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Using reverse correlation to study speech perception

Léo Varnet

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“Cracking the speech code”: finding the auditory primitives of speech comprehension



“Cracking the speech code”: finding the auditory primitives of speech comprehension

- Which acoustic cues underlie the segmentation of the speech signal into words?
- Which acoustic cues allow listeners to differentiate one phoneme from another?



“Cracking the speech code”: finding the auditory primitives of speech comprehension

- Which acoustic cues underlie the segmentation of the speech signal into words?
- Which acoustic cues allow listeners to differentiate one phoneme from another?

No easy answer, due to the spectrotemporal complexity of natural speech.

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Reverse correlation (aka **revcorr**) is the perfect tool to reveal perceptual cues used in a psychophysical task, based on purely behavioral data... in particular for auditory categorization tasks. [Varnet et al. 2013, 2015; Osses & Varnet, 2021; Varnet & Lorenzi, 2022]

Core idea: adding **random fluctuations** to the stimulus and measure how they affect the participant's responses on a trial-by-trial basis.

Original Article

High-Frequency Sensorineural Hearing Loss Alters Cue-Weighting Strategies for Discriminating Stop Consonants in Noise

Léo Varnet¹, Chloé Langlet¹, Christian Lorenzi¹, Diane S. Lazard², and Christophe Michey³

Abstract

There is increasing evidence that (NH) individuals, even when we perceptual strategies is an important two complementary approaches: noise and (b) measuring the recordings altered by the spectrotemporal locations of The cue-weighting strategies we frequency loss, and 15 HI list amplification to compensate for than on the low-frequency differences in internal noise. Ir

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JASA ARTICLE

Probing temporal modulation detection in white noise intrinsic envelope fluctuations: A reverse-correlation study

Léo Varnet¹ and Christian Lorenzi²

Laboratoire des Systèmes Perceptifs, Département d'Études Cognitives, École Normale Supérieure, Université Paris Sciences & Lettres, Centre National de la Recherche Scientifique, 75005 Paris, France

frontiers in
HUMAN NEUROSCIENCE

Using auditory classification images for the identification of fine acoustic cues used in speech perception

Léo Varnet^{1,2*}, Kenneth Knoblauch³, Fanny Meunier^{1,2,4} and Michel Hoen^{1,2}

¹ Neuroscience Research Centre, Brain Dynamics and Cognition Team, INSERM U1028, CNRS UMR5292, Lyon, France

² Ecole Doctorale Neurosciences et Cognition, Université de Lyon, Université Lyon 1, Lyon, France

³ Integrative Neuroscience Department, Stem Cell and Brain Research Institute, INSERM U846, Bron, France

METHODS ARTICLE

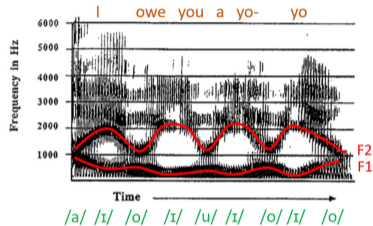
published: 16 December 2013
doi: 10.3389/fnhum.2013.00865



White noise on sound perception results from the mask random intrinsic envelope fluctuations arising from effects on this phenomenon to probe AM detection through normal-hearing listeners were asked to detect the carrier using a yes-no task with 3000 trials/participant. Reverse-correlation analysis was then carried on the effects of the stimulus' temporal envelope influences simulated with different implementations of a modulation. Normal listeners were able to track the position of AM. It showed a marked temporal decay and a consistent plateau. This data, this was interpreted as an evidence for envelope fluctuations. © 2013 Acoustical Society of America

Segmentation cues

How do listeners find the boundaries between words in continuous speech? (e.g. “I owe you a yo-yo”)



- lexical cues [McClelland & Elman, 1986]
- phonotactic cues [McQueen, 1998]

... but that's not the whole story!

Segmentation cues

We are able to discriminate between **phonemically identical sentences**

Dis, à m'aimer, consens, va ! / Dis à mémé qu'on s'en va.
– “Andrea c'est toi”, Bobby Lapointe



Je suis la sève héritée. Je suis lasse et vérité. Je suis la sévérité.
– “L'Oracle”, Jean Cocteau

*Dans ces meubles laqués, rideaux et dais moroses,
Danse, aime, bleu laquais, ris d'oser des mots roses.*
– “Le Coffret de santal”, Charles Cros



Segmentation cues

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⇒ There must be some **acoustic cues** for segmentation

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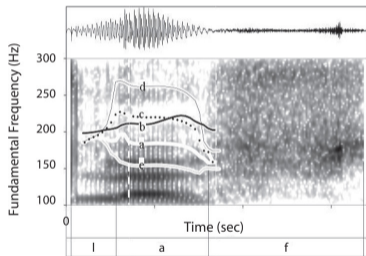
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C'est la mie / c'est l'amie – [Spinelli et al., 2007]

Standard approach for identifying segmentation cues: **manipulating** acoustic content



By artificially modifying the f_0 on a specific phonetic segment and running a perceptual experiment, we can demonstrate that this particular information is a cue for segmentation [Spinelli, Grimault, Meunier & Welby, 2010].

Limitations of this hypothesis-driven approach: potential cues tested one at a time

L'amie/La mie experiment [Osses et al., 2023]

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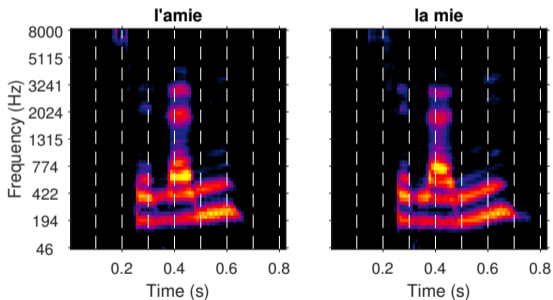
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Topic: Acoustic cues for the segmentation of a speech sentence into words.

Targets: 2 phonetically identical sentences /selami/ (t_0 ="c'est l'amie" and t_1 ="c'est la mie"), equalized in duration and rms [Spinelli et al., 2010].

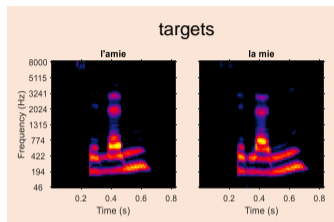


The targets were divided into 100-ms segments. Then, the f_0 trajectory in each segment was replaced by a random f_0 trajectory and each segment was compressed or stretched by a random amount, using WORLD [Morise et al., 2016].

L'amie/La mie experiment [Osses et al., 2023]

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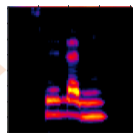
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stimulus for trial i
(random prosody)

segmentation

participant's
response

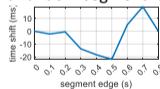


$$r_i = \begin{cases} 1 & \text{("l'amie")} \\ 0 & \text{("la mie")} \end{cases}$$

with random f_0



and random segment length



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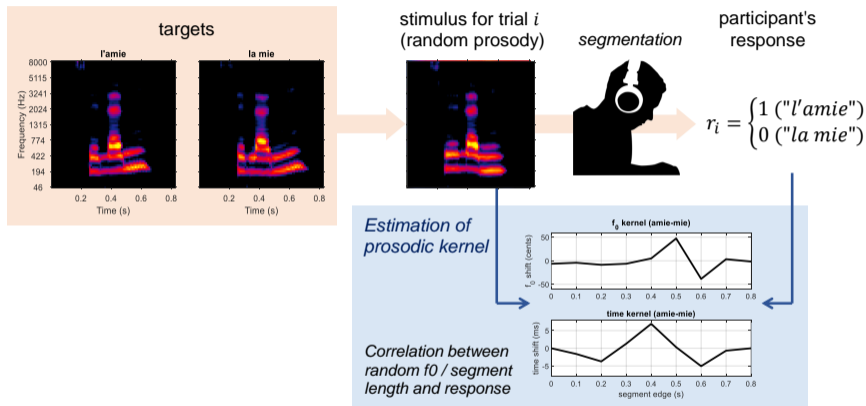
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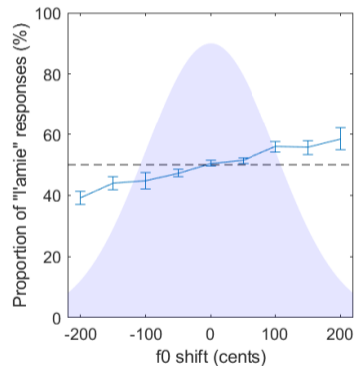
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We obtain two kernels (f_0 kernel and time kernel), indicating which aspects of the prosody are used as segmentation cues.

Results: effect of f_0 on /a/ segment

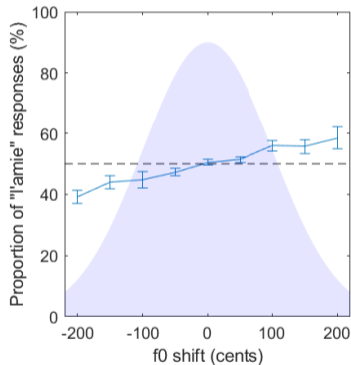
- There is a systematic effect of the random f_0 at 0.5 s (/a/ segment) on the response of participants.



Results: effect of f_0 on /a/ segment

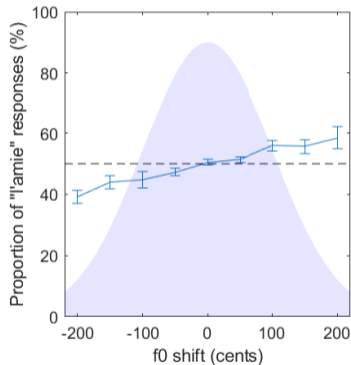
- There is a systematic effect of the random f_0 at 0.5 s (/a/ segment) on the response of participants.
- This is in line with the notion of “early f_0 rise” in French prosody: a high f_0 on the first vowel of a content word is a cue for segmentation.

[Spinelli et al. 2010; Welby, 2007]



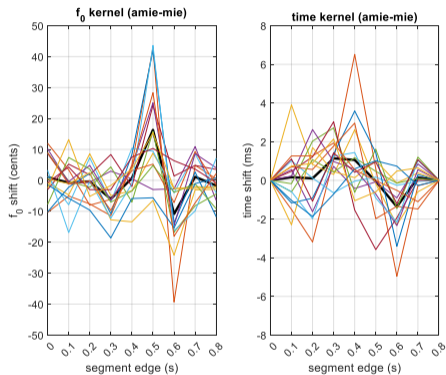
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[Spinelli et al. 2010; Welby, 2007]
- The strength of this relationship corresponds to the 0.5-s weight in the f_0 kernel.



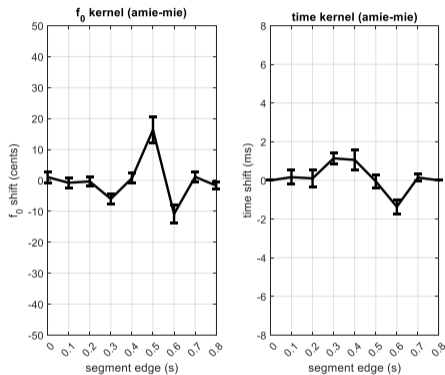
Results: prosody kernels

- Considerable variability at the group level (N=16)



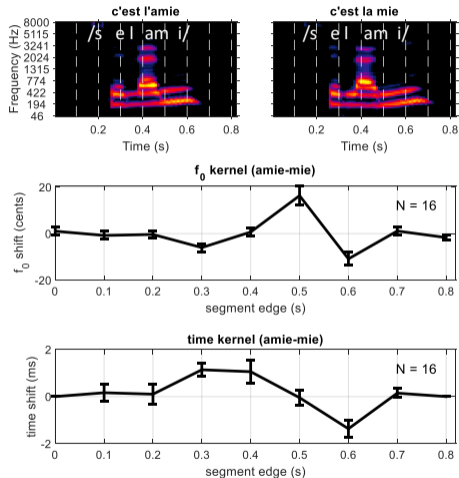
Results: prosody kernels

- Considerable variability at the group level (N=16)
- Nevertheless, a clear prosodic pattern emerges

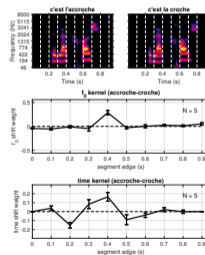
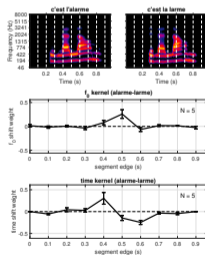
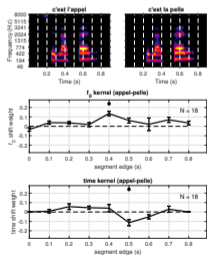
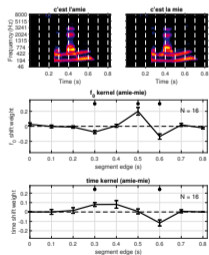


Results: prosody kernels

- Considerable variability at the group level (N=16)
- Nevertheless, a clear prosodic pattern emerges
- Two main segmentation cues can be identified: the relative f_0 of vowels /e/, /a/ and /i/ and relative duration of vowels /e/ and /i/.
- Again, consistent with previous findings obtained using hypothesis-driven methods [Spinelli et al. 2010; Welby, 2007; Shoemaker, 2014]



- Similar results were found for other pairs of ambiguous stimuli.
- Secondary cues seem to depend on the phonetical content of the targets (e.g. duration of the second syllable).



Aba/Ada experiment [Osses & Varnet, 2023]

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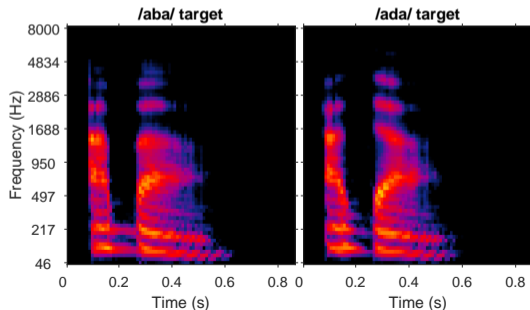
Conclusions

Topic: perception of stop consonants /b/ and /d/.

Targets: 2 VCV sounds (t_0 =/aba/ and t_1 =/ada/) from the Oldenburg Logatome Corpus [Wesker et al., 2005], equalized in duration and rms.



Alejandro Osses



Aba/Ada experiment [Osses & Varnet, 2023]

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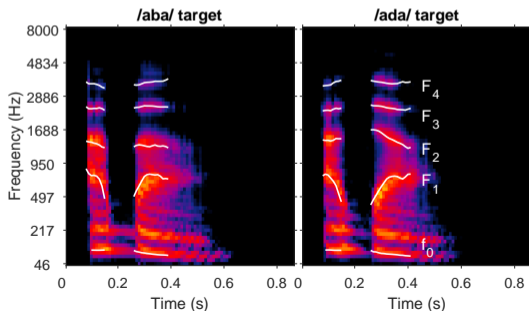
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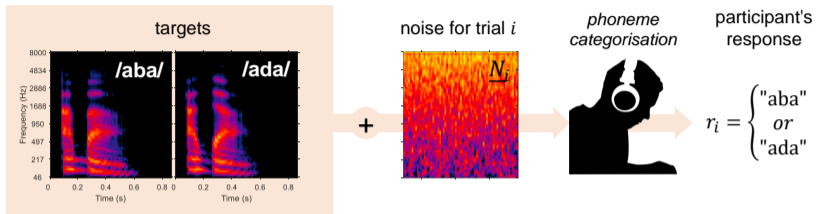
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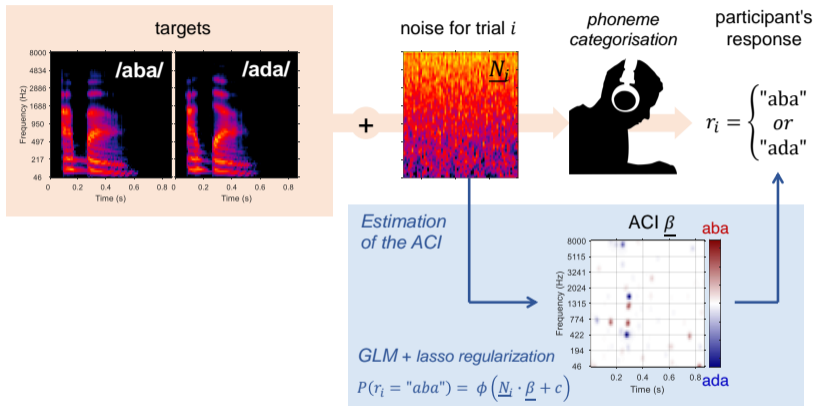
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Auditory Classification Image (ACI): time-frequency matrix of decision weights. Shows how a specific noise configuration can mislead the participant.

Results [Osses & Varnet, 2023]

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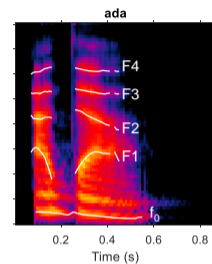
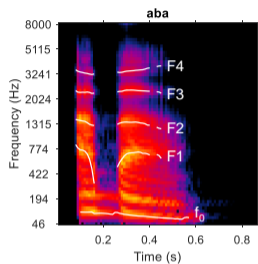
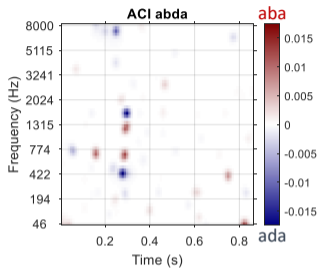
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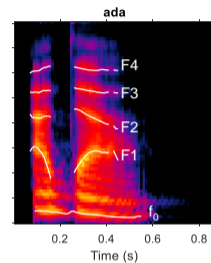
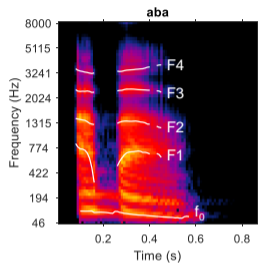
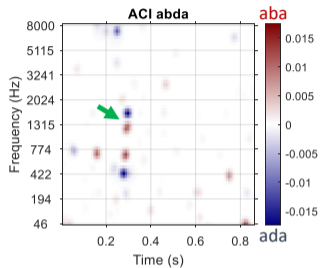
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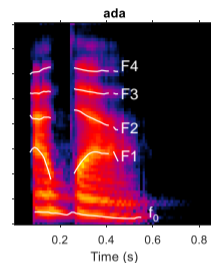
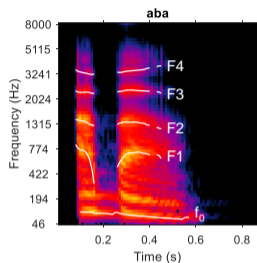
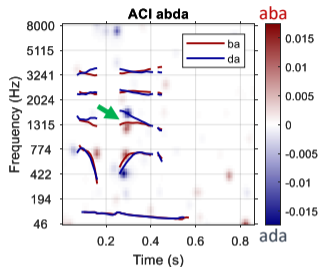
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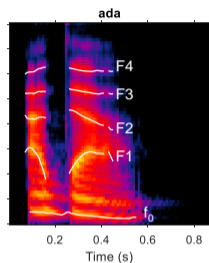
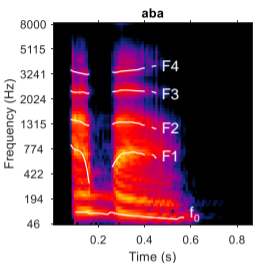
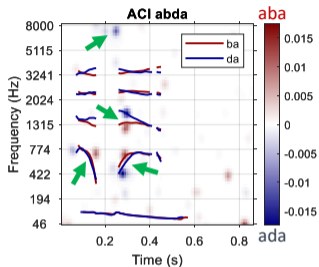
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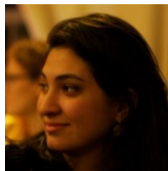
- The analysis successfully identified the **main cue** for the task (F2 onset), consistent with the phonetics literature [Lieberman et al., 1954]...



- The analysis successfully identified the **main cue** for the task (F2 onset), consistent with the phonetics literature [Lieberman et al., 1954]...
- ...as well as several **secondary cues** (e.g., F1 onset).

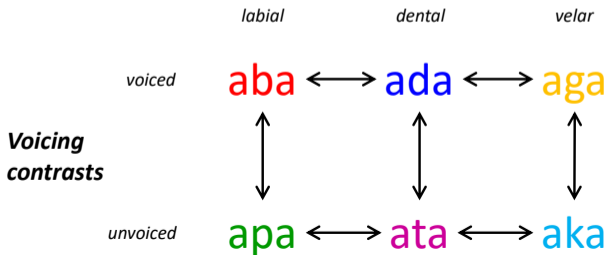
Stop consonants experiment [Carranante et al., in prep.]

- Discrimination task in noise
- 6 target sounds (plosive C in context /aCa/)
- 7 participants × 7 contrasts, 4.000 trials/condition



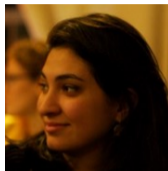
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Place of articulation contrasts



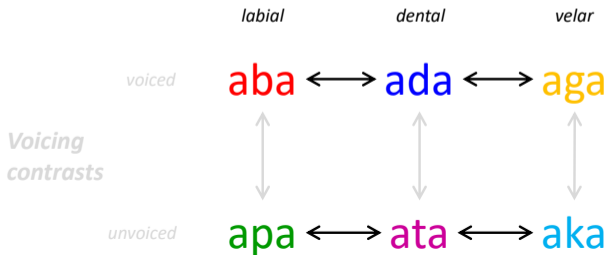
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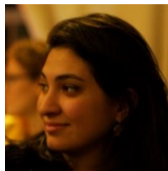
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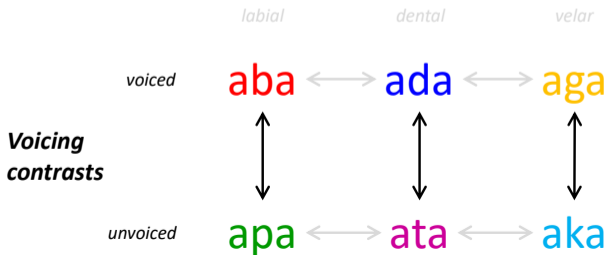
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Place of articulation contrasts



Group-averaged ACIs

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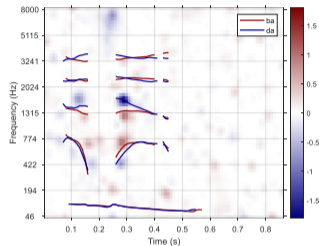
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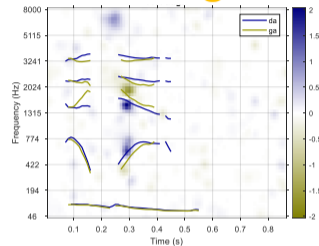
Place of articulation cues:

- F2 onset
- F1 onset
- release burst (/d/ and /t/)
- coarticulation on F1 and F2

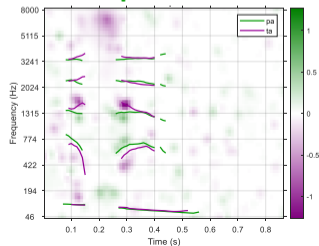
aba-ada



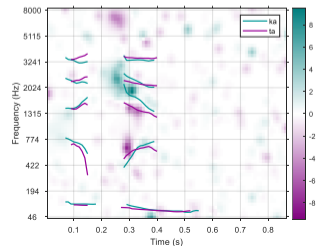
ada-aga



apa-ata



ata-aka

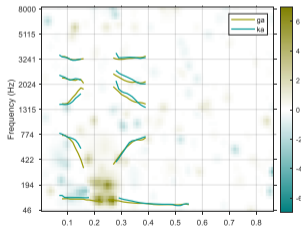


Group-averaged ACIs

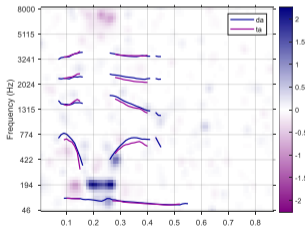
Voicing cues:

- voicing bar
- F1 onset
- release burst (only for /t/)

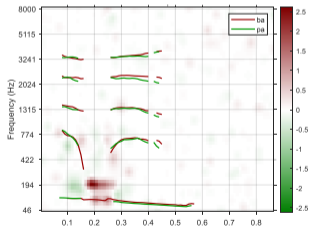
aga-aka



ada-ata



aba-apa



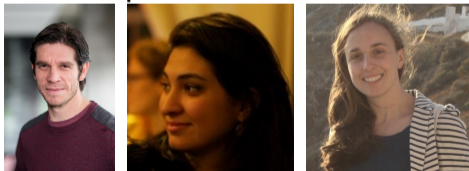
Thanks for your attention!

The “segmentation cues” team



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