The Dual Nature of Lengthening

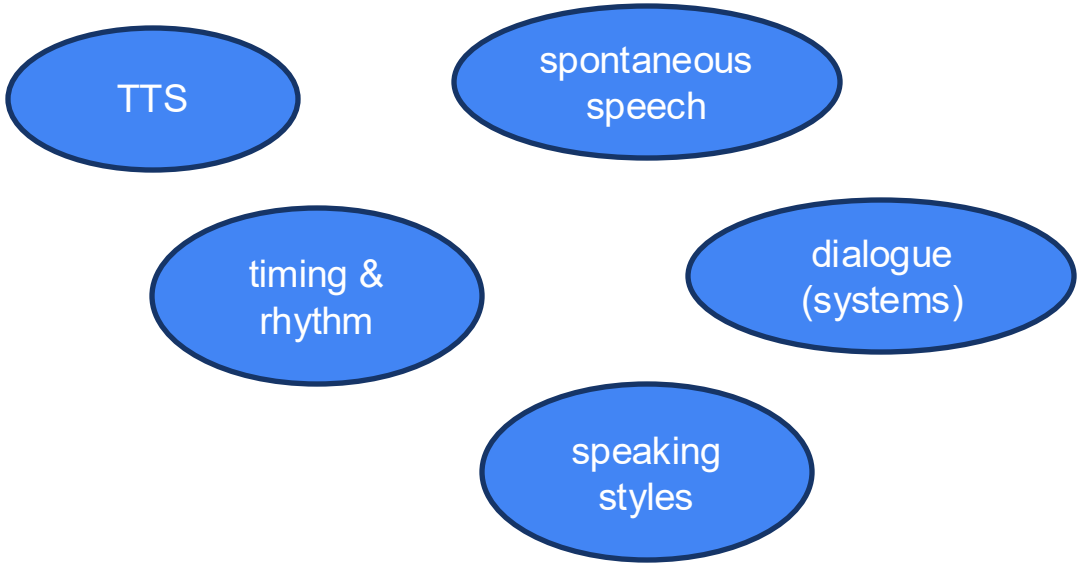
Simon Betz, Petra Wagner
DiSS Workshop 2025

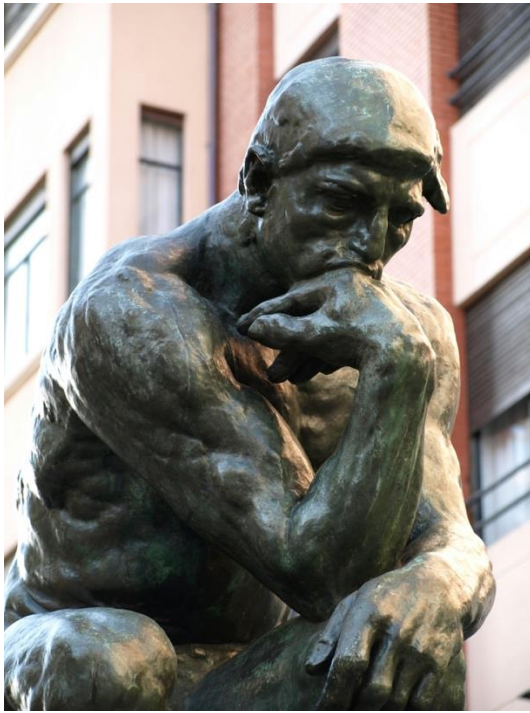
Public Service Announcement

All of our own papers mentioned in this presentation, and all slides, are available online and linked under this URL / QR code!

https://length-ecd2ab.pages.ub.uni-bielefeld.de/

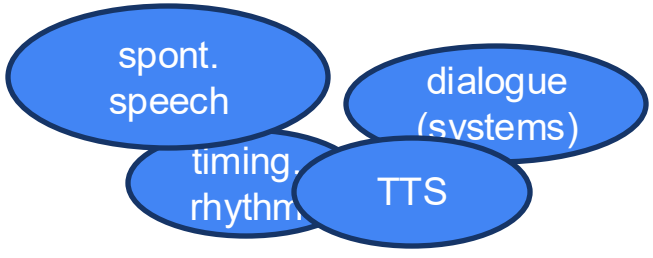
...a bunch of interests and ideas



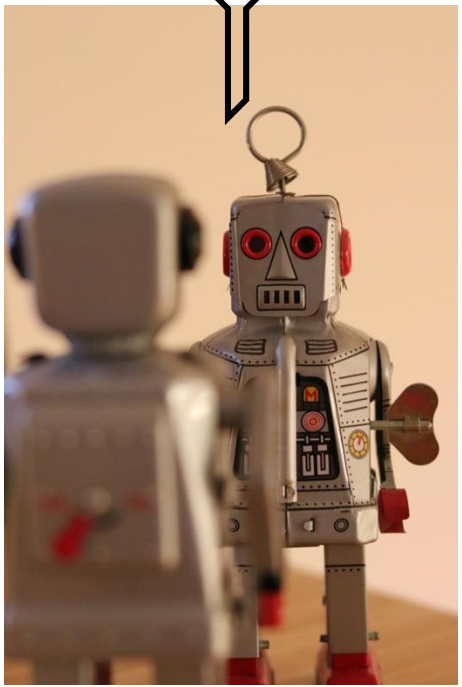


Picture by Fernando Santando on Unsplash

... a bunch of interests and ideas



- Dialogue systems sometimes delay their answers...as do people
- These delays need to be produced or synthesized
- Hesitations as “forward-looking, time-buying disfluencies“might be part of the answer... *(Ginzburg et al., 2014; Betz, 2020)*



Picture by Theo on Unsplash

Ginzburg, Jonathan, Raquel M. Fernández, and Schlangen David. "Disfluencies as intra-utterance dialogue moves." *Semantics and Pragmatics* 7.9 (2014): 64.
Betz, Simon. *Hesitations in Spoken Dialogue Systems*. Bielefeld: Universität Bielefeld, 2020.

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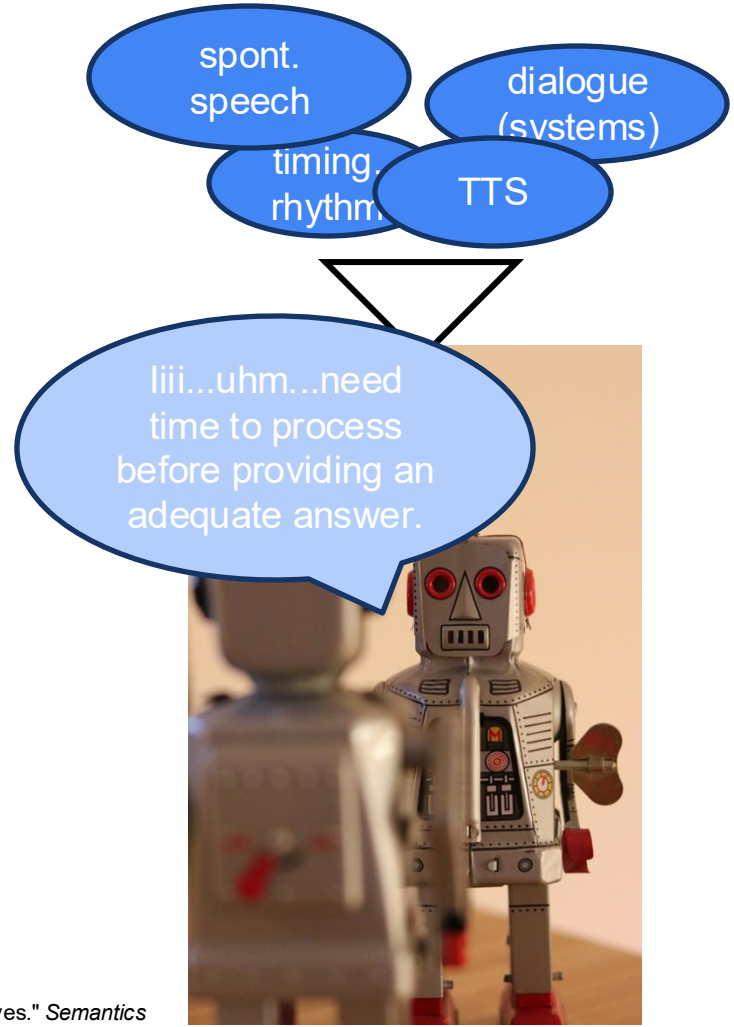

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The potential of hesitation lengthening

- Lengthening one of the most frequent disfluency phenomena, yet a “dark horse in the stable” *(Eklund 2001)*
- Often not the center of attention, unnoticed next to fillers and silences
- First hunch of a dual nature :
  - inserted strategically
  - often passes unnoticed

Eklund, Robert. "Prolongations: A dark horse in the disfluency stable." *DiSS'01 Disfluency in Spontaneous Speech, University of Edinburgh, August 29–31 2001*. 2001.
Horse image created with ChatGPT. All images in this presentation taken from their respective papers if not stated otherwise.

Hesitation vs. Non-Hesitation Lengthening

- Lengthening ubiquitous in languages: Phrase finality, domain initiality, accentuation, contrast, segmental quantity contrasts (gemination, vowel quantity)
- Non-hesitation lengthening tends to:
  - show other prosodic features (dynamic tonal contours, varied intensity etc.)
  - be not restricted to 1-2 phones
  - be syntagmatically restricted (stressed/stressable, final/initial)
  - be restricted in extent by phone elasticity *(Campbell et al., 1991)*

Campbell, W. Nick, and Stephen D. Isard. "Segment durations in a syllable frame." *Journal of Phonetics* 19.1 (1991): 37-47.
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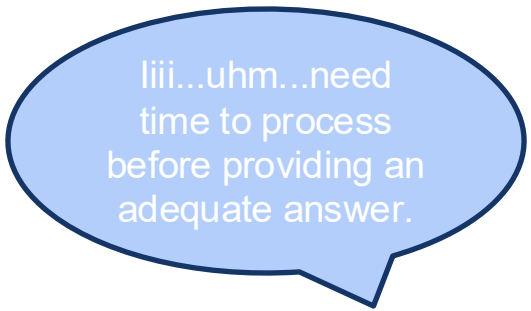

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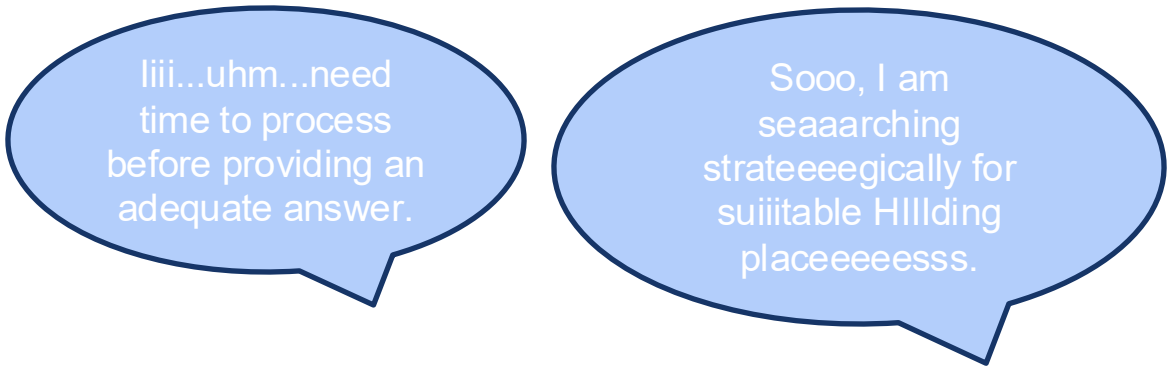

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How do we measure something hidden (by design)?

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Lengthening: A Journey of Discovery

2015: Modular Disfluency Synthesis

2016: Disfluent Lengthening in Spontaneus Speech

2016: Synthesized lengthening of function words

2017: Semi-Automatic Classification

2018: Interactive Hesitation Synthesis

2019: The Greennnn Tree

2023: Cognitive Load and Multimodal Hesitation

2024: Multimodal Lengthening and Non-Understanding

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Modular Disfluency Synthesis 2015

- Incremental processing enables real-time interactive speech synthesis.

MODULAR SYNTHESIS OF DISFLUENCIES FOR CONVERSATIONAL SPEECH SYSTEMS

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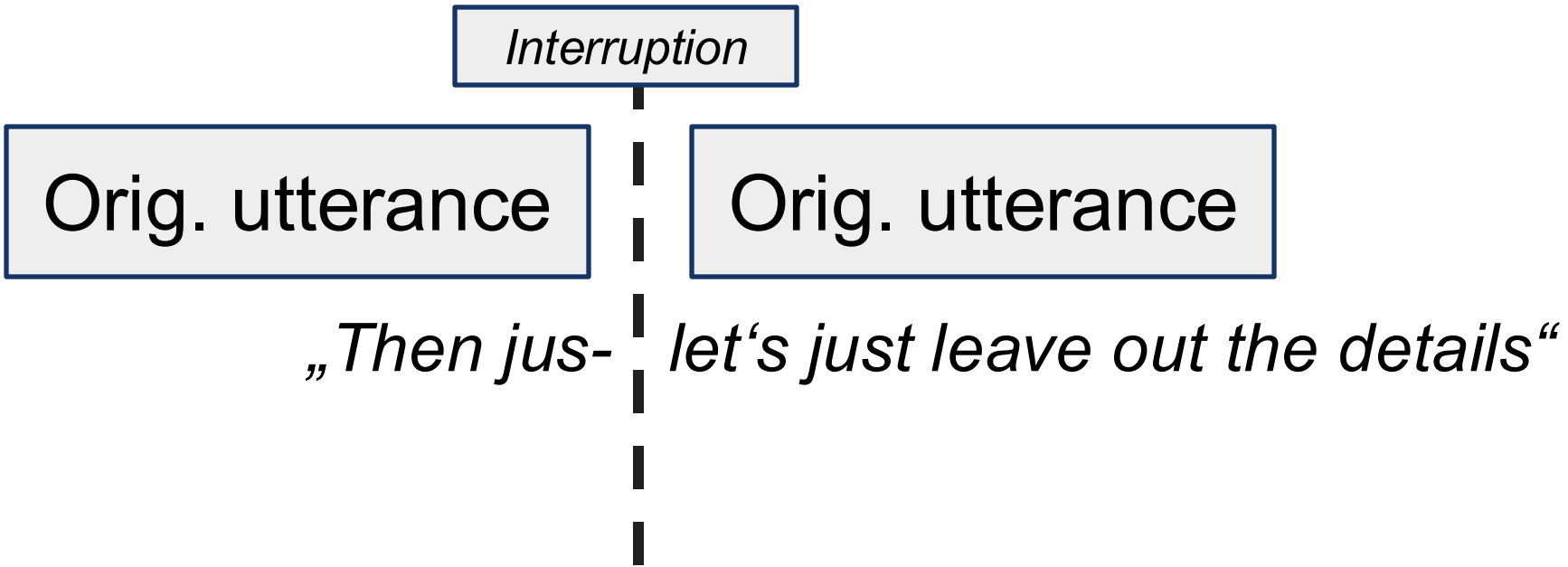
Modular Disfluency Synthesis 2015

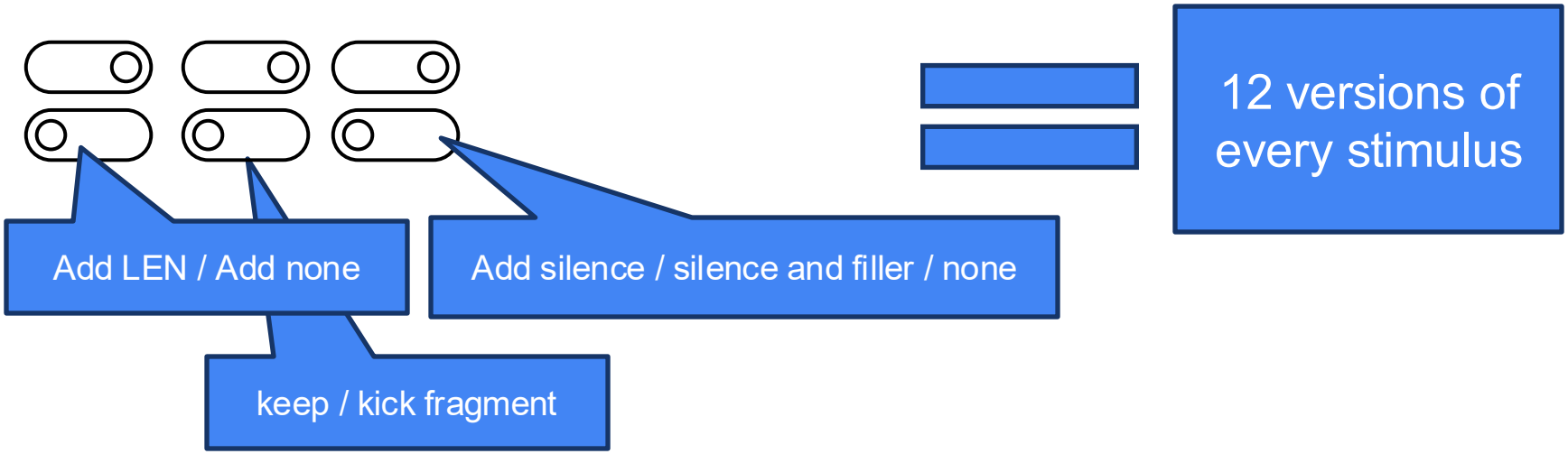
- Incremental processing risks committing to wrong input.
- No guarantee that it always works as quickly as desired.
- **This is precisely when speakers produce disfluencies.**
- As a first test, we synthesized different types of disfluencies and collected feedback on sound quality
- Goal: test which disfluencies work
- Hypothesis: disfluent dialogue systems will sound worse, but the gain in interactivity will make up for it

Modular Disfluency Synthesis 2015



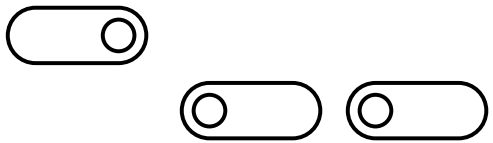
Modular Disfluency Synthesis 2015

„Then jus- let‘s just leave out the details“



Modular Disfluency Synthesis 2015
Example 100

„Then jus- let‘s just leave out the details“

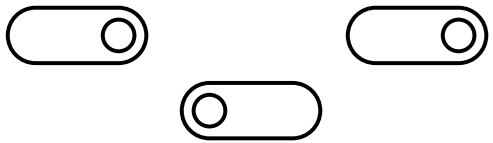


„Then::: let‘s just leave out the details“

(Length. ON Fragm. OFF Silence OFF)

Modular Disfluency Synthesis 2015
Example 102

„Then jus- let‘s just leave out the details“



„Then::: … uhm… let‘s just leave out the details“

(Length. ON Fragm. OFF Silence ON+Filler)

Modular Disfluency Synthesis 2015: Results

- Fillers and fragments get low ratings.
- Lengthenings (and some silences) get very high ratings.
- Some configurations get even higher ratings than the fluent baseline!

baseline

Lengthening	Fragment	Silence	Filler	Rating
0	0	0	0	3.41
1	0	0	0	3.45

Take-Home-Message:
Lengthening is not the same as other disfluencies!
It seems to have more potential in terms of sound quality and acceptability.

Disfluent Lengthening in Spontaneus Speech 2016

- Goal: Use lengthening as core for incremental disfluency synthesis.
- More foundational research needed.
- Large-scale corpus study into durational properties of lengthening
- Free spontaneous dialogue, German

DISFLUENT LENGTHENING IN SPONTANEOUS SPEECH

Simon Betz, Petra Wagner

Universität Bielefeld, Phonetics and Phonology Workgroup
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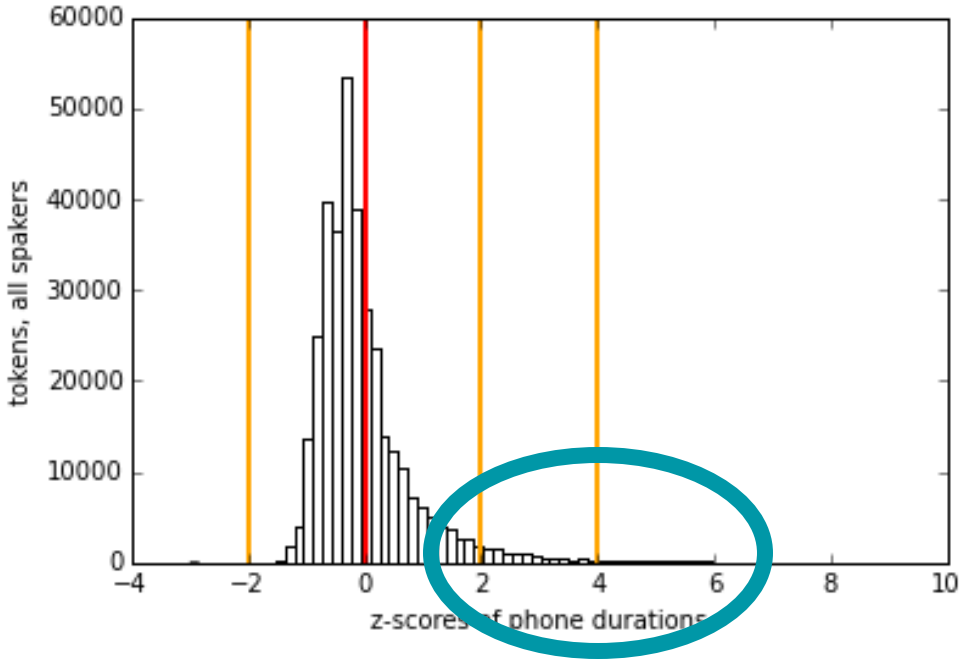
Disfluent Lengthening in Spontaneus Speech 2016

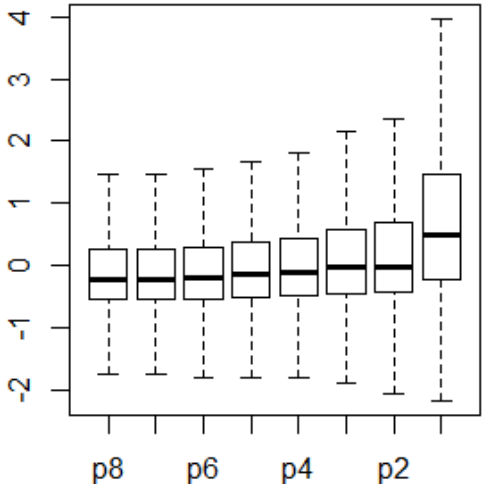
- How are phone durations distributed?
- Plot of all phone durations (no stops), z-normalized
- Why are there so many tokens above z=2?
- Almost all of them are **phrase final lengthening.**
- Hesitations hidden in the same duration range, but less frequent.



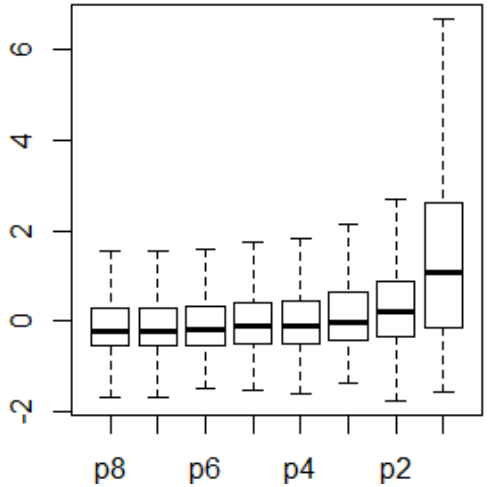
Disfluent Lengthening in Spontaneus Speech 2016

- gradual duration increase
- main load carried by last phone before boundary
- Same for lengthenings preceding fillers (uh, uhm)

The similarity between phrase-final and pre-filler lengthening suggests that the presence of a disfluency may split the intonation phrase into two.



Phrase final lengthening.
P8 = 8 phones before boundary
P1 = last phone before boundary
Y-axis: z-scores



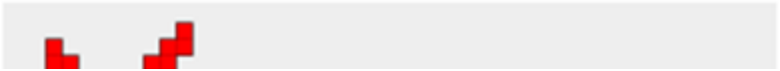
Pre-filler lengthening.

Disfluent Lengthening in Spontaneus Speech 2016

Take-Home-Message:
Hesitation lengthening can dress up as something else, e.g. as phrase-final lengthening. This makes it quite difficult to spot sometimes…

Synthesized lengthening of function words 2016

- Participants have to drag and



Synthesized lengthening of function words - The fuzzy boundary between fluency and disfluency

Simon Betz[1,2,3], Sina Zarrieß[2,3], Petra Wagner[1,3]
Bielefeld University, Bielefeld, Germany
[1]Phonetics and Phonology Workgroup [2]Dialogue Systems Group [3]CITEC*

Fig. 1. Game scene with sound quality feedback buttons: very good, rather good, rather poor, very poor.

Betz, Simon, Sina Zarrieß, and Petra Wagner. "Synthesized lengthening of function words-The fuzzy boundary between fluency and disfluency." *Proceedings of the International Conference Fluency and Disfluency*. 2017.

“Lengthening helps people to perform in tasks” 2016

- Two metrics:
- Sound quality
  - Generally good feedback, but:
  - Listeners don’t like long lengthening
- Task performance
  - Longer lengthening = shorter relative task completion time

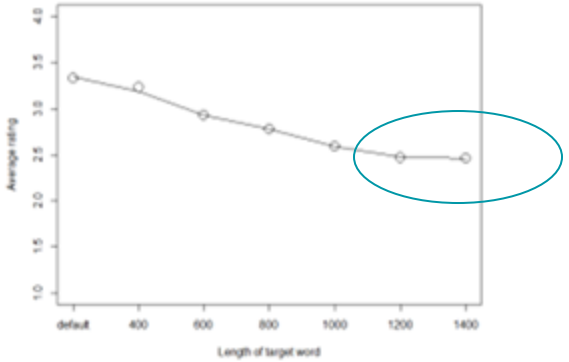


Fig. 2. User feedback with respect to word length. 4=good, 1=bad

Take-Home-Message:
Listeners like hesitation lenghtening, even synthesized, as long as it is not too long.
Still, long lengthening positively affects performances in cognitive tasks.
Probably due to the fact that it buys time for thinking.

Semi-Automatic Classification 2017

- *Lengthening is useful, we want more data.*
- A quite sobering glance at hesitation lengthening frequency in our two main corpora:

INTERSPEECH 2017
August 20–24, 2017, Stockholm, Sweden

Increasing Recall of Lengthening Detection via Semi-Automatic Classification

Simon Betz[1,2], *Jana Voße*[1], *Sina Zarrieß*[1,2], *Petra Wagner*[1,2]

[1]Bielefeld University, Bielefeld, Germany
[2]CITEC, Bielefeld, Germany
simon.betz@uni-bielefeld.de

Semi-Automatic Classification 2017

- Hypothesis: Lengthening is elusive
- Problem: How do we conduct corpus studies on a phenomenon that escapes the annotator?
- Solution: we built a simple lengthening detection tool
- Requires phonemically annotated corpus as input
- Outputs all instances with high z-normalized duration (z >= 3)
- This provides flags for annotators
- All flags then manually* classified into hesitation / other

Take-Home-Message:
Lengthening buys extra dialogue time **without listeners noticing!**

Multimodal Technologies and Interaction

MDPI

Article

Interactive Hesitation Synthesis: Modelling and Evaluation

Simon Betz [1,2,3,*], Birte Carlmeyer [1,3,4], Petra Wagner [1,2] and Britta Wrede [1,4]

1 Cluster of Excellence Cognitive Interaction Technology (CITEC), Bielefeld University, 33615 Bielefeld, Germany; b.carlmeyer@uni-bielefeld.de (B.C.); petra.wagner@uni-bielefeld.de (P.W.); bwrede@techfak.uni-bielefeld.de (B.W.)

2 Phonetics and Phonology Workgroup, Faculty of Linguistics and Literary Studies, Bielefeld University, 33615 Bielefeld, Germany

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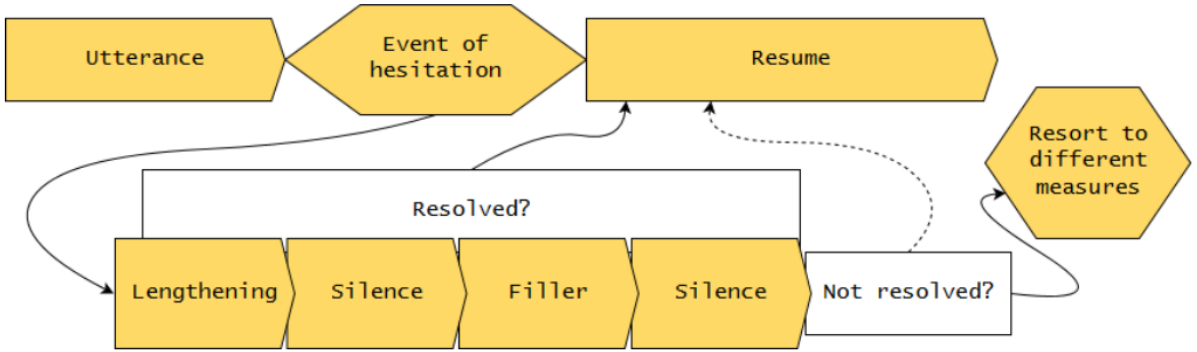
Received: 8 December 2017; Accepted: 26 February 2018; Published: 2 March 2018

Interactive Hesitation Synthesis 2018

- *While hesitation.event: (defined and managed by the dialogue system)*
  - *Find the next best target* for lengthening*
  - *Apply as much lengthening as elasticity** allows*
  - *insert silence, cap at 1s*
  - *insert filler*
  - *insert silence, cap at 1s*
  - *give up ;)*



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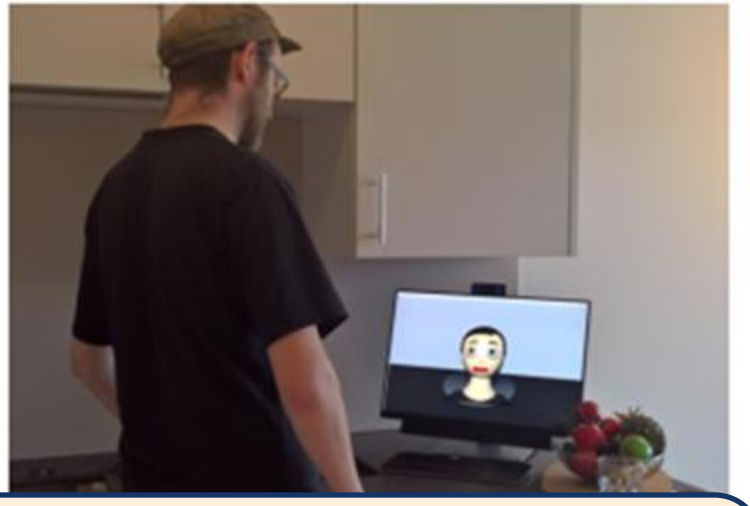
Interactive Hesitation Synthesis 2018

- Tested in an item-retrieval study
- Virtual agent on a screen gives instructions where to find items
- Event of Hesitation = lack of eye contact
- Two conditions: Hesitating and non-hesitating system
- **Participants instructed by**

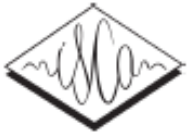


Take-Home-Message:
Lengthening works as entry point for hesitation insertion.
Real-time adaptive synthesis of hesitations possible.
Loss in sound quality trades off with gain in task performance.

The Greennnn Tree 2019

- For our hesitation insertion algorithm, we assumed that it is fine to lengthen at the next best position.
- But: it makes a difference, where in a word the lengthening is.

INTERSPEECH 2019
September 15–19, 2019, Graz, Austria



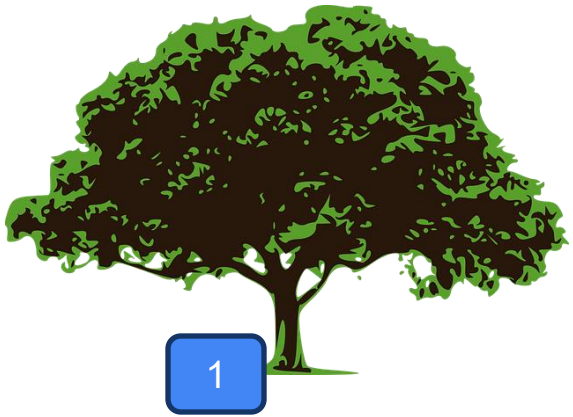
The greennn tree – lengthening position influences uncertainty perception

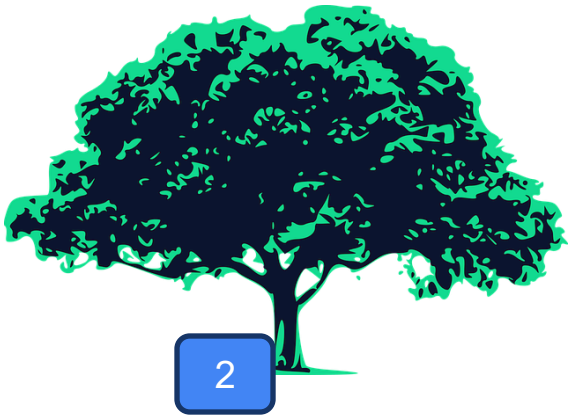
Simon Betz[1], *Sina Zarrieß*[1], *Éva Székely*[2], *Petra Wagner*[1]

[1]Faculty of Linguistics and Literary Studies, Bielefeld University, Bielefeld, Germany
[2]Division of Speech, Music and Hearing, KTH Royal Institute of Technology, Stockholm, Sweden
simon.betz@uni-bielefeld.de

The Greennnn Tree 2019

- Question for you: Which image am I referring to?
- „The green tree.“

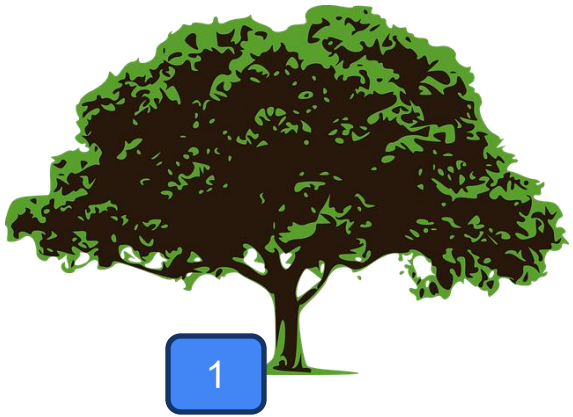


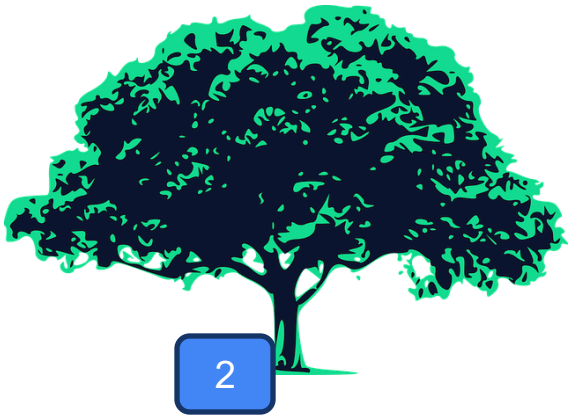


Royalty free Images from pixabay.

The Greennnn Tree 2019

- Question for you: Which image am I referring to now?
- „The grrrrrr:een tree.“





The greennnn tree 2019

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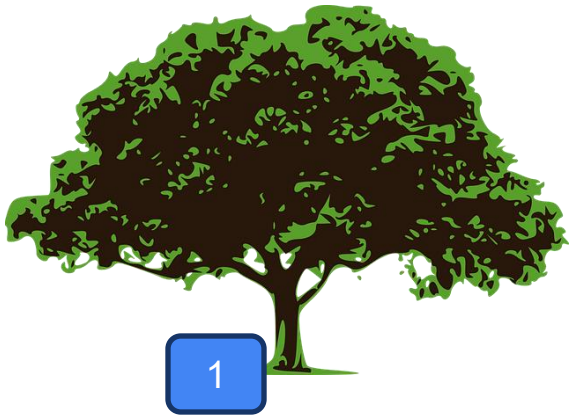

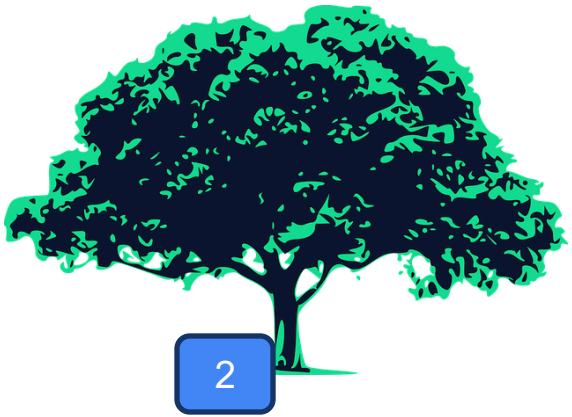

The Greennnn Tree 2019

- Usual result: Initial lengthening = Uncertainty about word itself, Final lengthening = Uncertainty about following word

The Greennnn Tree 2019

- Perception study to test this intuition
- Pretext: Our system can signal uncertainty about colors and shapes.

(a) (b)

Figure 1: *Two images (shown as examples in the warm-up phases of our experiment) illustrating different domains of uncertainty: object category (a) and color (b).*

The Greennnn Tree 2019

- Stimuli modified to have either initial or final lengthening in a color word
- Participants have to rate the system's uncertainty wrt color and shape for each stimulus.

RESULTS:

Initial LEN = word itself

Final LEN = next word or word itself

No LEN = no uncertainty

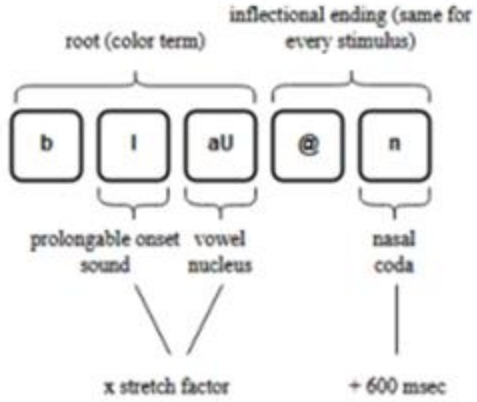

Figure 3: *Duration modification for initial and final lengthening exemplified on the color term "blauen" (blue + ending).*

The Greennnn Tree 2019

- *How many words would you need to phrase „grrrreen tree“ without lengthening available?*
- *„The tree that is actually green, not the one that is blueish green…“*
- For conveying uncertainty, lengthening is very efficient.
- One reason why lengthening is usually not rated negatively – it is familiar as part of fluent communication?

Take-Home-Message:
If lengthening is perceived, it can have massive communicative impact.

Cognitive Load and Multimodal Hesitation 2023

- We know that lengthening is very frequent, very useful in communication, and very hard to notice in corpora

Open Access Article

Cognitive Load Increases Spoken and Gestural Hesitation Frequency

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Cognitive Load and Multimodal Hesitation 2023

German Vocab Help:
Spielen – play
Zahnräder – Cogworks (card name)
Generieren – generate
Energie – energy
Rot – red
Grün – green
Blau – blue
Nutzen – use
Schaltkreise – Circuits (card name)
Eins – one
Zwei – two
Drei – three
Filter – Filter (card name)
Karte – Card
Ziehen – draw
Jibjibjib – jibjibjib ;)

Cognitive Load and Multimodal Hesitation 2023

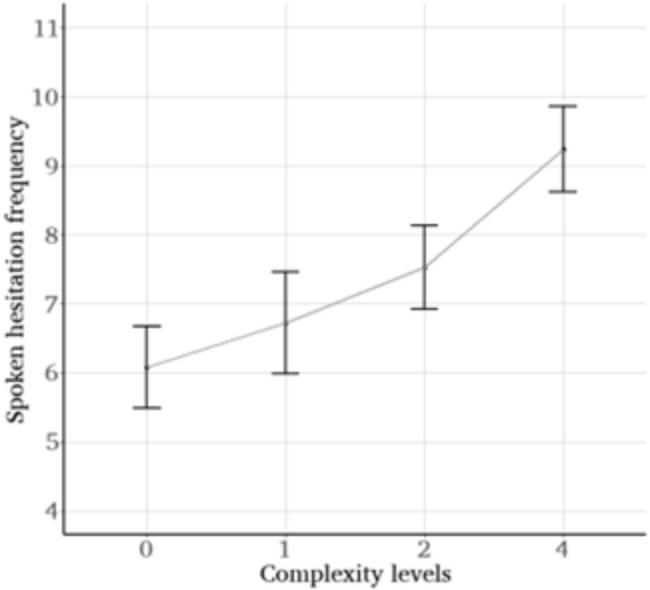
- Result 1: This setup yields abundant amounts of disfluencies

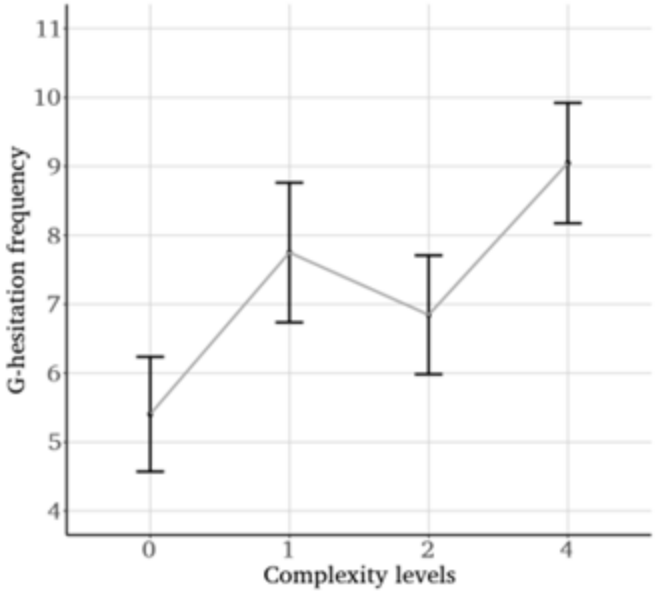
Hesitations	N	%	Corpus Specifics	
Silence	901	54.7	Words in corpus	8141
Lengthening	498	30.2	Corpus duration	110 min
Filler	249	15.1	Words affected by hesitation	20.2%
total	1648		Hesitations per minute	14.9

Corpus	Type	Size	Len. Freq.
DUEL	task-oriented	4.5 h	1.6 / minute
GECO	spontaneous	45 h	0.5 / minute
CARDGAME	task-oriented	1.9 h	4.5 / minute

Cognitive Load and Multimodal Hesitation 2023

- Result 2: Level of **complexity** (=**cognitive load)** is linearly correlated with **spoken** and **gestural** hesitation frequency





Cognitive Load and Multimodal Hesitation 2023

- Setup highly **efficient** to elicit ecologically valid disfluencies
- Spoken and gestural hesitations can be easily studied in connection
- Lengthening is very frequent.
- But more frequent than fillers? Interesting, and unexpected…
- *DiSS topic 2025: The nature of the corpus and the research question may influence how many lengthenings one finds.*

Cognitive Load and Multimodal Hesitation 2023

Take-Home-Message:
Lengthening is actually very frequent.
There is also lengthening in gestures.

Multimodal Lengthening and Non-Understanding

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≡ Article Navigation

Predictability of Understanding in Explanatory Interactions Based on Multimodal Cues

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DOI: https://doi.org/10.1145/3678957.3685741
ICMI '24: INTERNATIONAL CONFERENCE ON MULTIMODAL INTERACTION, San Jose, Costa Rica, November 2024

Multimodal Lengthening and Non-Understanding

- Data: 4s windows of (non-)understanding in 21 explanatory dialogues
- RF classifier, ranking of predictors

Türk, O., Lazarov, S., Wang, Y., Buschmeier, H., Grimminger, A., & Wagner, P. (2024). Predictability of understanding in explanatory interactions based on multimodal cues. In *Proceedings of the 26th International Conference on Multimodal Interaction*, 449-458, San José, Costa Rica.

Multimodal Lengthening and Non-Understanding

- Predictors: acoustics, multimodal kinematics and spatial info
- Non-understanding signalled by:
    - continued movement of index finger
    - Presence of adaptors, least eye openness
    - Lacking acceleration of head (tilting)
    - Longer durations, lower pitch, invariant intensity

Multimodal Lengthening and Non-Understanding

- Predictors: acoustics, multimodal kinematics and spatial info
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  - *continued movement of index finger*
  - Presence of adaptors, least eye openness
  - *Lacking acceleration of head (tilting)*
  - *Longer speech durations*, lower pitch, invariant intensity

Dual-Nature-Take-Home-Message:
Lengthenings are heavily multimodal and occur in places where speakers report a lack in understanding. These are *sometimes* perceived by an interlocutor.

Summary

- Lengthening is not a dark horse anymore - its talents have been revealed!
- Lengthenings are frequent and multimodal
- Lengthenings are harder to trace perceptually than other disfluencies
- Due to their **dual nature**, they can be used **to hide or signal** something: uncertainty, cognitive load, lack of understanding,…
- Lengthenings can also be used for:
  - buying dialogue time (like all hesitations)
  - buying dialogue time without the listener noticing
  - serve as the entry point for all hesitation intervals

Thank you!

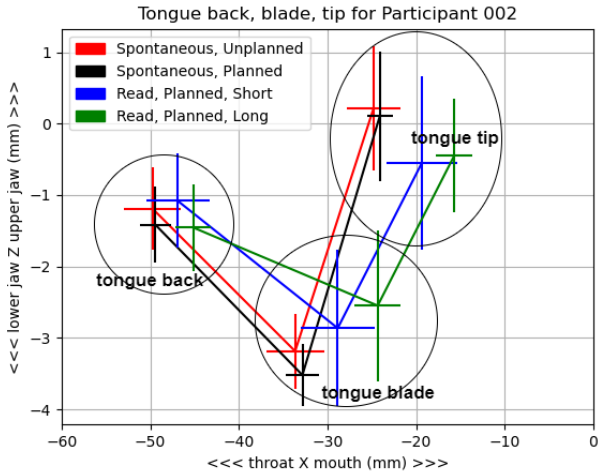
Scan me for a compilation of paper links!

Future and Ongoing Work

- Replicate the green tree (with broader context)
- Rocket science (Nickname for a study to disentangle filler and lengthening signaling functions)
- Hesitation grounding (after a filler has been produced, longer silences seem tolerable)
- EMA (Articulography research on Hesitations)
- Role of Lengthening in Multimodal Ensembles

EMA

- ElectroMagnetic Articulography investigation of hesitation (Joint work with Malte Belz & Tine Mooshammer, in preparation)
- Investigating articulatory resting positions and their interaction with hesitations and pauses



Left image: © Uni Bielefeld, https://www.uni-bielefeld.de/fakultaeten/linguistik-literaturwissenschaft/forschung/zentrallabor/
Right image: Preliminary results plot featured in an abstract to be presented at P&P Conference Leipzig in Oct 2025.