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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

ଏ ଲାଠିଂ ଲିଖିବୁ ନା  
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**“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 Varnet<sup>1</sup>, Chloé Langlet<sup>1</sup>, Christian Lorenzi<sup>1</sup>, Diane S. Lazard<sup>2</sup>, and Christophe Michey<sup>3</sup>

### Abstract

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

Trends in Hearing  
Volume 23: 1–18  
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SAGE

JASA ARTICLE

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

Léo Varnet<sup>1</sup> and Christian Lorenzi<sup>2</sup>

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<sup>1,2\*</sup>, Kenneth Knoblauch<sup>3</sup>, Fanny Meunier<sup>1,2,4</sup> and Michel Hoen<sup>1,2</sup>

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

<sup>2</sup> Ecole Doctorale Neurosciences et Cognition, Université de Lyon, Université Lyon 1, Lyon, France

<sup>3</sup> Integrative Neuroscience Department, Stem Cell and Brain Research Institute, INSERM U846, Bron, France

METHODS ARTICLE

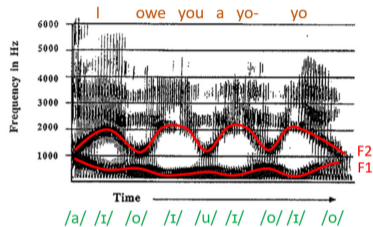
published: 16 December 2013  
doi: 10.3389/fnhum.2013.00865



ary noise on sound perception results from the mas random intrinsic envelope fluctuations arising from es on this phenomenon to probe AM detection straght normal-hearing listeners were asked to detect the ne carrier using a yes-no task with 3000 trials/particip reverse-correlation analysis was then carried on the d cts of the stimulus' temporal envelope influences simulated with different implementations of a modul nan listeners were able to track the position of AM f showed a marked temporal decay and a consistent p alated data, this was interpreted as an evidence for nvelope fluctuations. © 2022 Acoustical Society of A

# 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





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

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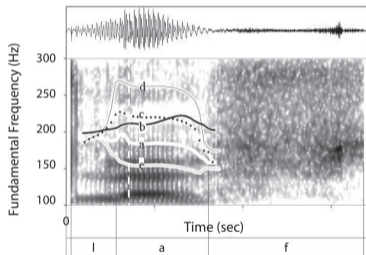
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*C'est la mie / c'est l'amie* – [Spinelli et al., 2007]

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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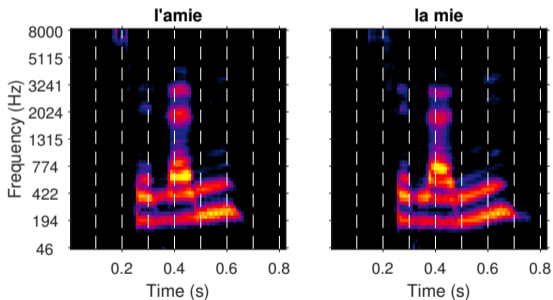
Aba/Ada experiment

Stop consonants experiment

Conclusions

**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].

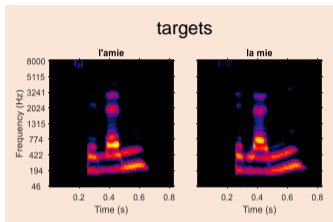


The targets were divided into 100-ms segments. Then, the  $f_0$  trajectory in each segment was replaced by a random  $f_0$  trajectory and each segment was compressed or stretched by a random amount, using WORLD [Morise et al., 2016].

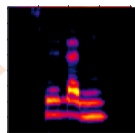
# L'amie/La mie experiment [Osses et al., 2023]

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stimulus for trial  $i$   
(random prosody)

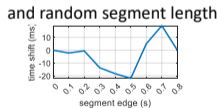
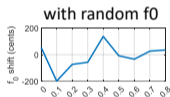


segmentation



participant's  
response

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



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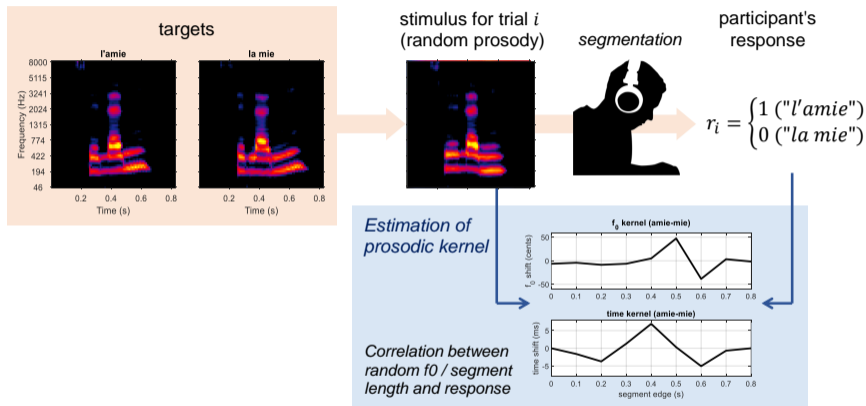
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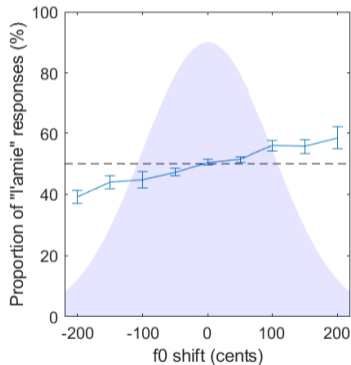
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We obtain two kernels ( $f_0$  kernel and time kernel), indicating which aspects of the prosody are used as segmentation cues.

# Results: effect of $f_0$ on /a/ segment

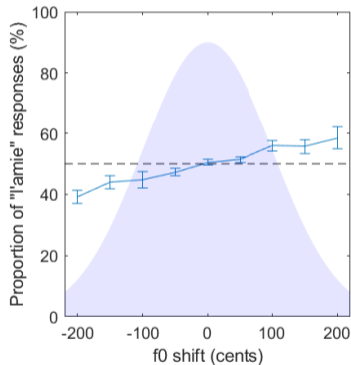
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- This is in line with the notion of “early  $f_0$  rise” in French prosody: a high  $f_0$  on the first vowel of a content word is a cue for segmentation.

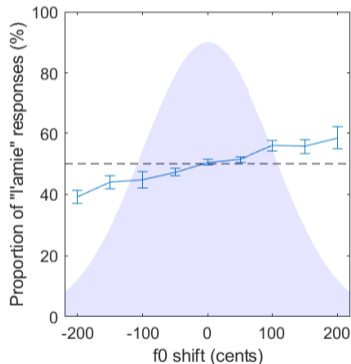
[Spinelli et al. 2010; Welby, 2007]





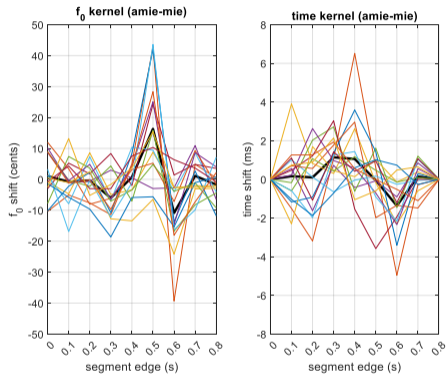
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*[Spinelli et al. 2010; Welby, 2007]*
- The strength of this relationship corresponds to the 0.5-s weight in the  $f_0$  kernel.



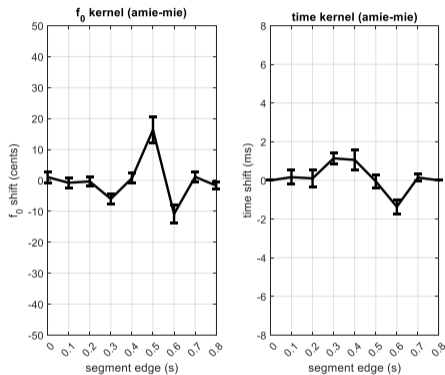
# Results: prosody kernels

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



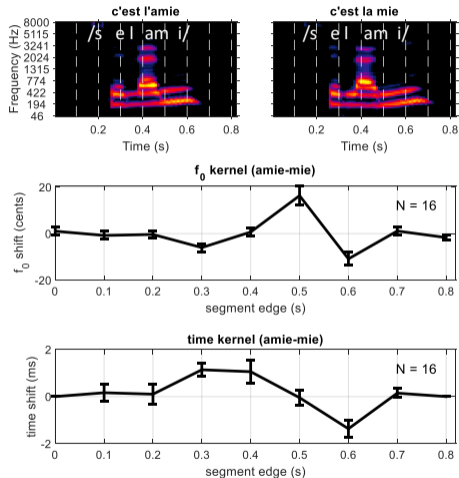
# Results: prosody kernels

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

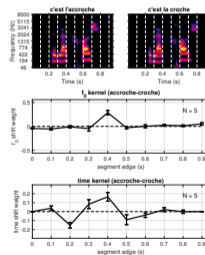
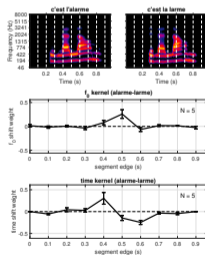
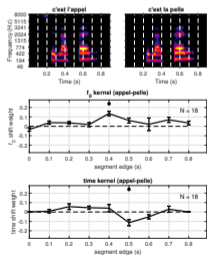
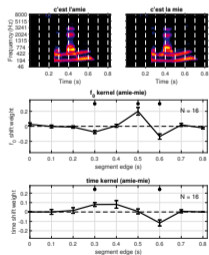


# Results: prosody kernels

- 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]

Using reverse correlation to study speech perception

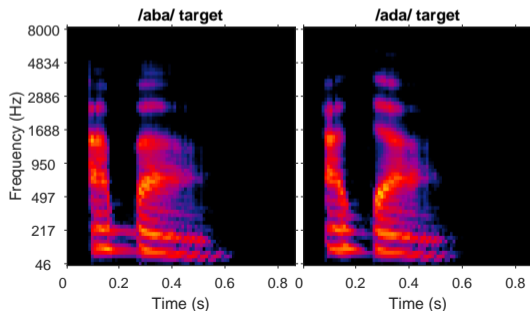
Léo Varnet

**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



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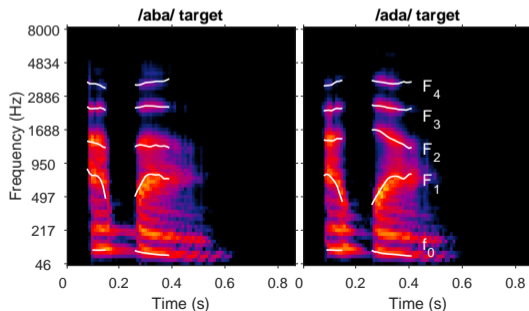
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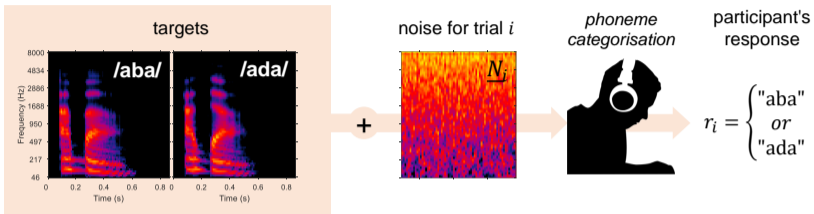
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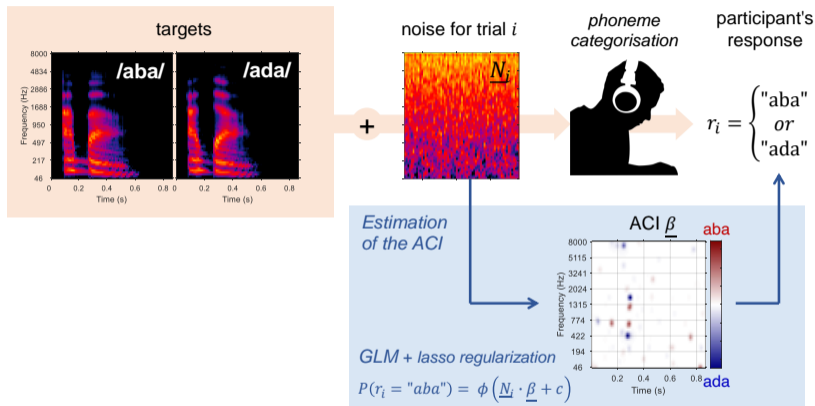
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**Auditory Classification Image (ACI):** time-frequency matrix of decision weights. Shows how a specific noise configuration can mislead the participant.

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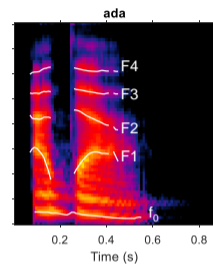
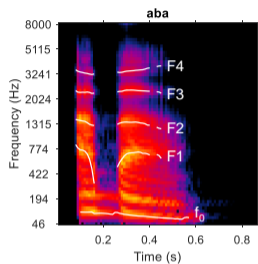
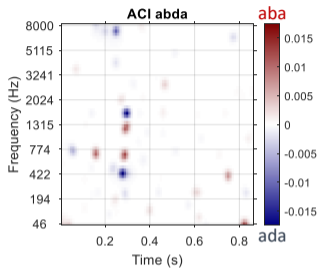
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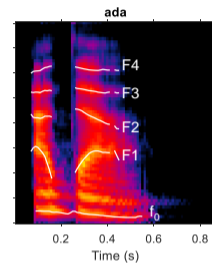
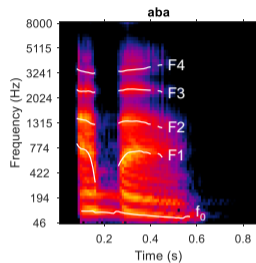
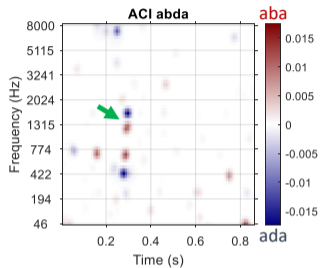
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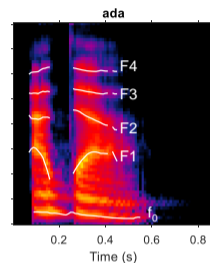
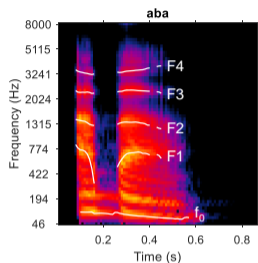
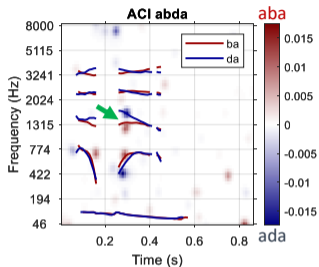
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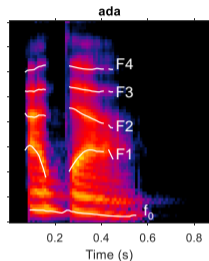
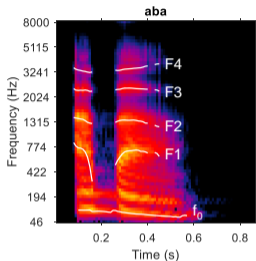
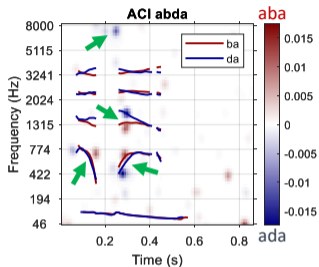
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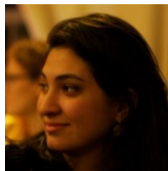
- The analysis successfully identified the **main cue** for the task (F2 onset), consistent with the phonetics literature [Lieberman et al., 1954]...



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- ...as well as several **secondary cues** (e.g., F1 onset).

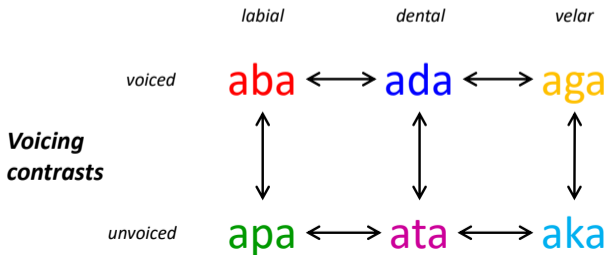
# Stop consonants experiment [Carranante et al., in prep.]

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



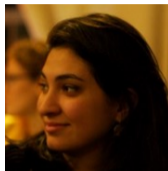
Géraldine Carranante

## Place of articulation contrasts



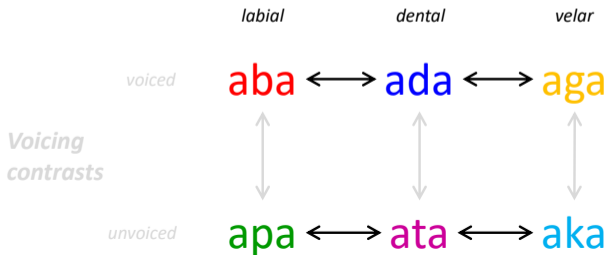
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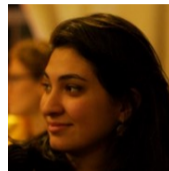
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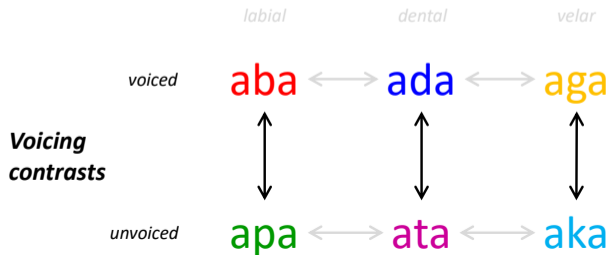
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Géraldine Carranante

## Place of articulation contrasts





# Group-averaged ACIs

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Phonetic cues

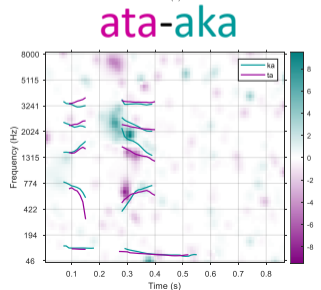
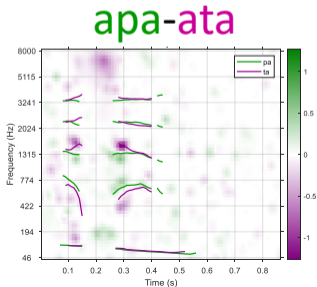
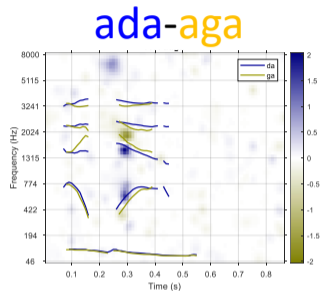
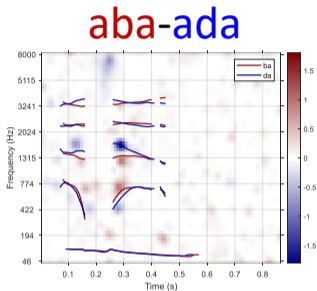
Aba/Ada experiment

Stop consonants experiment

Conclusions

## Place of articulation cues:

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

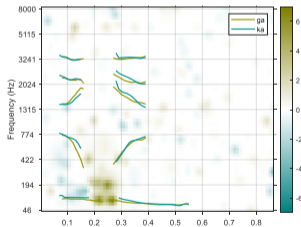


# Group-averaged ACIs

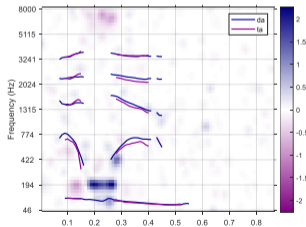
## Voicing cues:

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

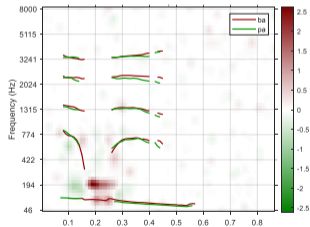
aga-aka



ada-ata



aba-apa



Introduction

Segmentation cues

L'amie/La mie experiment

Phonetic cues

Aba/Ada experiment

Stop consonants experiment

Conclusions

- The **auditory revcorr approach** can reveal listening strategies and acoustic cues in psychoacoustic tasks (e.g., pitch perception, AM detection) and psycholinguistic tasks (e.g., phoneme discrimination, segmentation).

**Code available on GitHub** as an open-source MATLAB toolbox with documentation and turnkey experiments [Osses & Varnet, 2021]:  
<https://github.com/aosses-tue/fastACI>





- The **auditory revcorr approach** can reveal listening strategies and acoustic cues in psychoacoustic tasks (e.g., pitch perception, AM detection) and psycholinguistic tasks (e.g., phoneme discrimination, segmentation).
- It can also produce reliable results at the individual level, making it possible to explore **individual listening strategies**.
- Listening strategies for speech perception are complex and rely on the **weighted combination of many cues**.

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<https://github.com/aosses-tue/fastACI>



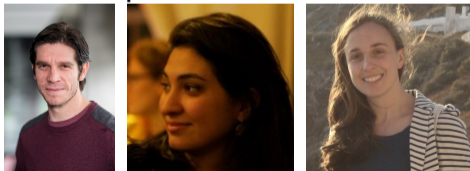
# Thanks for your attention!

## The “segmentation cues” team



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