EEG




- Classifying reconstruction scores from both English and Dutch model on EEG segment
- Scores computed on left-out subjects
- Segment length: 10sec

# Conclusion




Lars Meyer, Yue Sun & Andrea E. Martin, **2019**, *Language Cognition and Neuroscience*

Imperial College London

EPSRC Centre for Doctoral Training in NEUROTECHNOLOGY for life and health

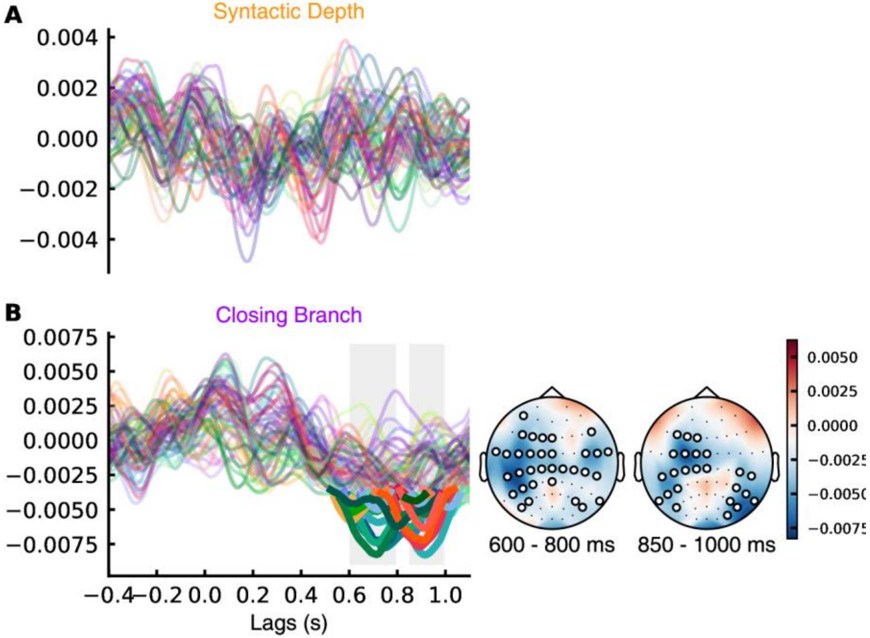
# Acknowledgments

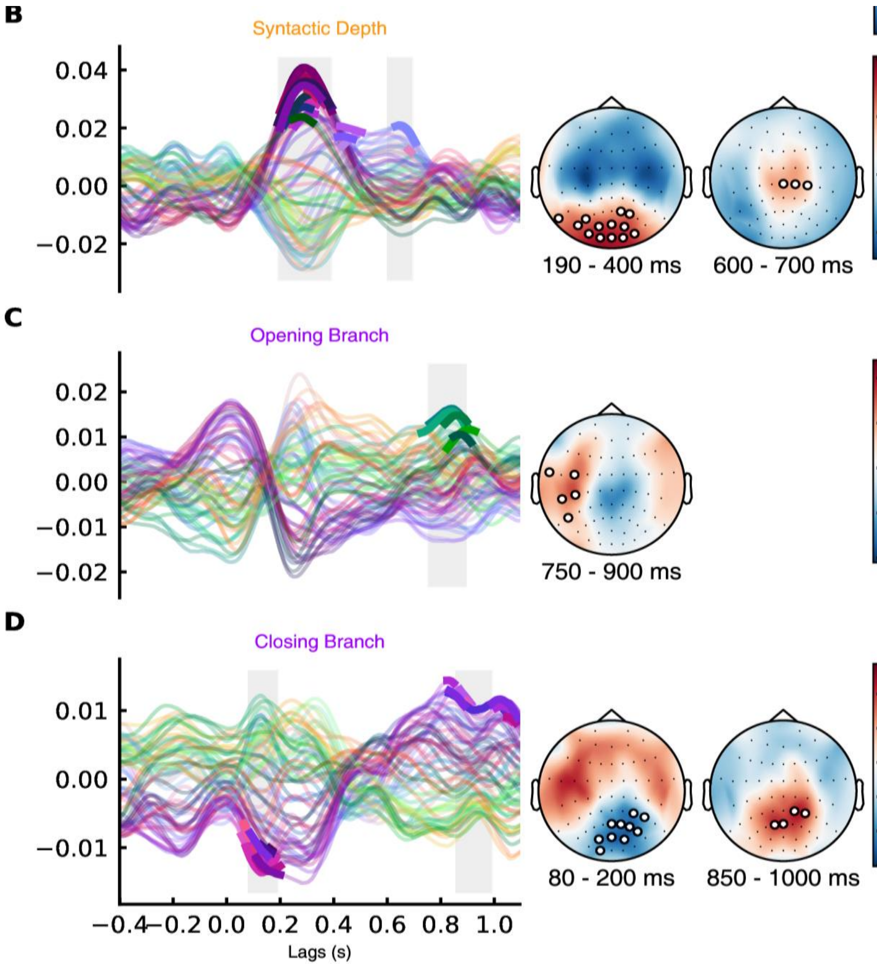
Post-docs:

- **Katerina Kandylaki** (now in Maastricht University)
- Octave Etard

And all the rest of the lab →

## Thank you for your comprehension!


A
Syntactic Depth
0.004
0.002
0.000
−0.002
−0.004
B
Closing Branch
0.0075
0.0050
0.0025
0.0000
−0.0025
−0.0050
−0.0075
−0.4 −0.2 0.0 0.2 0.4 0.6 0.8 1.0
Lags (s)
600 - 800 ms
850 - 1000 ms
0.0050
0.0025
0.0000


B
Syntactic Depth
0.04
0.02
0.00
−0.02
190 - 400 ms
600 - 700 ms
C
Opening Branch
0.02
0.01
0.00
−0.01
−0.02
750 - 900 ms
D
Closing Branch
0.01
0.00
−0.01
80 - 200 ms
850 - 1000 ms
−0.4 −0.2 0.0 0.2 0.4 0.6 0.8 1.0
Lags (s)