Neural markers of speech comprehension

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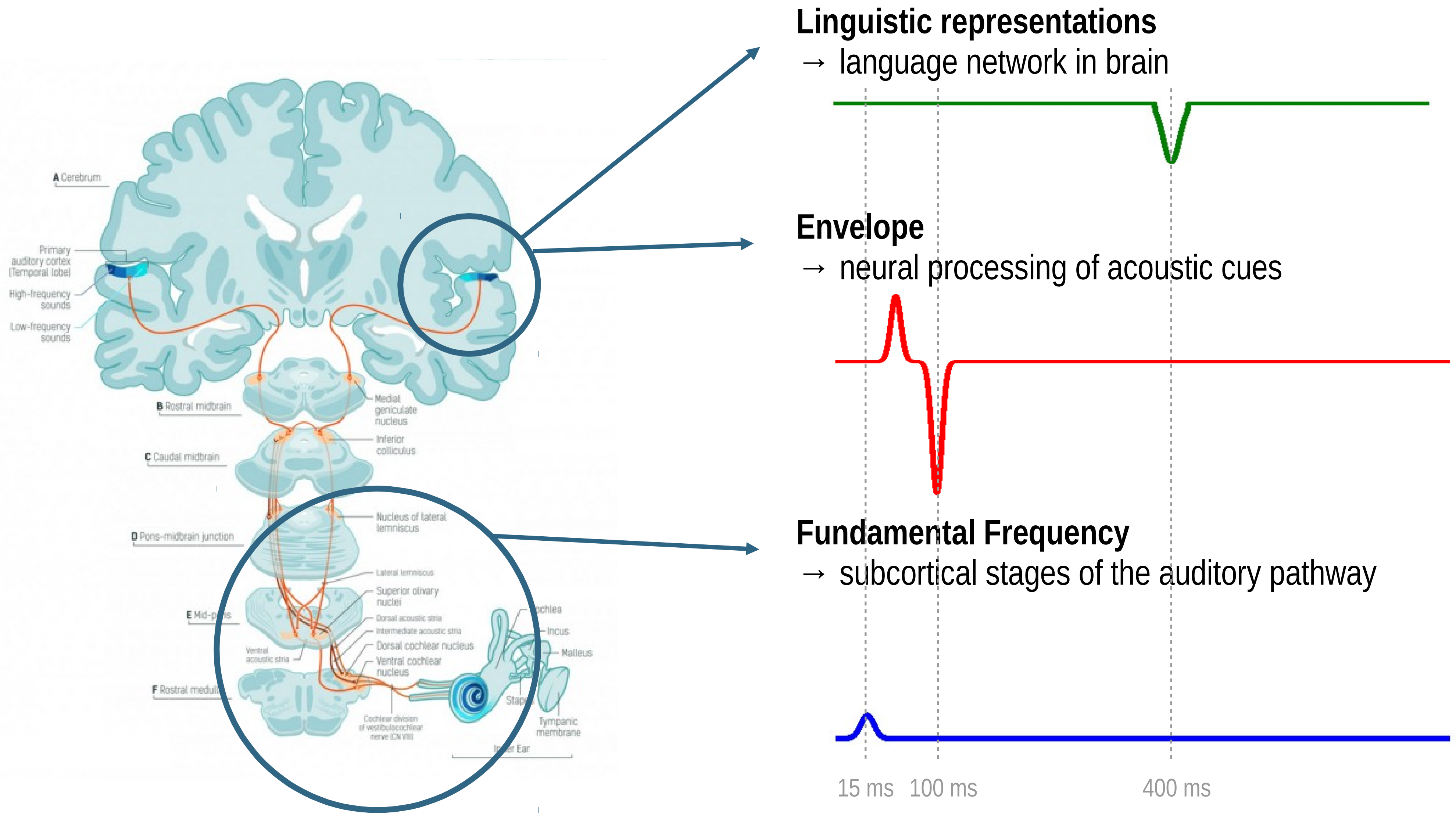
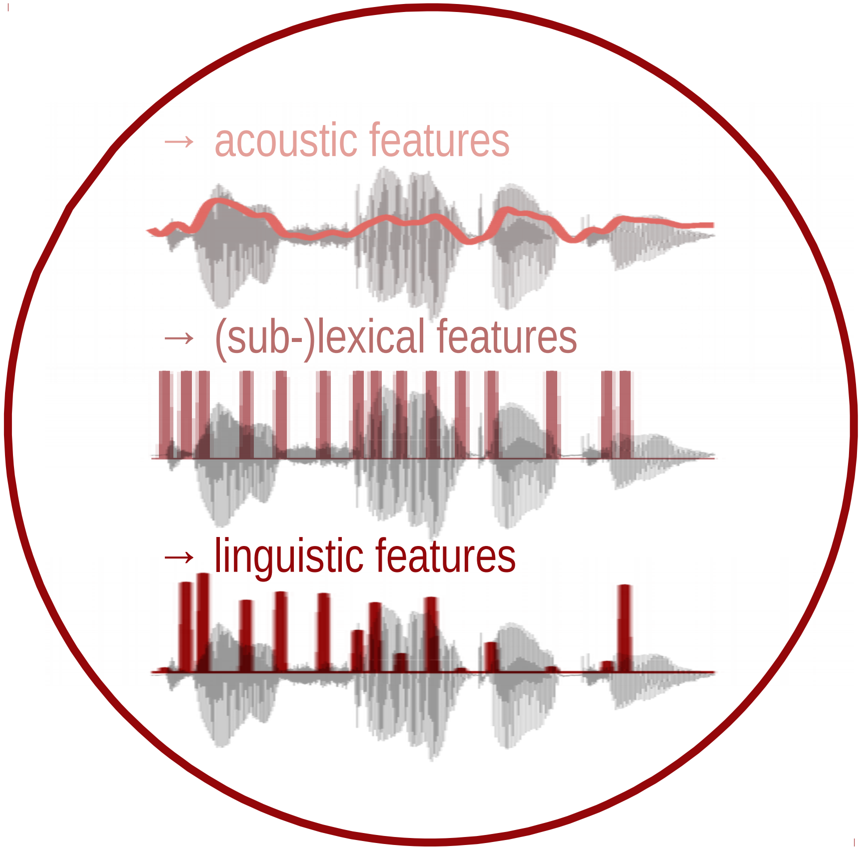

Linguistic representations
→ language network in brain
Envelope
→ neural processing of acoustic cues
Fundamental Frequency
→ subcortical stages of the auditory pathway
15 ms
100 ms
400 ms
A Cerebrum
Primary auditory cortex (Temporal lobe)
High-frequency sounds
Low-frequency sounds
B Rostral midbrain
Medial geniculate nucleus
Inferior colliculus
C Caudal midbrain
Nucleus of lateral lemniscus
D Pons-midbrain junction
Lateral lemniscus
Superior olivary nuclei
Dorsal acoustic stria
Intermediate acoustic stria
Dorsal cochlear nucleus
Ventral cochlear nucleus
Ventral acoustic stria
Cochlear division of vestibulocochlear nerve (CN VIII)
Incus
Malleus
Tympanic membrane


→ acoustic features
→ (sub-)lexical features
→ linguistic features

1. Acoustic Features: Spectrogram & Acoustic Onsets

2. (Sub-)Lexical Features: Phoneme Onsets & Word Onsets

3. Linguistic Features

4. Determination of Linguistic Tracking – the Subtraction Approach

The data

Confirmatory Results

Follow this preprint

SparrKULee: A Speech-evoked Auditory Response Repository of the KU Leuven, containing EEG of 85 participants

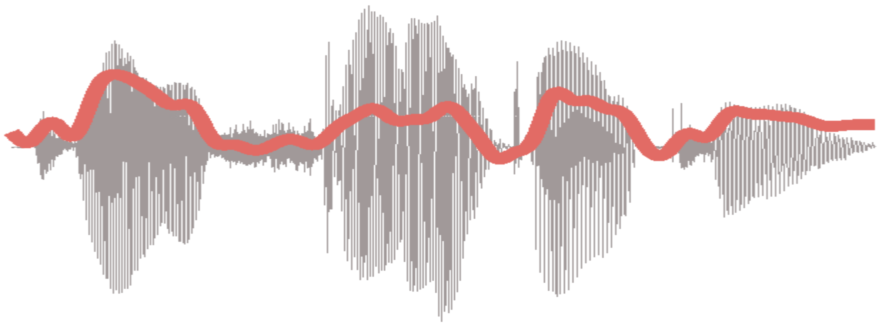
Bernd Accou, Lies Bollens, Marlies Gillis, Wendy Verheijen, Hugo Van hamme, Tom Francart

doi: https://doi.org/10.1101/2023.07.24.550310

This article is a preprint and has not been certified by peer review [what does this mean?].

https://www.biorxiv.org/content/10.1101/2023.07.24.550310v1

What do we want?

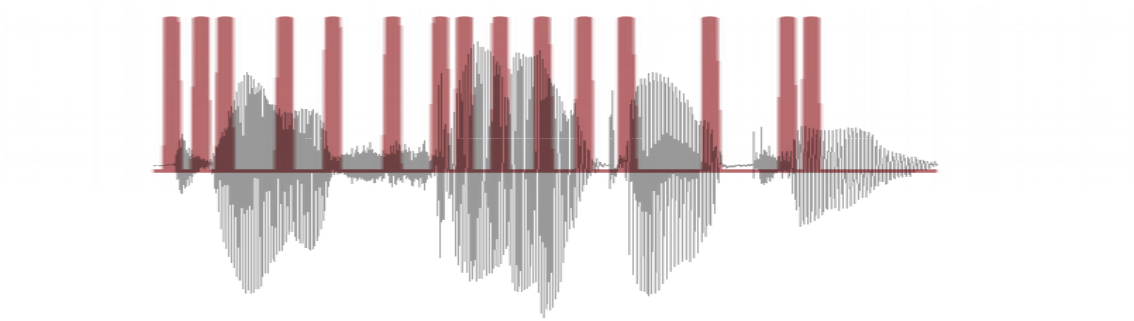


What do we need?

The audio file

To the code!

What do we want?



What do we need?

Transcript: which words were spoken during the audio fragment?

WhisperX
https://github.com/m-bain/whisperX
+ manual correction

TextGrid File: which words are spoken when and how?

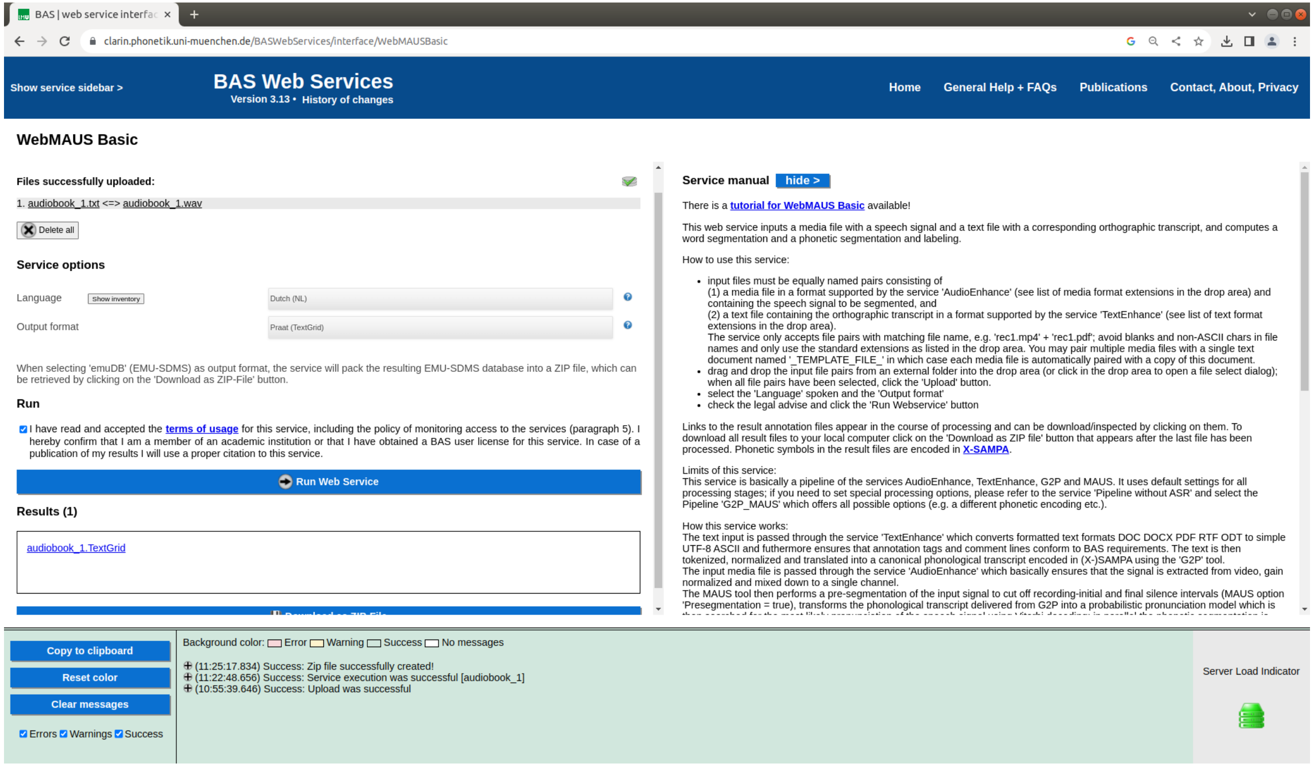
Web MAUS basic
https://clarin.phonetik.uni-muenchen.de/BASWebServices/interface/WebMAUSBasic
+ manual correction (use PRAAT!)
https://www.fon.hum.uva.nl/praat/download_linux.html

Get that transcript!

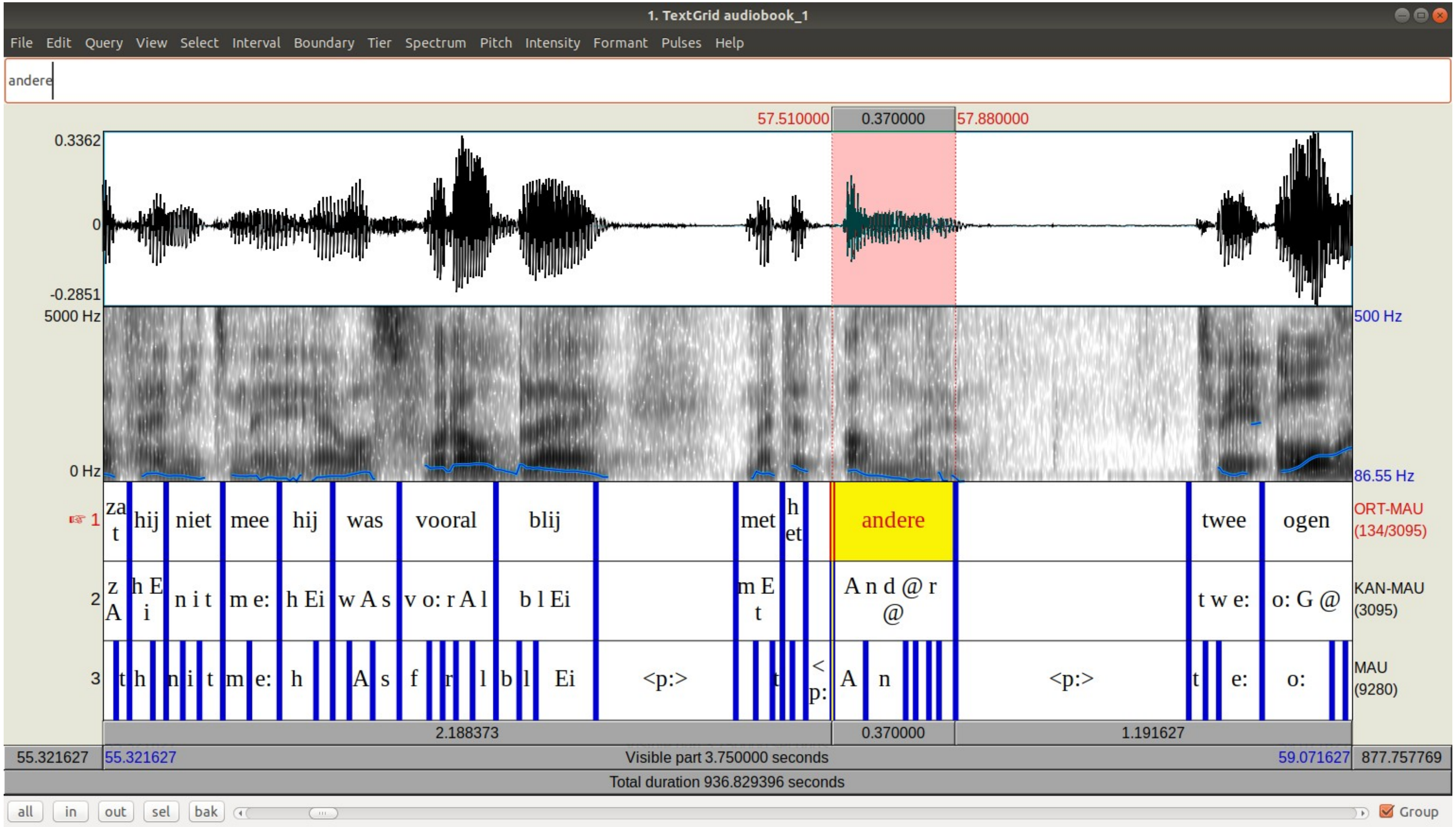
```
mgillis@fasso:~/python_makeTranscripts
File  Edit  View  Search  Terminal  Help
(makeTranscripts) [mgillis@fasso python_makeTranscripts]$ whisperx --language nl audiobook_1.wav
Performing transcription...
[00:00.000 --> 00:15.000]  Radio boeken, verhalen van Nederlandse en Vlaamse auteurs die u nergens kunt lezen,
[00:15.000 --> 00:25.000]  maar overal en altijd kunt beluisteren.
[00:25.000 --> 00:31.000]  Hij zag er helemaal uit als een normale jongen.
[00:31.000 --> 00:39.000]  Hij had armen, twee, benen, ook twee, met aan de uiteinde de nodige handen en voeten.
[00:39.000 --> 00:44.000]  En daar aan weer een heleboel vingers en tenen, telkens tien, om precies te zijn.
[00:44.000 --> 00:49.000]  Dan had hij ook een buik met zo'n gekke navel en schouders
[00:49.000 --> 00:52.000]  en daarop een hoofd met links en rechts zijn oor.
[00:52.000 --> 00:57.360]  zijn oor. Het linker een beetje flappig, maar daar zat hij niet mee. Hij was vooral blij met
[00:57.360 --> 01:03.080]  het andere. Twee ogen zoals het hoorde, een wipnoes ergens in het midden en vlak daaronder
[01:03.080 --> 01:09.040]  een nogal grote mond. Alles was er. Alles zat op de juiste plaats en alles werkte.
[01:09.040 --> 01:17.760]  Hij kon kijken en horen en proeven en ruiken en wandelen en zingen en hij heette...
[01:17.760 --> 01:28.360]  Tja, Jasper misschien, of Frederik, of Hans, want het kon ook Hans zijn, of Tom, of Pietrof,
[01:28.360 --> 01:35.120]  wie weet wel, Wannes, of Gert, of Bas, Bas kon ook, maar ook van Bas was hij eigenlijk
[01:35.120 --> 01:36.120]  niet zeker.
[01:36.120 --> 01:44.080]  Het jongetje waarvan verder alles werkte en klopte, wist maar niet wie hij was, en dat
[01:44.080 --> 01:46.960]  wat vond hij helemaal niet leuk.
[01:46.960 --> 01:52.040]  Hallo, vroeg hij soms al een voorbijganger die er voldoende vriendelijk en slim uitzacht.
[01:52.040 --> 01:56.760]  Mag ik jou even stooren, weet jij soms wie ik ben of hoe ik heet of waar ik vandaan kom
[01:56.760 --> 01:58.760]  en naartoe ga?
[01:58.760 --> 02:03.280]  De mensen keken hem dan dwaas aan en moesten lachen, zo'n vreemde vraag hadden ze nog nooit
[02:03.280 --> 02:04.280]  gehoord.
[02:04.280 --> 02:06.760]  Hoe kon niemand nu niet weten wie hij was?
[02:06.760 --> 02:08.760]  Dat was toch al te gek.
[02:08.760 --> 02:12.120]  Maar het jongetje vond dat niet zo gek.
[02:12.120 --> 02:15.120]  Het leek hem best wel handig te weten wie hij was.
[02:16.120 --> 02:20.120]  Op een keer, toen hij voor de zoveelste keer zijn vraag herhaalde,
[02:20.120 --> 02:23.120]  greep een vrouw hem uitbundig bij de armen.
[02:23.120 --> 02:25.120]  Ze leek op een gigantische pudding.
[02:25.120 --> 02:28.120]  Ze had een kapsel als een vogelnest en een onderkin zoals een kalkoen.
[02:28.120 --> 02:30.120]  Veel te groot.
[02:30.120 --> 02:35.120]  Maar, maar, maar toch, jij bent gewoon een jongetje.
```

Cool right?! It spares you lots of time. But **listen** and **correct** the transcript afterwards!
→ available for English, French, German, Spanish, Italian, Japanese, Dutch, ...

Get that phoneme segmentation!

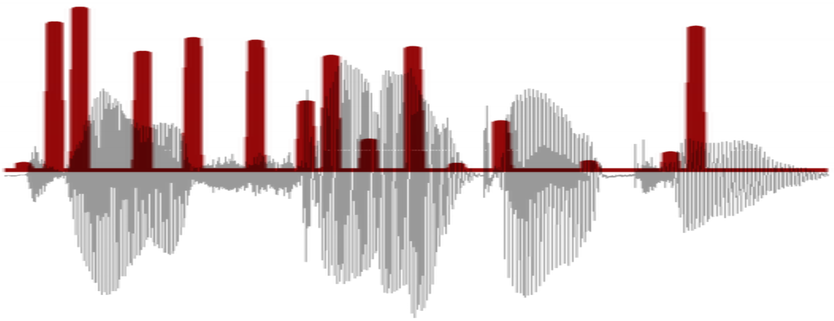


Get that phoneme segmentation!



To the code!

What do we want?



At phoneme level

Sound
/ba/

Activation of word cohort
Activated lexical items

- Baby
- Back
- Barbecue
- Basilisk
- Badminton
- Back-flip
- Bakery
- Bandit
- Bathtub
- Bald
- Bambino
- Bamboo
- Baggy
- Banana
- Basil
- ...

Phoneme surprisal
= - log(P(next phoneme | previous phonemes))

Cohort entropy
= Shannon entropy of phonemes compatible with the given input
→ "degree of competition"

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

Based on Brodbeck et al. (2018)
Probabilities derived from SUBTLEX-NL

What do we need?

Pronunciation dictionary: a mapping from the word to its phonemes

WebMAUS!
https://clarin.phonetik.uni-muenchen.de/BASWebServices/interface/

Word probabilities: the likelihood of a word

Subtlex!
https://www.ugent.be/pp/experimentele-psychologie/en/research/documents

At word level

"But you know, happiness can be found even in the darkest of times, if one only remembers to turn on the light."

— J.K. Rowling, Harry Potter and the Prisoner of Azkaban

Word surprisal
= - log(P(next word | previous 4 words))

Word frequency
= P(word)

Does not take sentence boundaries into account!

Based on Weissbart et al. (2019)
Derived from a 5-gram model

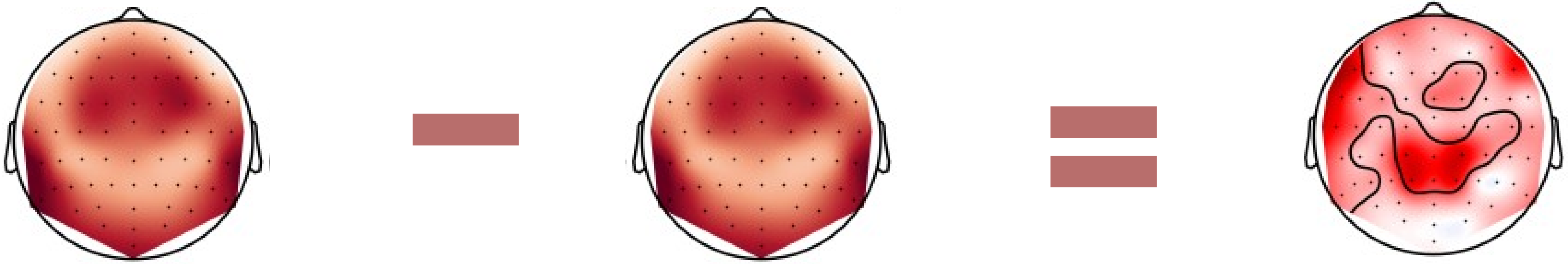
What do we need?

Ngram model: the likelihood of a word given the preceding words

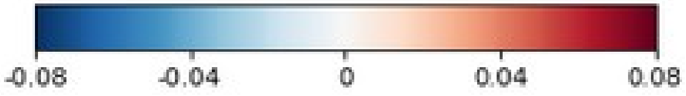
KenLM
https://kheafield.com/code/kenlm/

To the code!

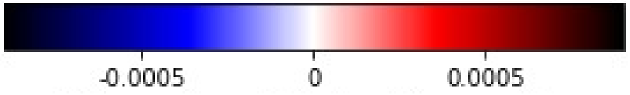
Neural tracking of linguistic features



"complete model"		**"baseline model"**		**difference in prediction accuracy**	
Acoustic features	v	Acoustic features	v	Acoustic features	x
(Sub-)Lexical features	v	(Sub-)Lexical features	v	(Sub-)Lexical features	x
Linguistic features	v	Linguistic features	x	Linguistic features	v



Prediction accuracy [Pearson's r]



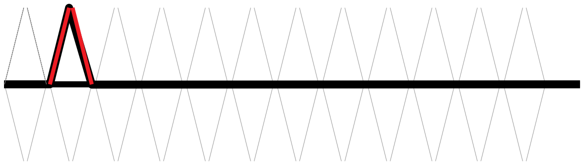
Difference in prediction accuracy [Pearson's r]

How boosting works

→ TRF is estimated using a iterative procedure:

– Start with a 0-trf
  - A small amount is added to or subtracted from the first lag → MSE is calculated (repeated for all lags)
  - Best increment is the one that produces the largest decrease in the mean-squared error

– Repeated until an additional increment/decrement only adds noise



David, S. V., Mesgarani, N., & Shamma, S. A. (2007). Estimating sparse spectro-temporal receptive fields with natural stimuli. Network: Computation in neural systems, 18(3), 191-212.

To the code!

Let’s accelerate science **together**!

My contact detail:

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GitHub Repository (where you will find all the code, and more):

XXXX

Feel free to use the code, a citation would be appreciated ☺

References

- Own work, related to linguistic speech tracking:

  - Gillis, M., Vanthornhout, J., Simon, J. Z., Francart, T., & Brodbeck, C. (2021). Neural markers of speech comprehension: measuring EEG tracking of linguistic speech representations, controlling the speech acoustics. Journal of Neuroscience, 41(50), 10316-10329.
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  - Gillis, M., Kries, J., Vandermosten, M., & Francart, T. (2023). Neural tracking of linguistic and acoustic speech representations decreases with advancing age. NeuroImage, 267, 119841.

- Other useful references:

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  - Broderick, M. P., Anderson, A. J., Di Liberto, G. M., Crosse, M. J., & Lalor, E. C. (2018). Electrophysiological correlates of semantic dissimilarity reflect the comprehension of natural, narrative speech. Current Biology, 28(5), 803-809.

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  - And many, many more