Linguistic exploration via speech processing technologies

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Introduction

- Major advances in speech processing technologies over the last decade
- Technologies available for a growing number of languages
- Growing number of challenges: e.g., Interspeech 2018 speech recognition for Indian languages, Formosa speech recognition challenge for Taiwanese
- Speech technologies for corpus based linguistic studies

A methodological shift

- Re-pose traditional research questions studied on small corpora for big data studies
- Extract trends from data which can lead to research hypotheses for more indepth exploration
- Foster interdisciplinarity between linguistics, phonetics, medecine, mathematics, signal processing, IT computer sciences...
- Foster team research using shared data and shared research questions

Corpus-based linguistic studies

- Study language variation
  - Contextual and reduction variation [Adda-Decker & Snoeren, 2010]
  - Regional variants [Woehrling, 2009]
  - Non-native speakers [Vieru, 2008]
  - Diachronic change [Candea et al, 2013]
- Error analysis
- Workshops
  - New Tools and Methods for Very-Large-Scale Phonetics Research (2011)
  - Errors by Humans and Machines in multimedia, multimodal and multilingual data processing (Errare, 2013, 2015)
  - Big Data & Speech: New Technologies speech corpus exploration (2017) `http://bigdataspeech.alwaysdata.net/`

Corpus-based linguistics

Some case studies:

- Reduction: English, French, Romanian, Spanish
- Diachronic change
- Code-switching: bilingual Algerian Arabic/French
- BULB: Breaking the unwritten language barrier

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Methodology: speech alignment with pronunciation variants

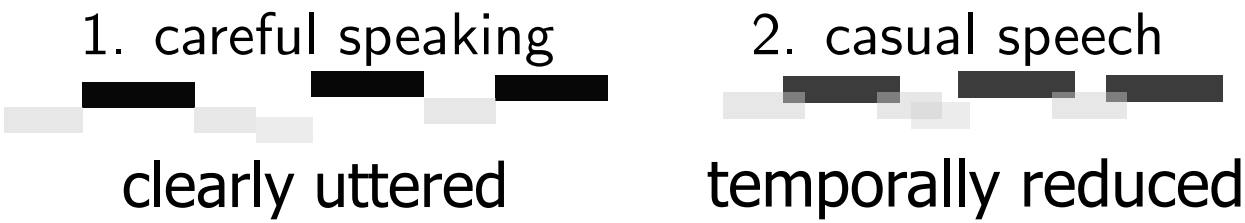
- Alignment mode:
  $\Rightarrow$ transcript constrains the matching process between speech and text
- Produce alignments with specific lexica for each phonological study

Temporal speech reduction

- Speech reduction: vowel reduction, consonant lenition, consonant cluster reduction, syllabic restructuring [e.g. Ernestus 2000, Duez 2003, Van Son & Pols 2003, Adda-Decker et al. 2005, Dilley & Pitt 2010]
- Traces of speech reduction in written language:
  - dunno (don't know, do not know)
  - ça [sa] (cela [səla] 'that'), 'y a [ja] (il y a [ilija] 'there is')
  - ins [ɪns] (in das [ɪn das] 'in the')
- Temporal reduction [Adda-Decker & Snoeren 2010, Adda-Decker & Lamel 2018]:
  - any reduction process resulting in fewer segments in the produced speech
  - mainly found in unstressed segments
  - conditioned by speaking style

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Temporal reduction

Temporal reduction phenomena raise issues:

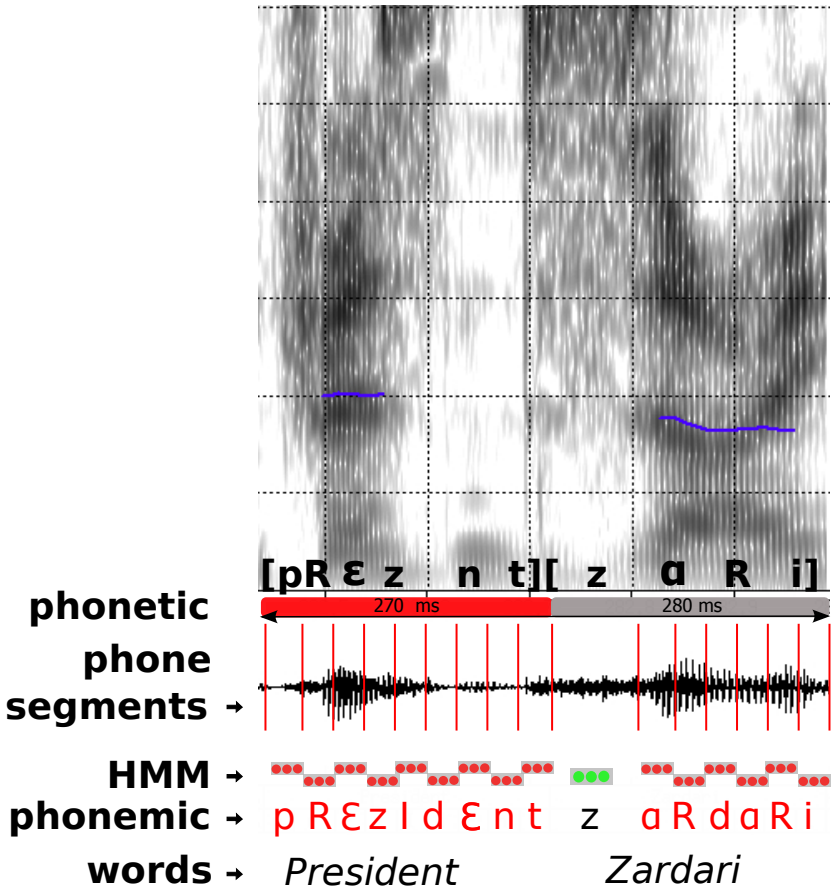
- for automatic speech processing (both recognition, synthesis)
- for human processing in psycholinguistics
- for language learning/teaching...

Large speech corpora can help answer questions:

- Where do temporal reductions occur?
- How frequent is temporal reduction?
- To what extent is it conditioned by language, by speaking style?

Illustration of strong temporal reduction

Speech extract: 'President Zardari'



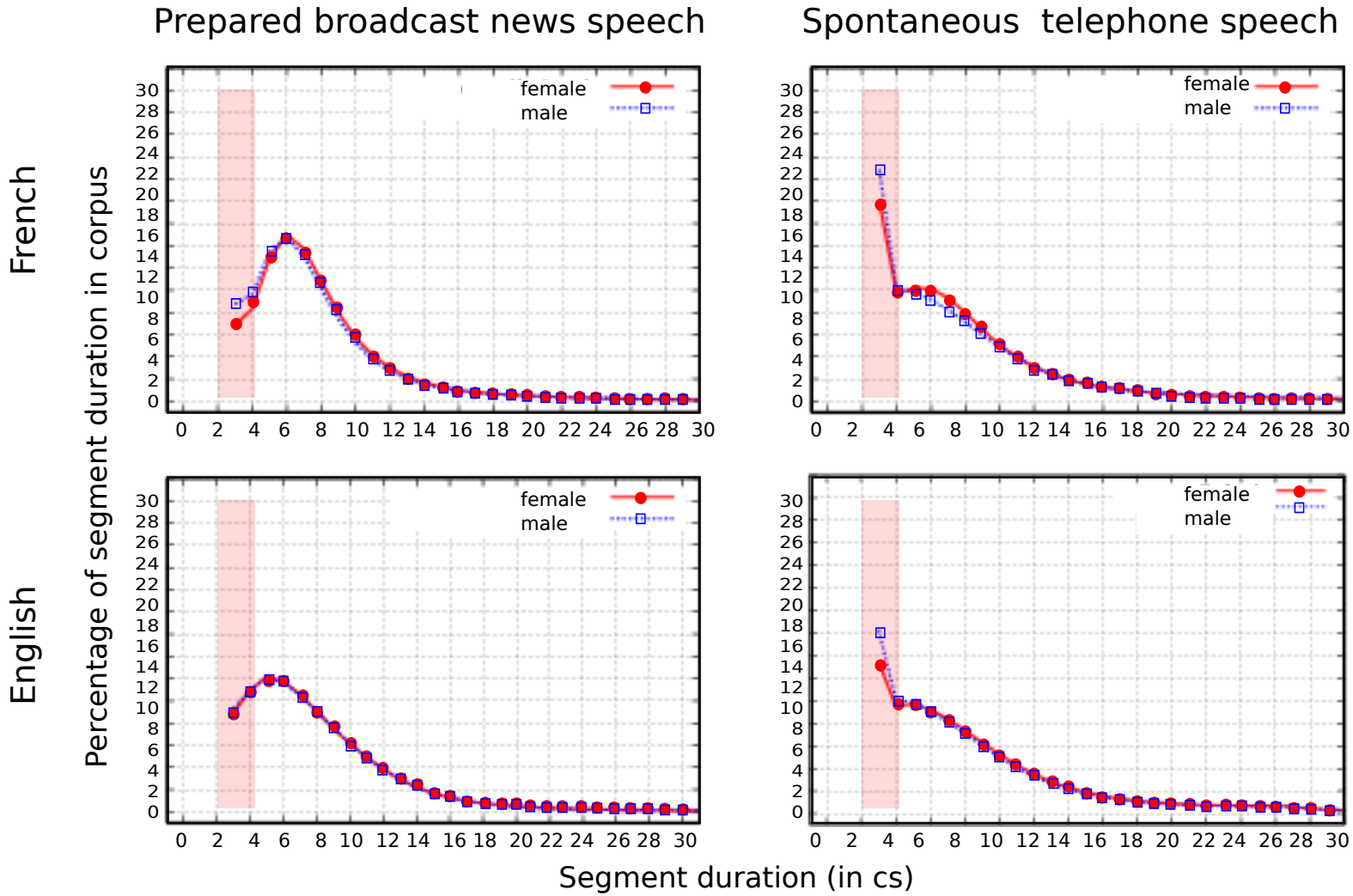
Forced alignement using reference pronunciations

Phonetic: manual labels

Phonemic: automatic labels

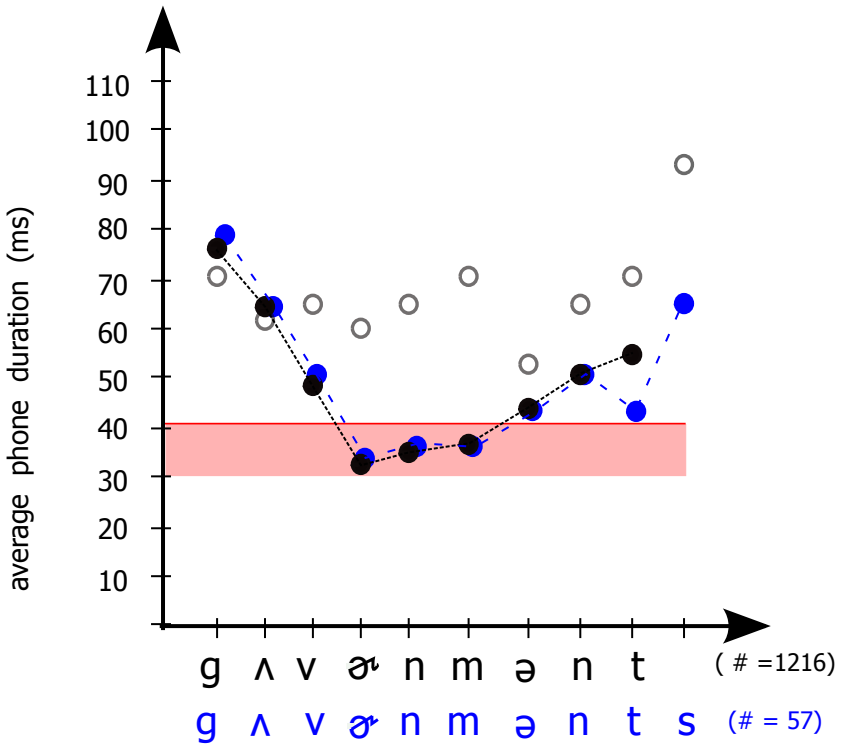
⇒ sequence of short segments (30 ms duration) with false/misplaced labels

Segment duration distributions



Word-internal segment duration variation

English words 'government', 'governments'



empty circles: average phone duration (all segments pooled per phone)
coloured circles: word-position dependent average phone duration

Several word-internal segments in minimum duration region (30-40 ms)

Pronunciation variants: English

American English causal speech (Switchboard)

Switchboard *Multi-word*	#Total	*Full form* + *Variants*	#Align	%Align	Comments
did-not	2559	dɪd nɑt	103	4.0	full form
		+ dɪdn̩t	275	10.7	n(ɑ→ ə)
		+ **dɪdn̩**	**1175**	**45.9**	+ final-/t/ deletion
		+ dɪn	1006	**39.3**	+ coda /d/ deletion
going-to-be	750	gɔɪng tʊbi	73	9.7	full form
		+ **gɔnəbi**	**432**	**57.6**	complex: ɪng t → n
		+ gəbi	245	**32.7**	+ complex: ɔnə→ ə
wants-to	157	wɔntstu	15	9.6	full form
		+ wɔnstu	78	**49.7**	coda C-cluster simplification
		+ wɔntsə	7	4.5	onset /t/-deletion
		+ wɔnsə	57	**36.3**	both /t/-deletions

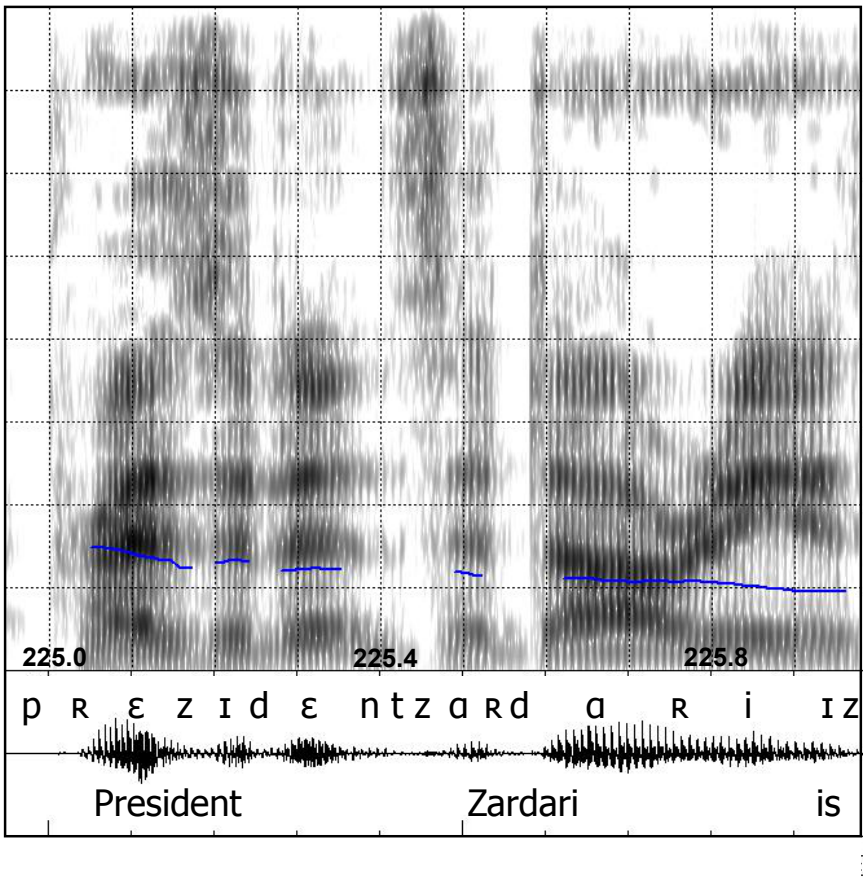
Testing pronunciation variants: French

French casual speech corpus (NCCFr)

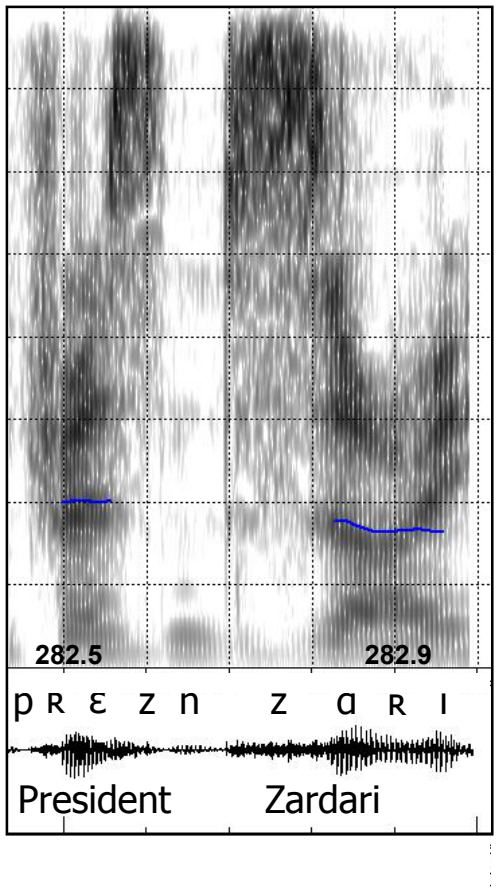
Word	#Total	*Full form* + *Variants*	#Align	%Align	Comments
parce (que)	2590	pɑʀsə	4	0.2	full form
'because'		+ pɑʀs	45	1.7	no final schwa
		+ **pas**	1309	**50.6**	+ C-cluster simplification
		+ ps	1232	**47.6**	+ vowel deletion
maintenant	352	mɛ̃tənɑ̃	8	2.3	full form
'now'		+ mɛ̃tnɑ̃	114	32.4	no internal schwa
		+ **mɛ̃nɑ̃**	230	**65.3**	+ /t/-deletion
quelques	56	kɛlkə	14	25	full form
'some'		+ **kɛkə**	28	**50**	+ /l/-deletion
		+ kɛ(k—g)	14	25	+ schwa deletion

English reduction (broadcast data)

Reduction in more formal, informative data



Play



Play

Spanish voiced stop and code-s lenition



Spanish voiced stop and code-s lenition

- Started with a study of ASR errors, many due to lenition
- Empirical study of:
  - lenition of intervocalic voiced stops /bdg/
  - lenition of /s/ in syllable or word coda position
- Lenition concerns the weakening and/or supression of the consonants – in this study lenition means elision
- Corpora with different speaking styles:
  broadcast news (BN), broadcast conversations(BC), monologs (Mono), telephone conversations (TC)
- Peninsular (Sp) and Latin American (LA) varieties of Spanish
- Explore geographic and stylistic frequency of lenition[Vasilescu et al, Interspeech 2018]

Intervocalic /bdg/ & /s/ lenition in linguistics



Lenition: "phonetic mechanism by which consonants become more similar to the surrounding vowels as a consequence of the gestural overlap and of the aerodynamic constraints on consonant voicing" [Lavoie, 2001; Ohala, Browman & Goldstein, 1986]

- Historical processes and synchronous variation in Romance languages
- Lenition occurs Spanish (Peninsular and Latin American), but also in Catalan, Portuguese, Italian dialects [Hualde & Nadeu, 2011], [Hualde & Prieto, 2014]
- Intervocalic /bdg/ $\rightarrow$ /βðɣ/ or are deleted
- Coda and word final-s can variably aspirate or be entirely deleted [Haulde, 2005]
- Another large scale study: acoustic patterns of Spanish coda-s lenition, 86 hours, audio books [Ryant & Liberman, 2016]

Speech corpora

22 hours of manually transcribed speech:Castilian (Peninsular Spain); Caribbean; 31 Latin American samples (Catalogo de Voces Hispanicas) [Quesada Pacheco, 2014]



Corpus	#Words	Speech
Mono LA	14k	1h40
BN LA	32k	3h20
BN Sp	84k	11h15
BC Sp	3k	0h44
TC LA	1k	0h13
TC Sp	59k	5h
Total	**251k**	**22h10**

Speech recognizer

- Large vocabulary (250k words), DNN-based continuous speech recognizer
- Trained on 165 hours of broadcast speech in Peninsular Spanish
- WER: 11.2% (BN Spa), 15.9% (BN LA), 18.0% (CVC LA)

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Lenition	ASR error
V/bdg/V	REF: con ellos también ESTÁBAMOS en el lugar HYP:con ellos también ESTAMOS en el lugar
Coda-s	REF: PRINCIPIOS que él señaló EN SUS DISCURSOS HYP: PRINCIPIO que él señaló ** SU DISCURSO

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- Code-s errors are the most frequent error type
- 7% of errors in LA monologs
- 3-4% of errors in LA and Sp broadcast data

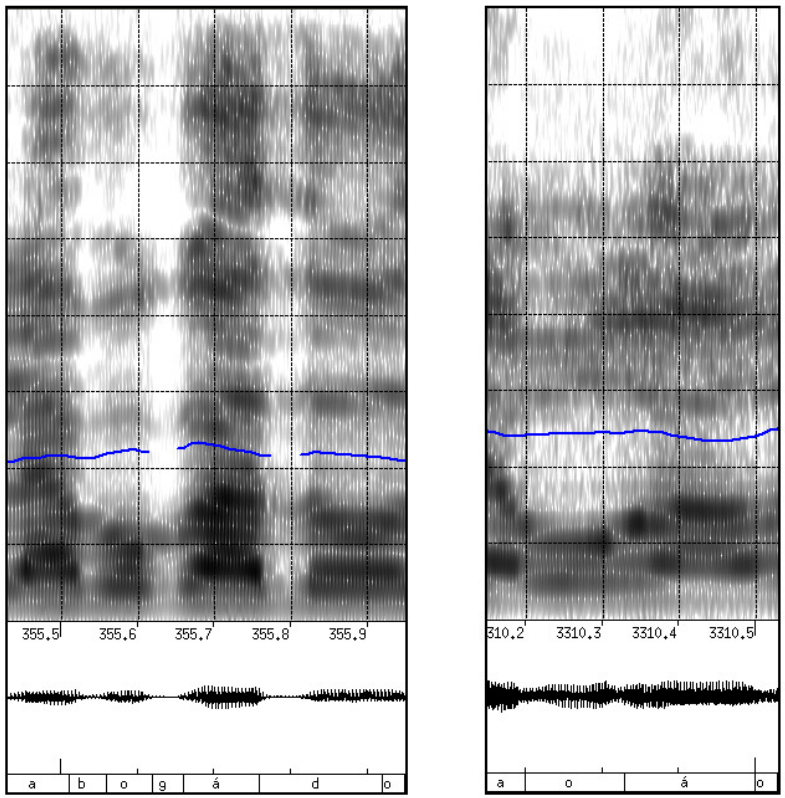
Pronunciation variants for alignment

- Forced alignment of pronunciation variants with and without lenition (supression) of V/bdg/V and of intra-lexical (coda) or word-final -s
- Lexicon enriched with non canonical variants:

Context	Examples
V/bdg/V	**abono** /aβono/ /aono/ **abogado** /aoao/ /aβoao/ /aoɣao/ /aβoɣao/ /aoaðo/ /aβoaðo/ /aoɣaðo/ /aβoɣaðo/
Coda-s	**desde** /dede/ /desde/ **estos** /eto/ /esto/ /estos/

- Lenition rate is computed as the number of sequences (V/bdg/V, s-coda, word-final -s) aligned without the targeted consonant e.g. /aβoao/ instead of /abogado/

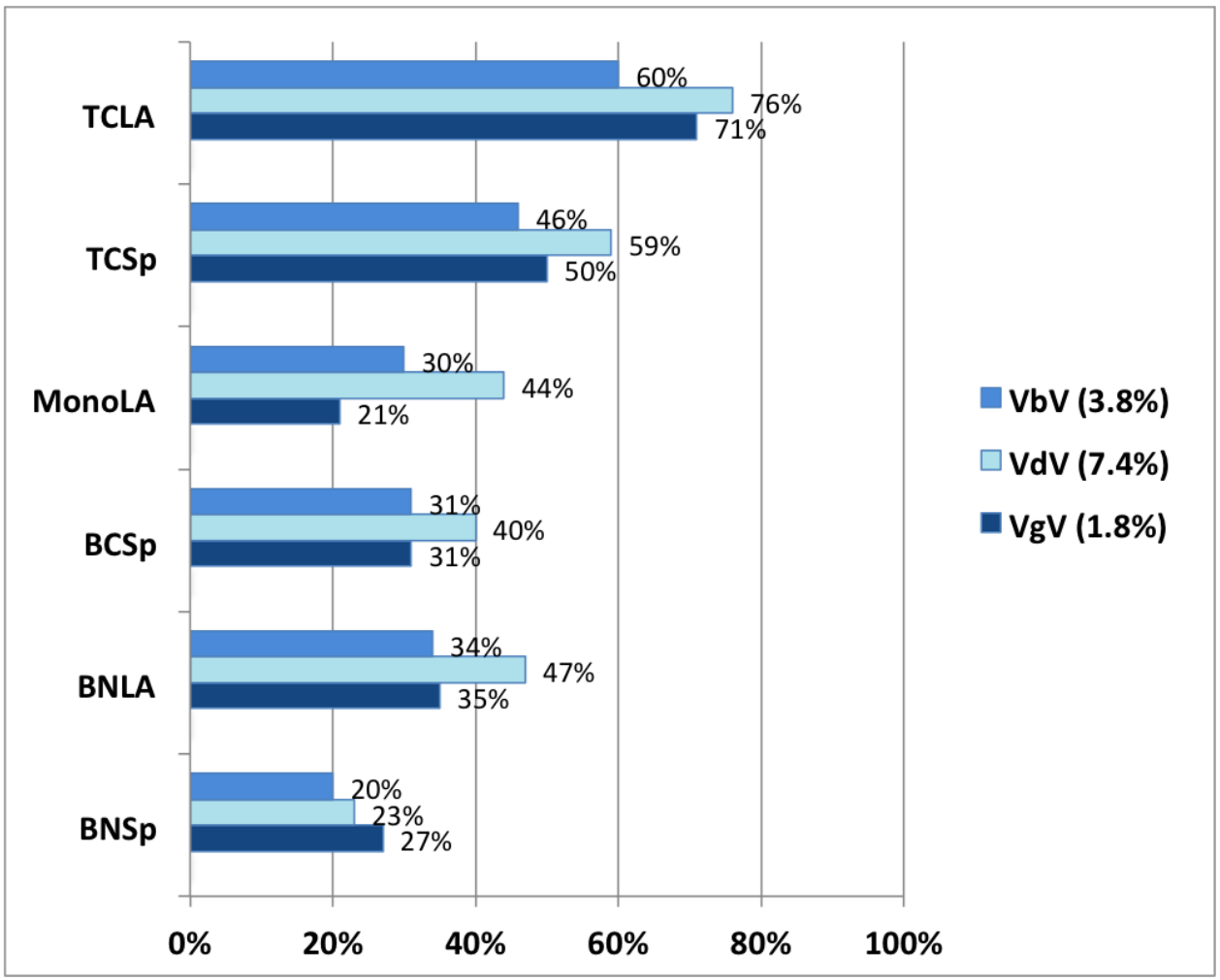
Example of /bdg/ lenition - abogado



▸ Play ▸ Play

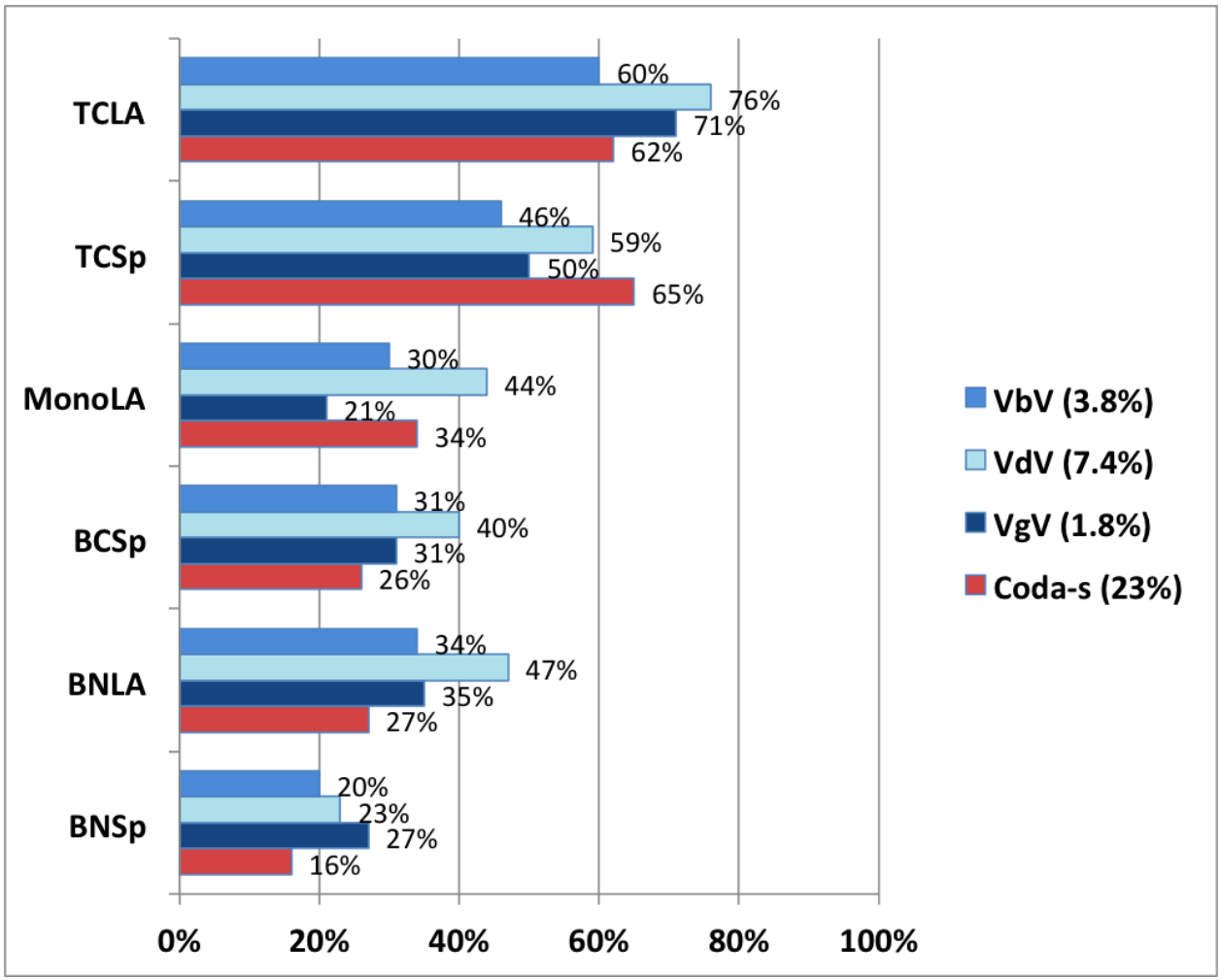
/abogado/ *'attorney'* aligned with /aβoɣaðo/ (left) and /aoao/(right)

Voiced stop lenition rates



Corpus	V_V Freq (%)		
	b	d	g
TCLA	4.5	4.9	1.0
TCSp	3.0	5.1	1.7
MonoLA	3.7	6.8	2.0
BCSp	3.4	6.5	1.4
BNLA	4.2	8.4	1.6
BNSp	4.1	8.8	1.9
Average	3.8	7.4	1.8

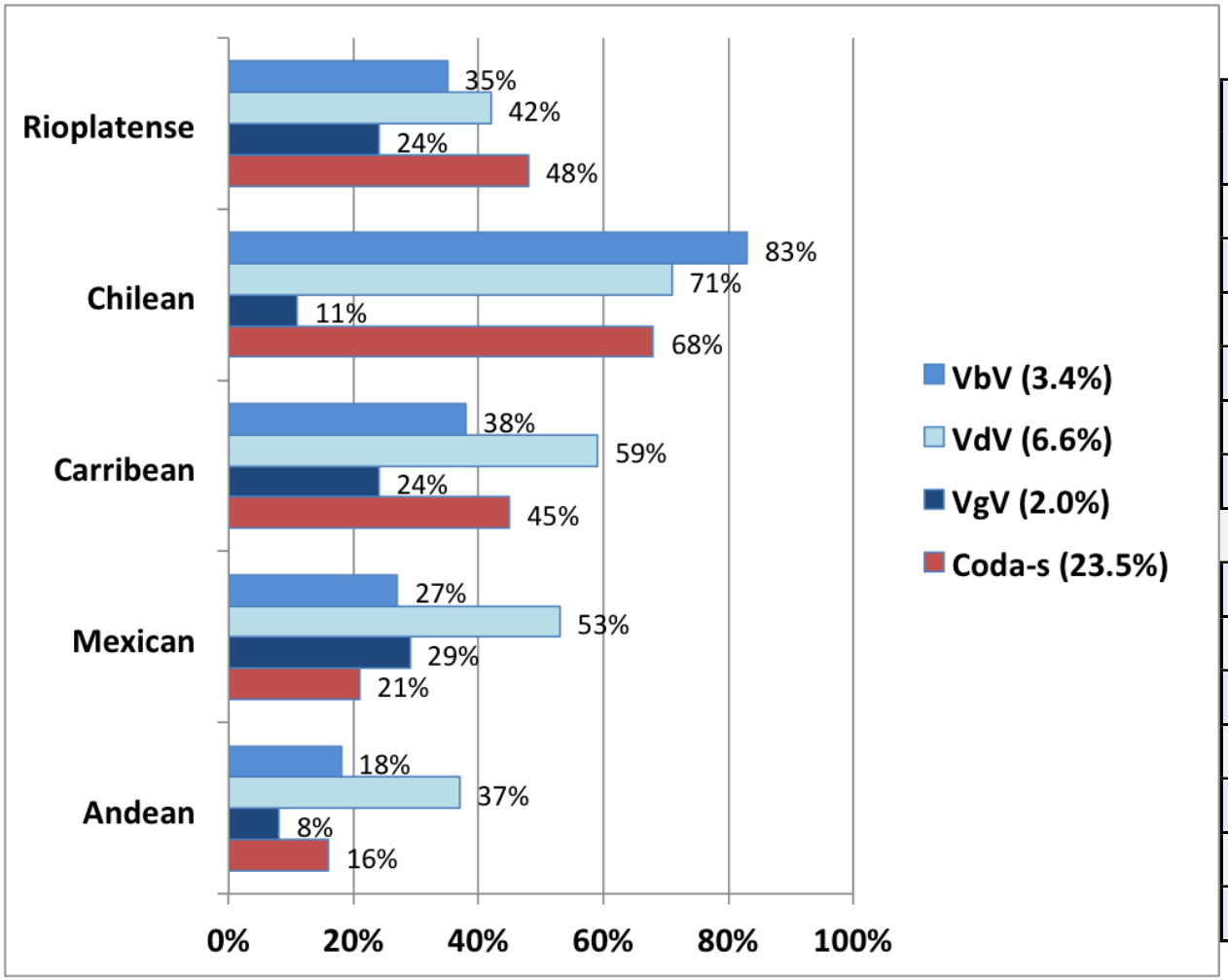
Lenition rates by corpus



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BCSp	3.4	6.5	1.4
BNLA	4.2	8.4	1.6
Average	3.8	7.4	1.8

Corpus	coda-s Freq(%)
TCLA	14
TCSp	18
MonoLA	23
BC Spa	23
BNLA	25
BNSp	26
Average	23

Lenition in Latin American varieties



Variety	V_V Freq(%)		
	b	d	g
Rioplaten	3.0	6.6	2.6
Chilean	3.3	8.0	1.6
Caribbean	4.1	7.0	1.5
Mexican	4.2	5.8	1.8
Andean	2.5	6.4	1.8
Average	3.4	6.6	2.0

Variety	coda-s Freq(%)
Rioplaten	23
Chilean	25
Caribbean	25
Mexican	24
Andean	23
Average	24

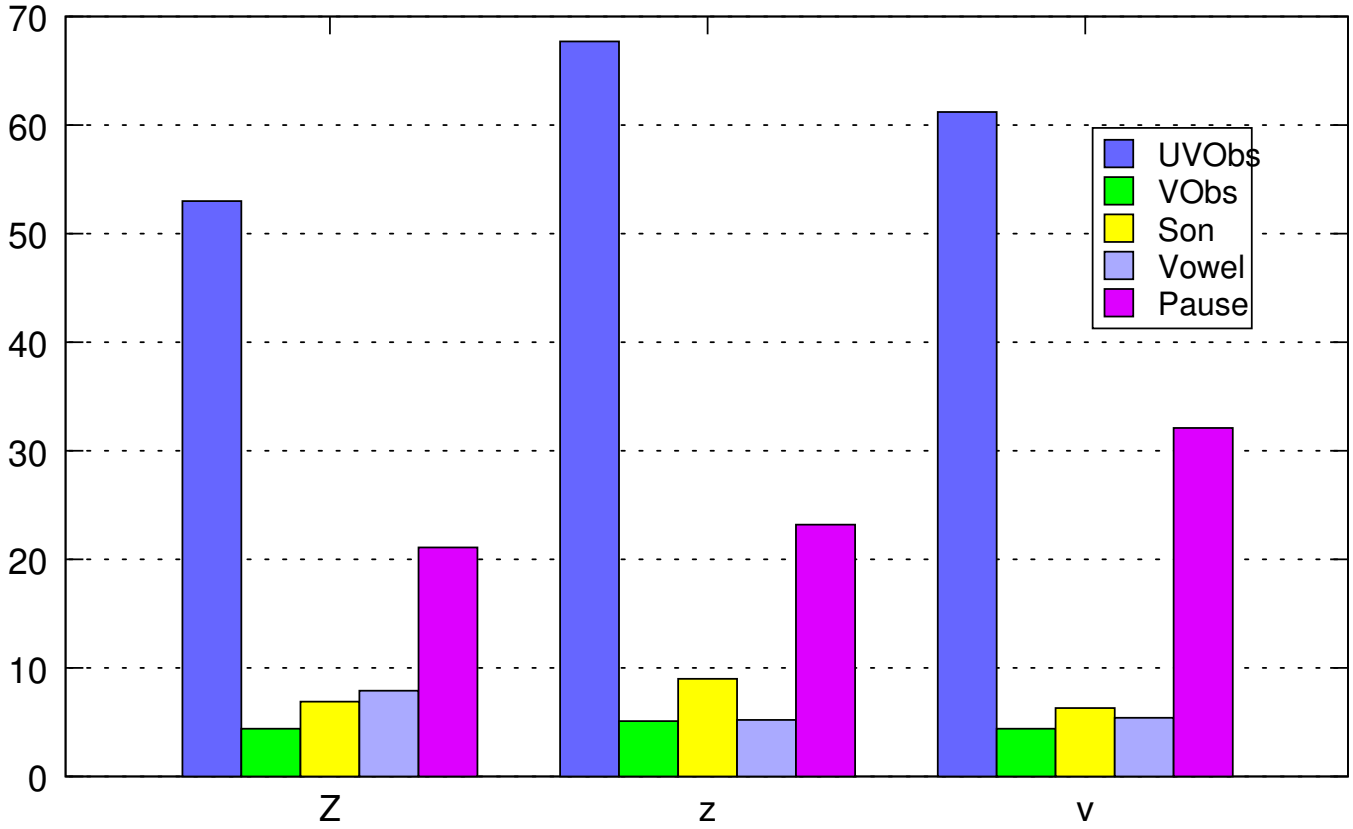
Some comments

- Results confirm trends observed on smaller data sets, that Latin American varieties show higher deletion rates than Peninsular Spanish
- Spontaneous settings favor lenition (in line with other studies on temporal reduction: spontaneous speech is more affected reduction than prepared speech)
- Refine the analysis to go beyond the binary perspective (+/- elision), such as allowing voiced frictives or semivowels as alternate realisations

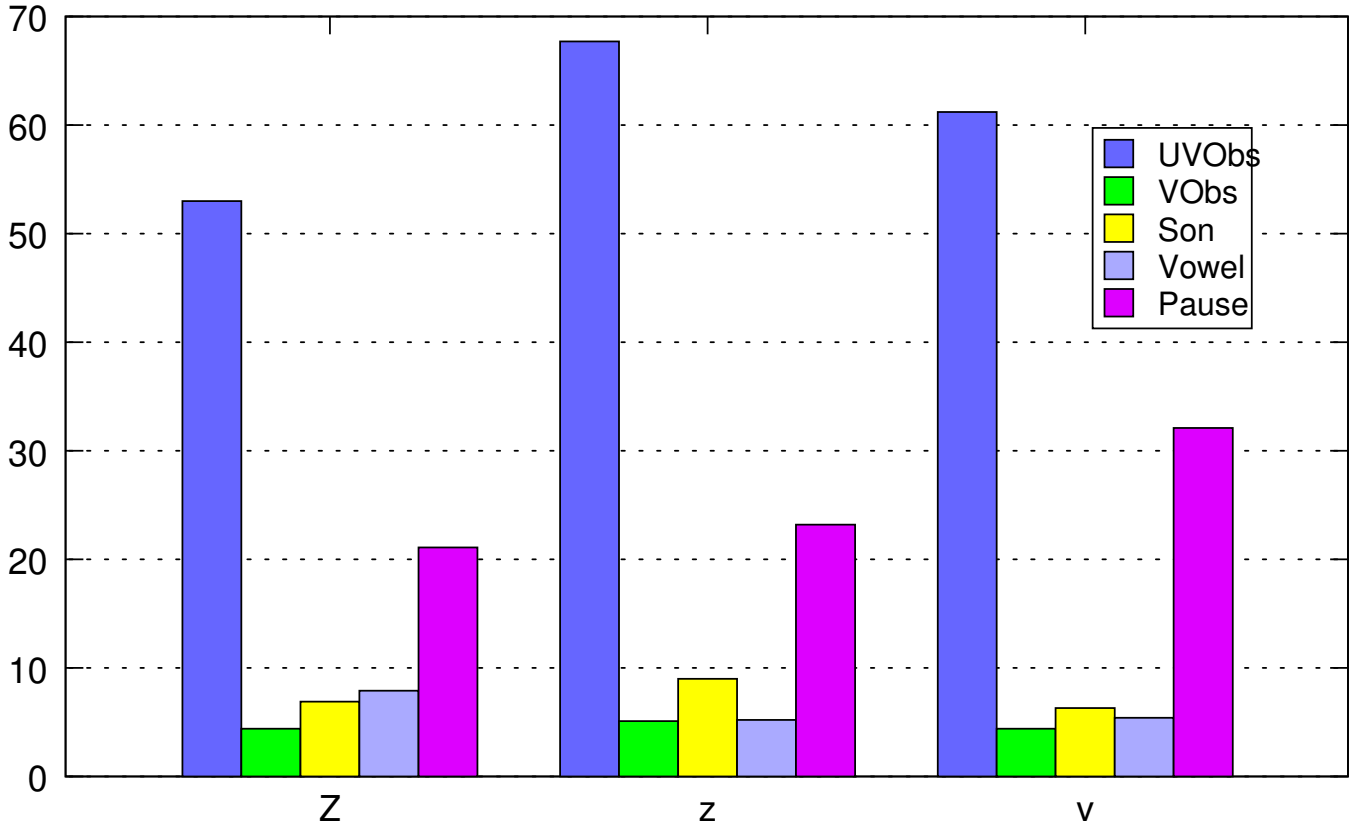
Final fricative devoicing in French

- Empirical study of devoicing of /z,Z,v/ in French
- Two types of speech:
  - Semi-prepared speech from radio/TV broadcasts: ESTER [Galliano et al, Interspeech 2005]
  - Conversational speech: Nijmegen corpus of causal French [Torreira et al, Speech Communication 2010]
- Questions explored
  - Is it a phonological rule? physical? regional variant? sound change?
  - Are some sounds more subject to devoicing?

Final fricative devoicing - results



Final fricative devoicing - results

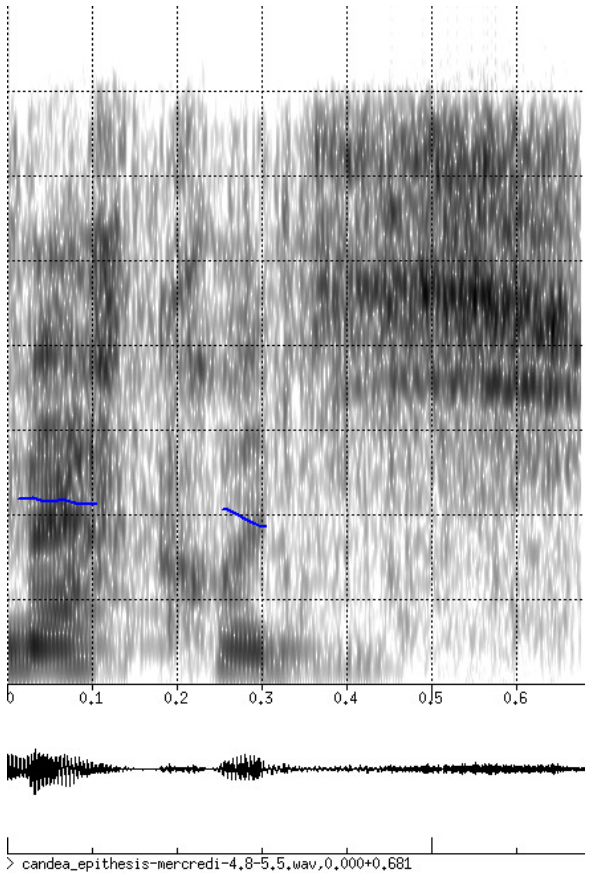


- Highest devoicing preceding voiceless obstruent
- More devoicing preceding pause than vowel or sonorant
- Laryngeal assimilation with following consonant (also voicing of /sSf/)
- Tendancy for devoicing in causal speech

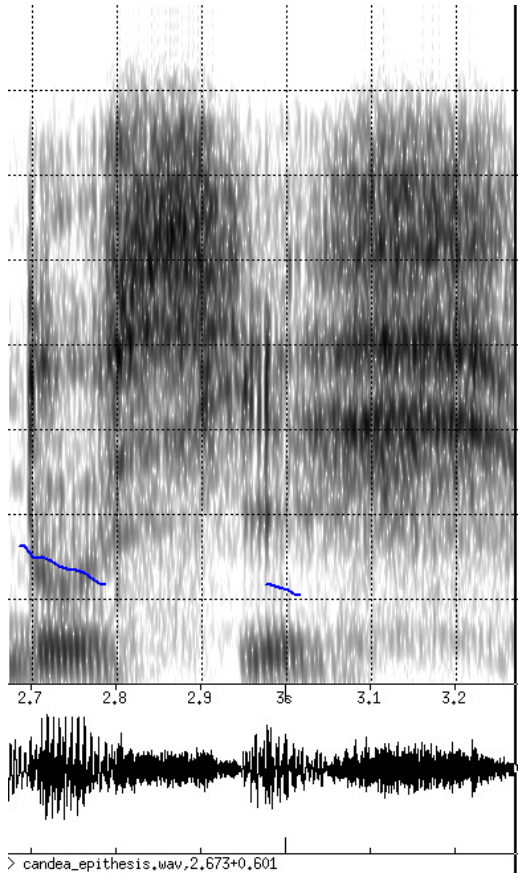
Diachronic change

- Socio-phonetic, corpus-based linguistic study of journalistic speech in French news [Candea et al, Interspeech 2013]
- Consonant cluster reduction *explique, exclaim* $\Rightarrow$ /k/ dropped in /kspl/, /ksl/
- Palatalization and affrication of dental stops
- Fricative epithesis [ç] after final vowels (mostly /i,e,y/)

Epithesis examples

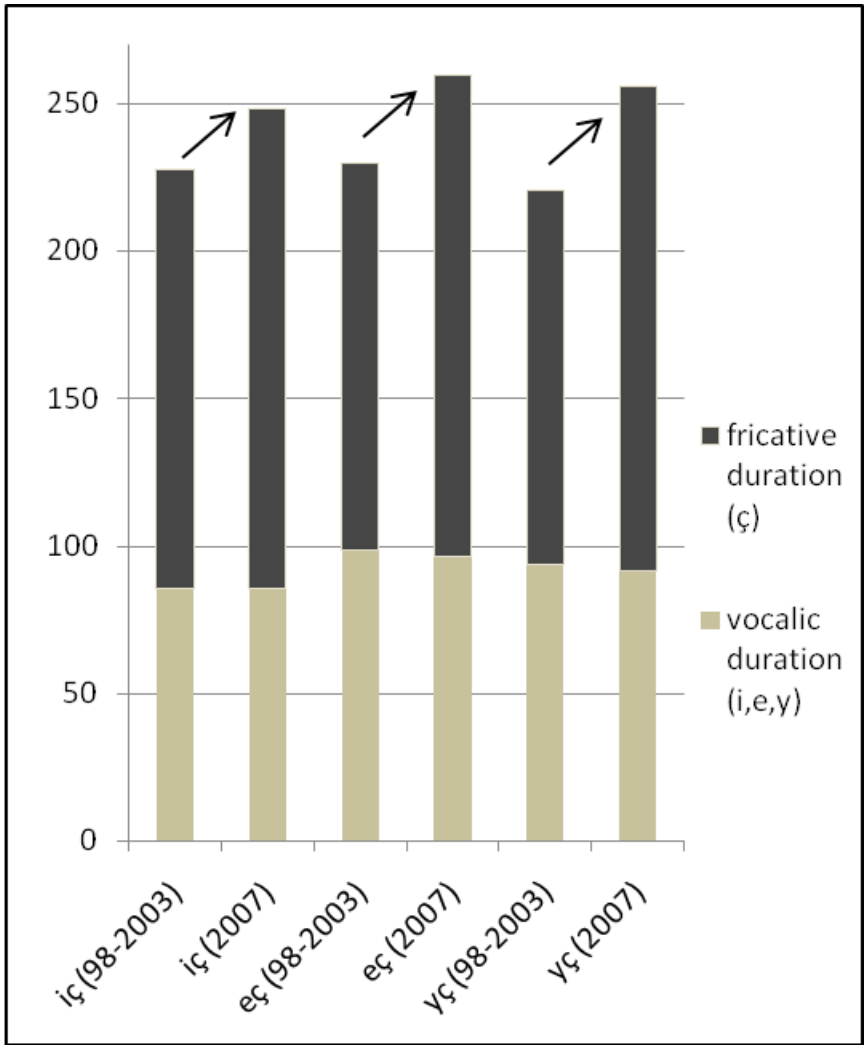


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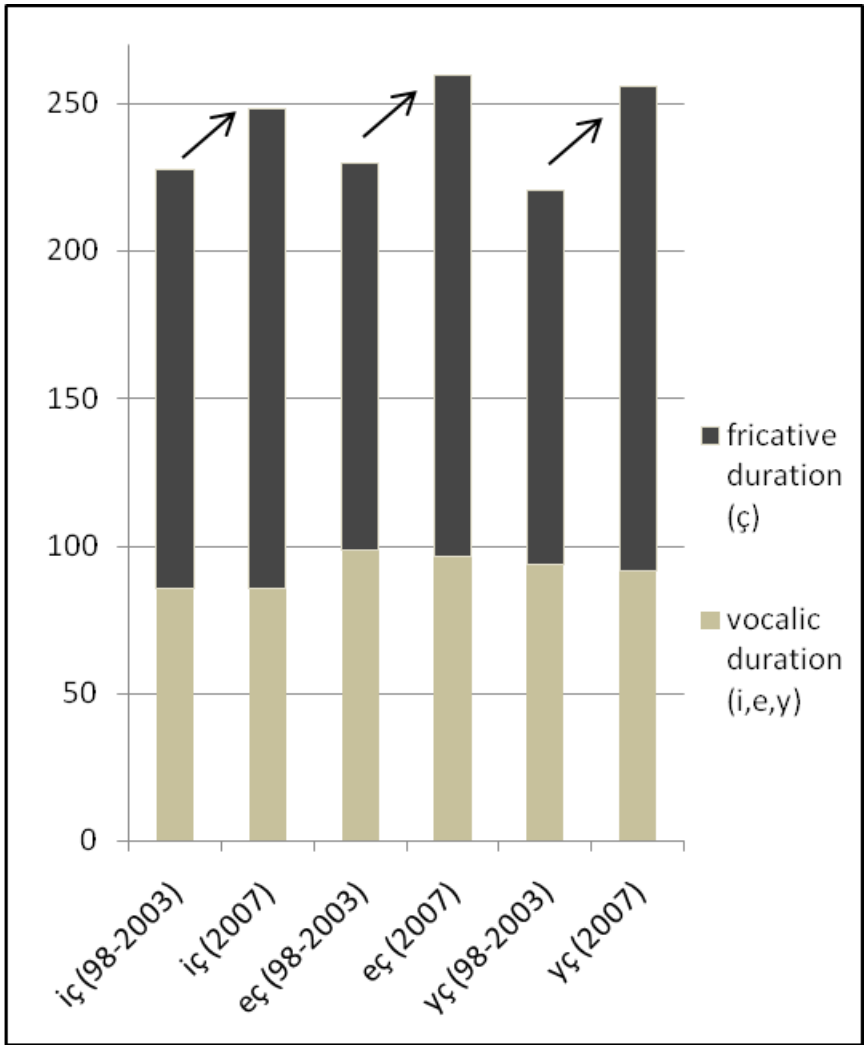
sur ce dossier

Epithesis duration change



- Epithesis duration increased by about 20-30% (+20ms 2003-2007)

Epithesis duration change



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Some outstanding questions:

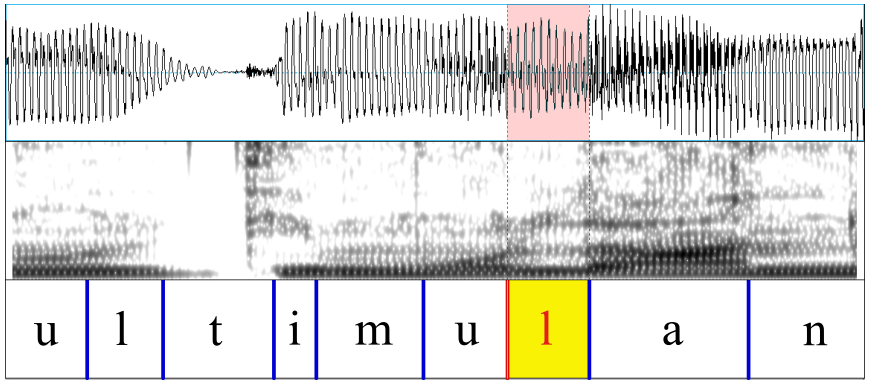
- is it an additional fricative or the devoicing of the vowel?
- is it predominantely mechanical or stylistic?

Romanian L dropping

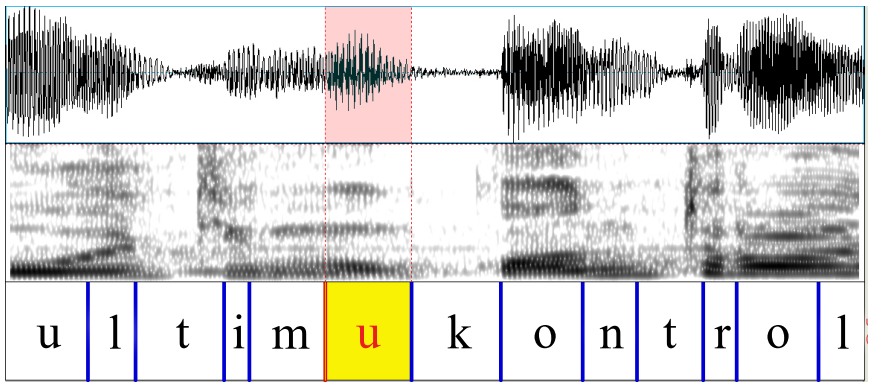
Deletion of the masculine, singular marker of the definite article -l
[Vasilescu et al. 2018]

- What is the frequency of the L-dropping in continuous speech?
- How does L-dropping depend on the communicative setting?
- What right contexts favor L-dropping or L-retention?
- Language change or not?

Examples: Romanian -ul



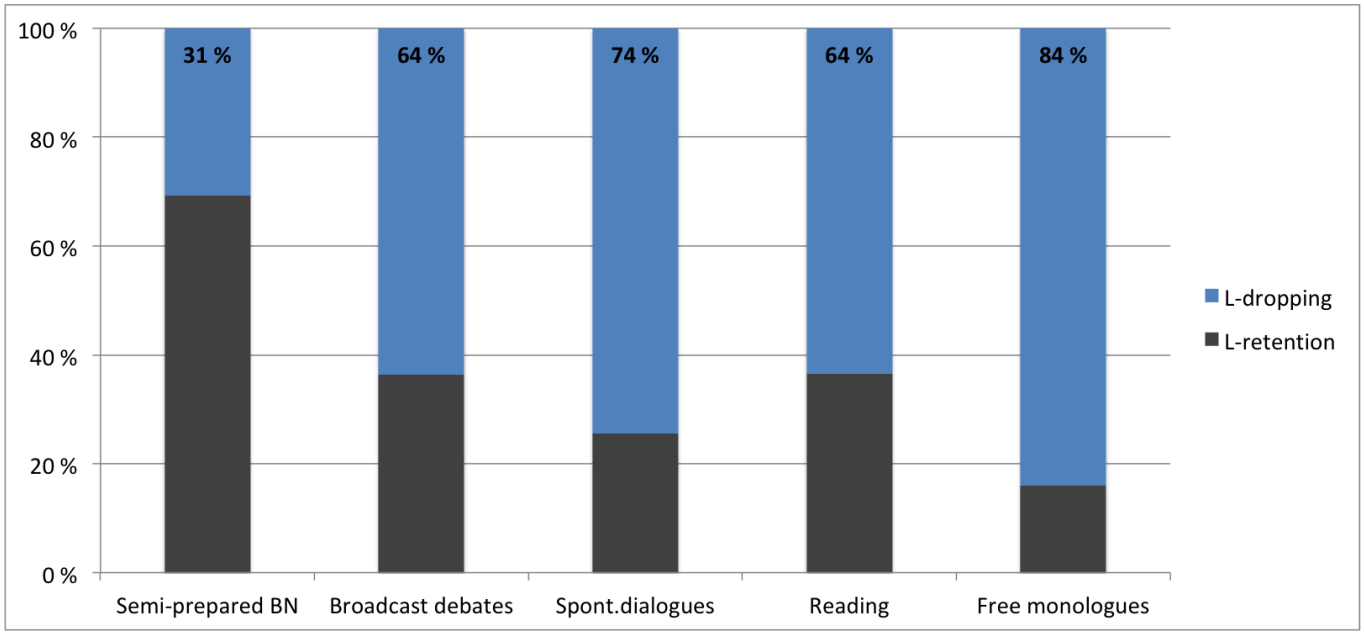
L-retention (#V) [ultimul#an] “the last year”



L-dropping (#C) [ultimu#kontrol] “the last control”

#C-initial words account $>$ 70% of all word tokens and targeted contexts

L-dropping/retention rates



- High L-retention rate for prepared broadcast news speech, despite fast speaking rate suggesting link to written form
- Lowest retention for spontaneous dialogs and monologs (only 1 speaker)
- Supports hypothesis that the communicative setting strongly influences speech deletion [Avram, 2009, Miret 2017]

French-Algerian code switched speech

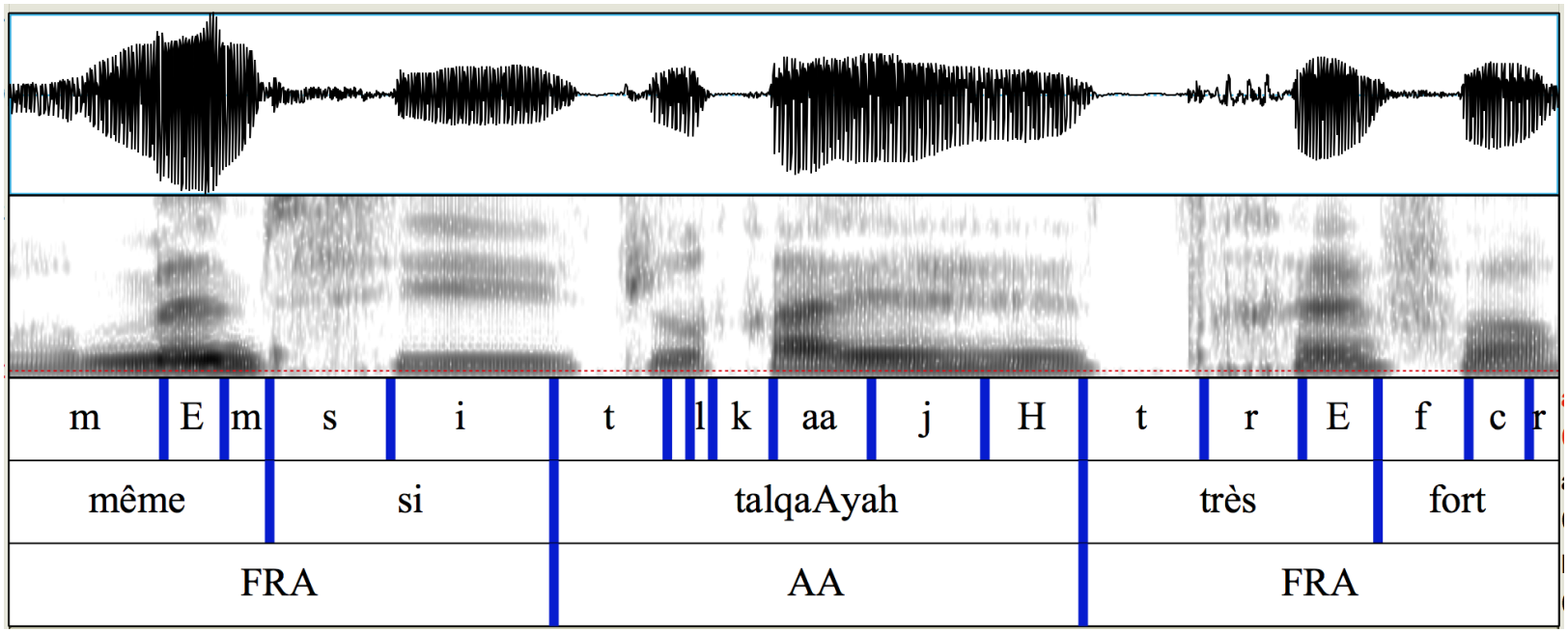


- Investigate speech of bilingual French/Arabic speakers
- French Algerian Code-switching (CS) Triggered (FACST) corpus [Amazouz et al., LREC 2018]
  - Bilingual speakers selected based on reponses in online questionnaire about bilingualism, education and CS practice
  - Conversations with CS triggered by questions in both languages
  - 20 speakers: 10 male/female, aged: 20-40 years
  - 7h30m speech, 15-40 m/speaker, elicited spontaneous & read speech
- Characterize CS
- Study phonetic realization of speech by bilinguals
  - French richer vowel inventory than Arabic
  - Arabic has a richer consonant inventory than French

Example of code-switching types

yacniy
je pense
hiyyaM HaAjaM spontanée
wa xSuwSan yacniy fiy al mustawaY al FaAl niveau trois
fiy al aTfaAl talqaAy Tifl yatkallam taqriyban
soixante-dix pour cent le français
il essaye en faite de dire disons un mot — CS inter-sentential
bi al carbiyyaM — CS intra-sentential
non seulement pour montrer — Borrowing
bi alliy bdaA yatcallm al carbiyyaM
mais FaAniy baAX yacraf
yacraf ruwHuw yacniy iddiyr al FFiqaM fiy
iddiyr al FFiqaM fiy nafssuw bi alliy yaq
haAViyk al lluGaM kiymaA nhaAr al HHad ma
kaAn candiy niveau trois
al baAraH kaAmal malgré
yacniy cinq ans quatre ans et tout
mais kaAnuw fiy haAViyk l'étape.

Aligned transcripts CS

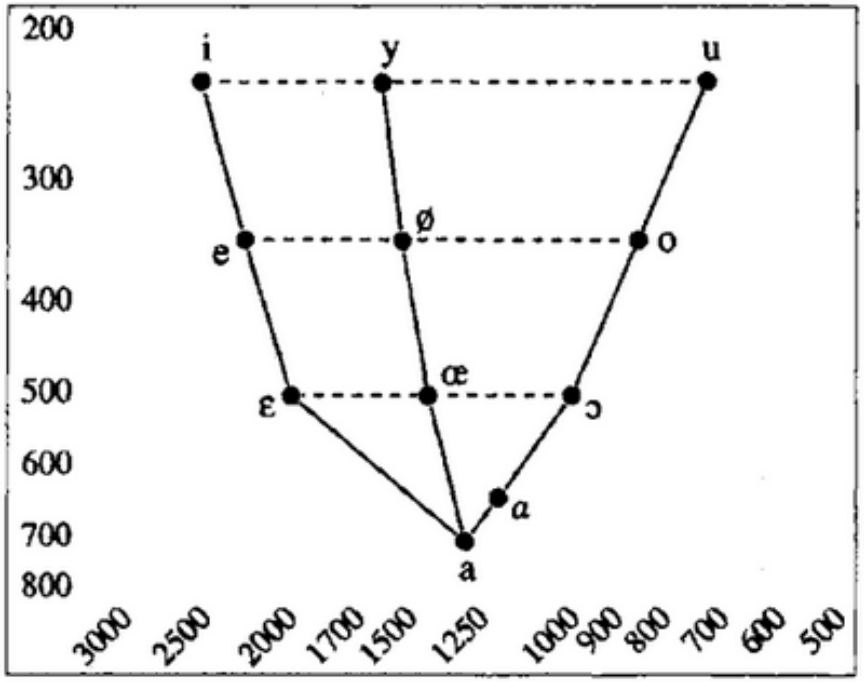


- Manual segmentation based on language change, breath groups and speaker turns
- CS segments less than 30 ms not segmented
- Automatic alignments for phone segmentations

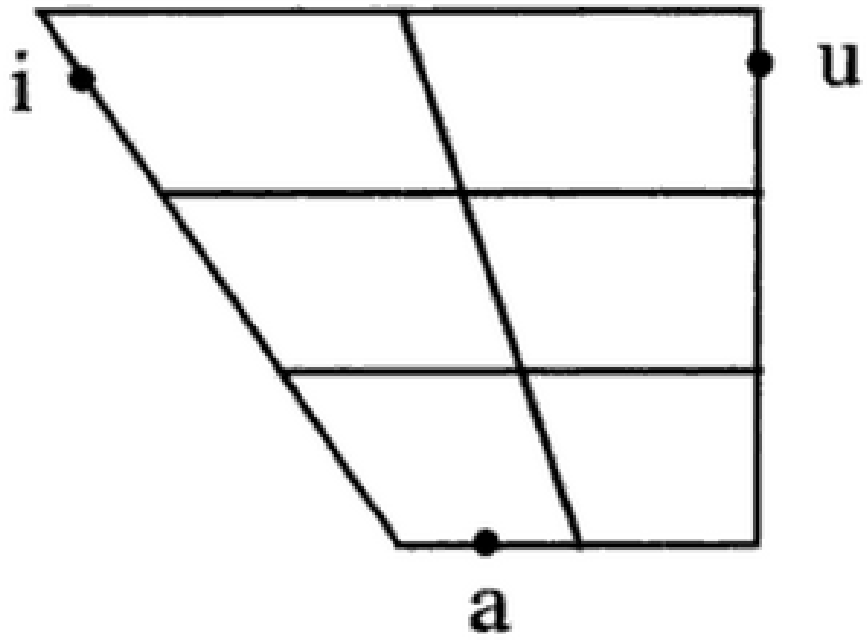
Vowel production by FR-AA bilinguals

- Bilingual speakers' speech presents more acoustic variation than that of monolinguals [Bullock, 2012; Auer, 2013]
- Bilinguals access more than one phonemic inventory which may lead to potential interferences [Fricke 2016; Grosjean, 1995]
- Vowel inventories of different sizes (French is richer)
- To what extent do bilinguals adapt their vowel productions to the linguistic context?
- Methodology: use automatic speech alignment to study vowel variants
- Frequent replacements of the target vowel by competing vowels are considered an indicator of variation

Vowels in French and Arabic



[Delattre, 1966]



[Thelwall & Akram Sa'adeddin, 1990]

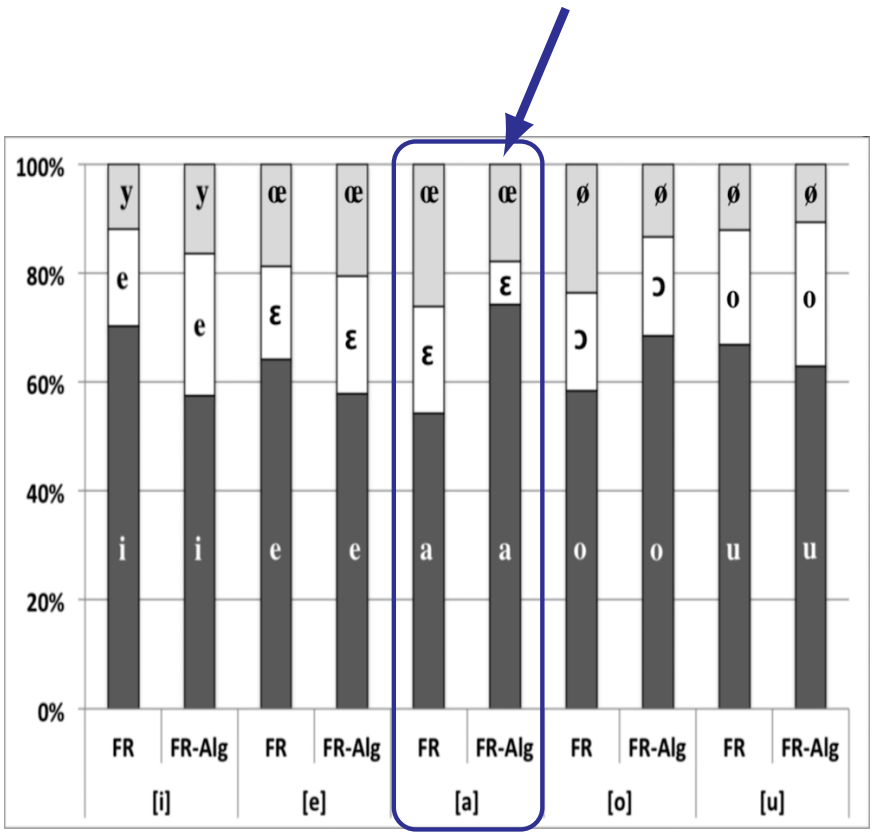
- Standard French: 11 oral vowels, 4 nasal vowels, 1 schwa
- Classic Arabic: 3 oral vowels
- How does this difference influence speech production in bilingual speakers?

Exp. 1: Vowel variants in French

- Populations: French natives vs. bilinguals (French-Algerian Arabic)
- Language: French
- NCCFr [Torreira et al, Speech Communication 2010]
  - 36h of conversational French, 46 speakers (24 female)
- French acoustic model
- Two production variants for each target vowel

Vowel	Variants	Examples
i	[e, y]	*lit* (bed): li, le, ly
e	[ɛ, œ]	*nez* (nose): ne, nɛ nœ
a	[ɛ, œ]	*chat* (cat): ʃa, ʃɛ, ʃœ (anterior)
a	[ɔ, œ]	ʃa, ʃɔ, ʃœ (posterior)
o	[ɔ, ø]	*chaud* (hot): ʃo, ʃɔ, ʃø
u	[o, ø]	*loup* (wolf): lu, lo, lø

Exp. 1 - Results (French: natives vs. bilinguals)



- Observed variation is vowel independent
- Comparable amount of variation in both groups (French natives, bilinguals)
- One exception: for [a] with anterior variants, bilinguals show considerably less variation than French natives

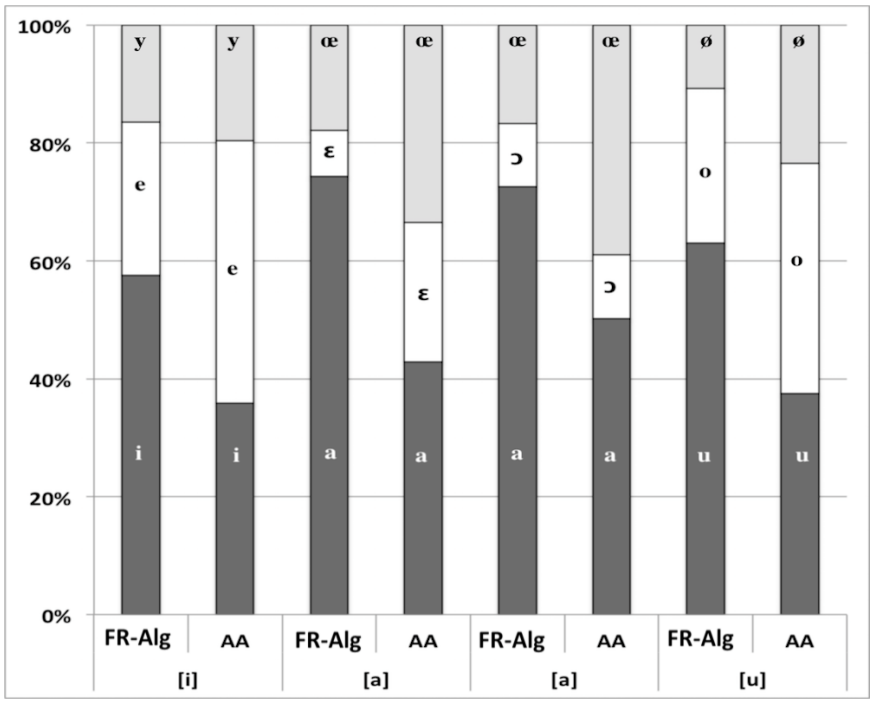
Exp. 2: Vowel variants in code-switching

- Population: bilinguals (French-Algerian Arabic)
- Languages: French, Algerian Arabic
- Production variation for three target vowels, each with two variants
- Vowel production variation in bilinguals as a function of language
- French acoustic model

Are the realizations of Arabic vowels acoustically close to French vowels? and if so, which?

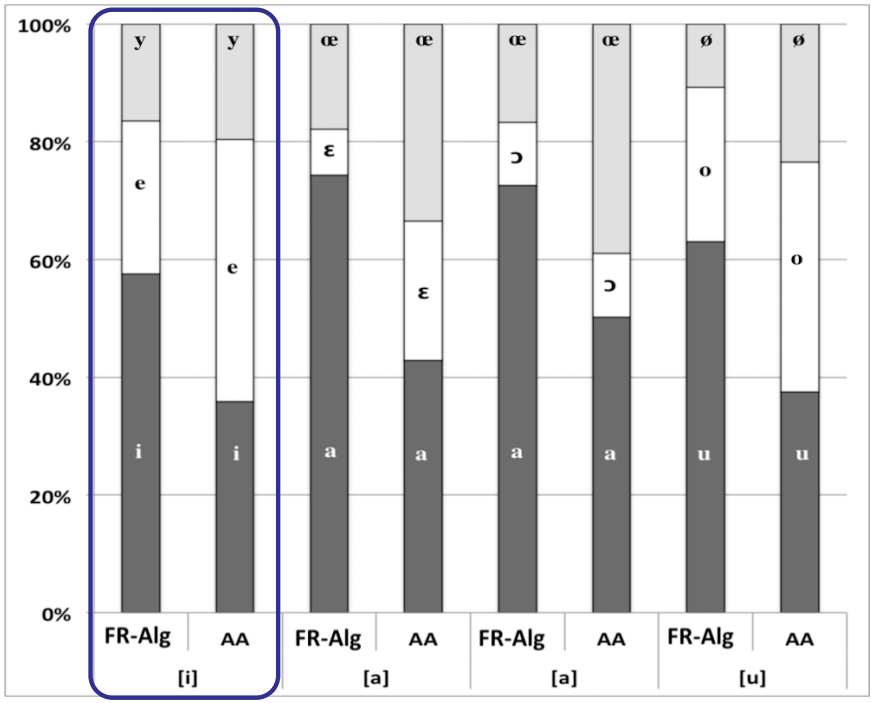
Vowel	Variants
i	[e, y]
a	[ɛ, œ] (anterior)
a	[ɔ, œ] (posterior)
u	[o, ø]

Exp. 2: Results (bilinguals: code-switching)



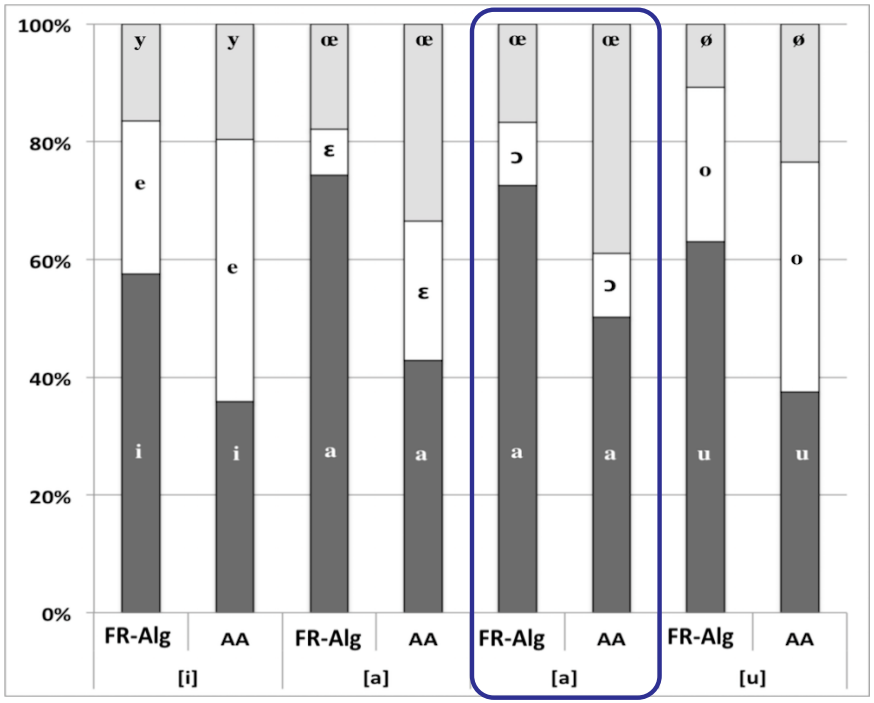
- The observed variation is vowel dependent

Exp. 2: Results (bilinguals: code-switching)



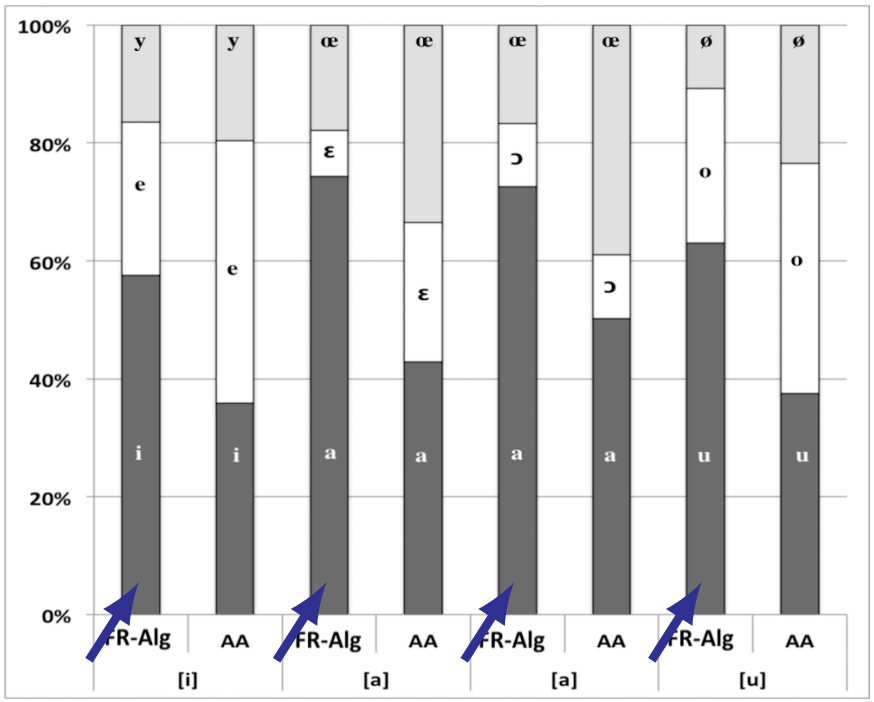
- The observed variation is vowel dependent
  - [i] is substituted more often than the other vowels ([a], [u])

Exp. 2: Results (bilinguals: code-switching)



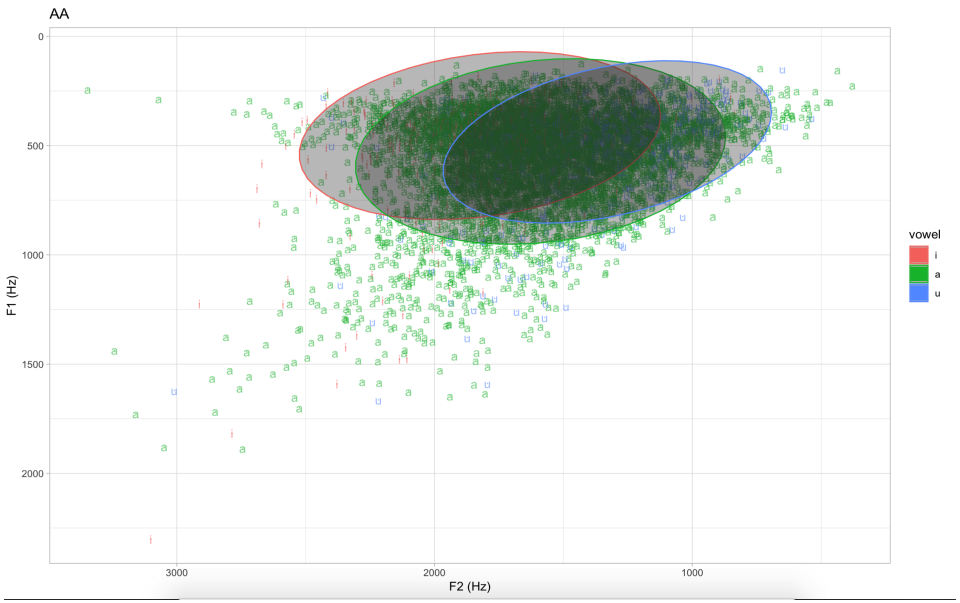
- The observed variation is vowel dependent
  - [i] is substituted more often than the other vowels ([a], [u])
  - [a] (post) is least often substituted

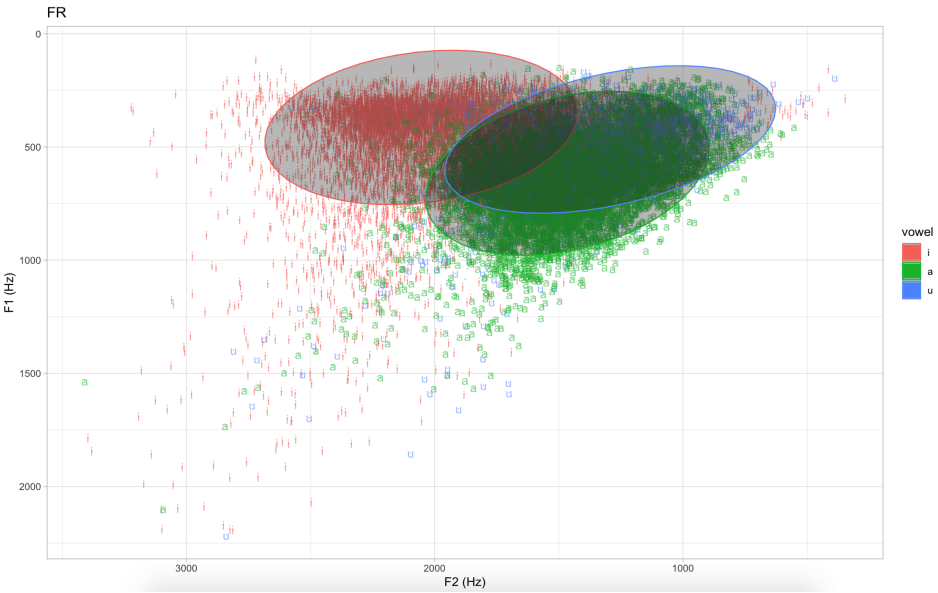
Exp. 2: Results (bilinguals: code-switching)



- The observed variation is vowel dependent
  - [i] is substituted more often than the other vowels ([a], [u])
  - [a] (post) is least often substituted
- Language also has an impact on vowel variation
  - in French, the target vowel is more often produced than in Algerian Arabic
  - this pattern is observed for all target vowels

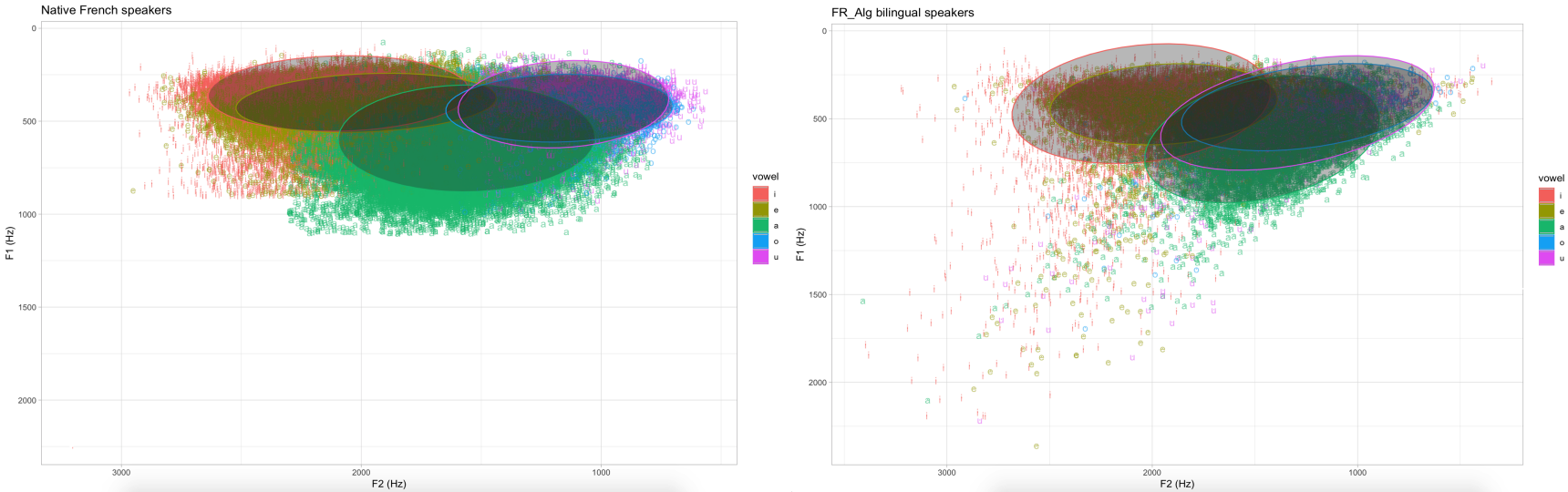
Vowels: bilinguals in French and Arabic





- Observe overlap in Algerian (AA) than French (FR)

French vowels by bilinguals and natives



- Somewhat clearer separation seen for native French speakers

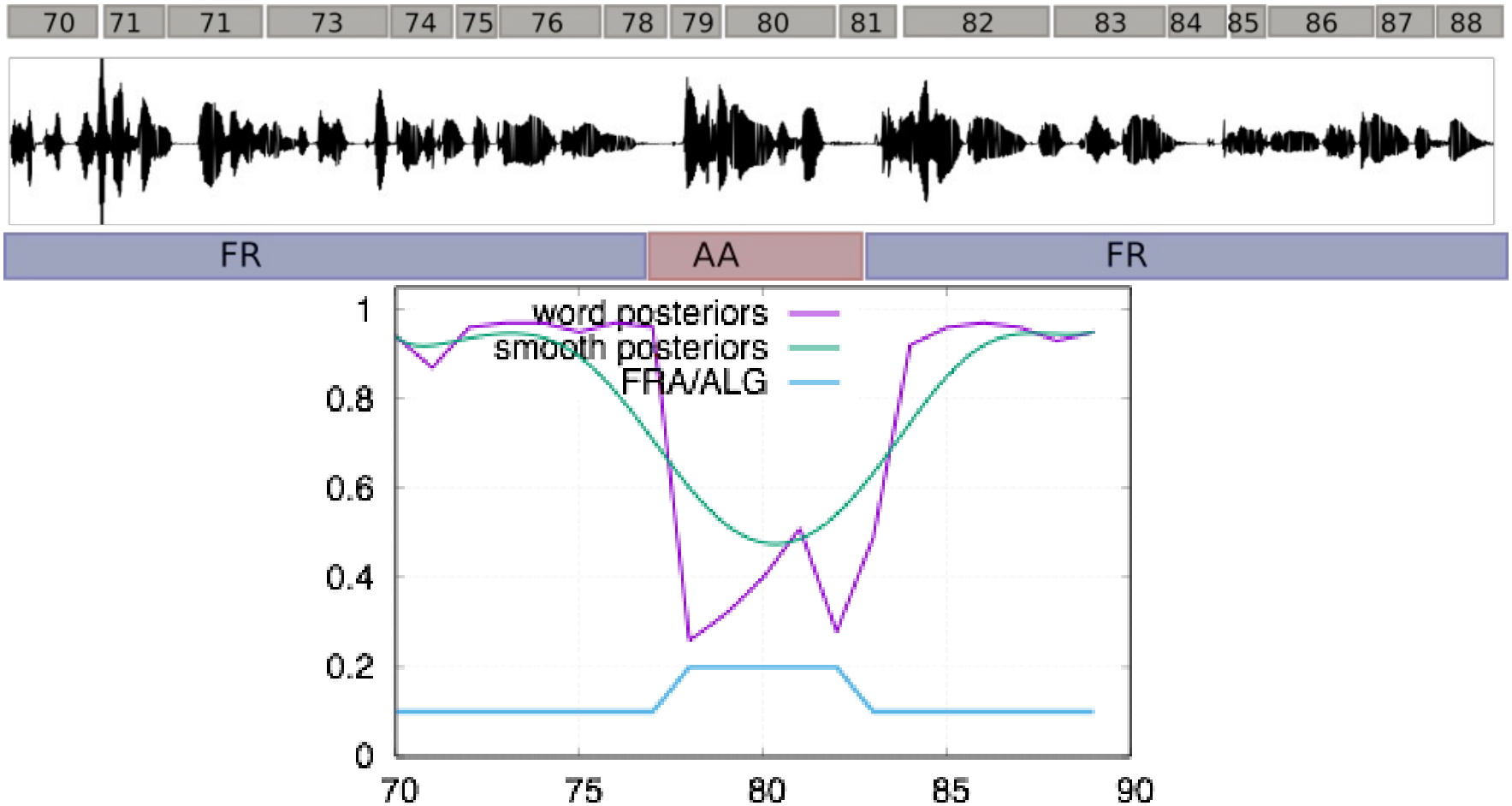
Some observations

- In French (French natives, bilinguals):
  - comparable amount of variation in both populations
  - bilinguals have less variation on low vowels than high vowels
    $\rightarrow$ different pattern of variation compared to French natives
  - French natives centralize more than the bilinguals
- Productions in bilinguals (French, Algerian Arabic):
  - more vowel variation in Algerian Arabic than in French
  - different production strategies according to the language
  - bilingual speakers appear to adapt to the language and vary their vowels accordingly
  - in Arabic [iː] is less often centralized than the other vowels
- Our data suggest that in Algerian Arabic, the phonetic variant [eː] seems rather a variant of [i] than [a]

Ongoing work

- Consonant variants
  - Algerian Arabic has a richer consonant base than French
  - Allow parallel consonant variants: gemmination, emphatic, manner or place change
  - What consonants are most affected by lenition? gemination? emphatisation?
- Detecting code switching via multiple decoding, allow language switch at any word

Illustration of French system's con dence scores in the signal



Breaking the Unwritten Language Barriers



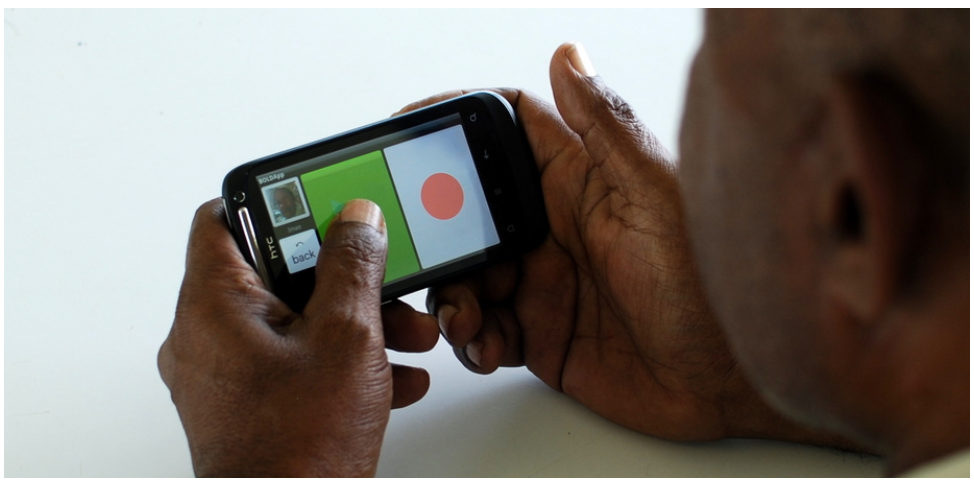
Breaking the Unwritten Language Barriers



- Speech technologies to help field linguists document unwritten languages
- Primarily speech recognition and machine translation
- 3 Bantu languages: Basaa, Myene, Embosi
- ANR-DFG funded French-German project `www.bulb-project.org`
- Recording tool: Aikuma
- Collaboration of speech technologists and linguists
- Training workshops (technology for linguists, lingustics for technologists)

BULB: Lig_Aikuma

- Smartphone application for data collection (after Bird et al, ACL 2014)
- `https://lig-aikuma.imag.fr`
- Collects speaker meta data
- Supports recording, respeaking (rs) and translation (tr)



(from L. Besacier, CMLD 2018)

BULB: data

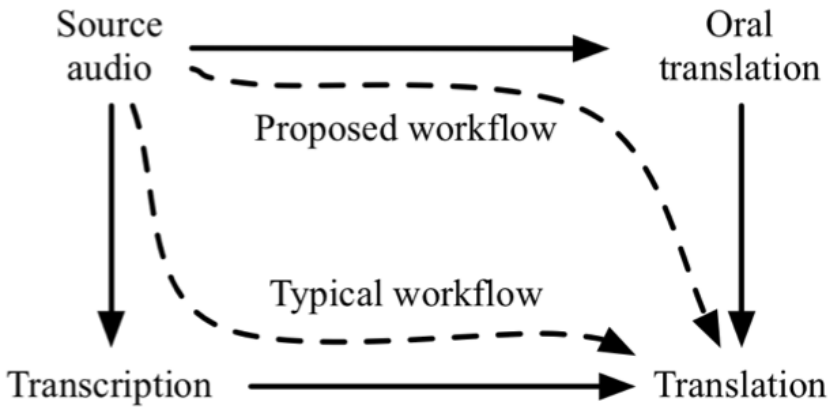
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Language	#hours (rs,tr)
Bassa	31 (23, 33)
Emboshi	55 (30, 30)
Myene	45 (44, 11)

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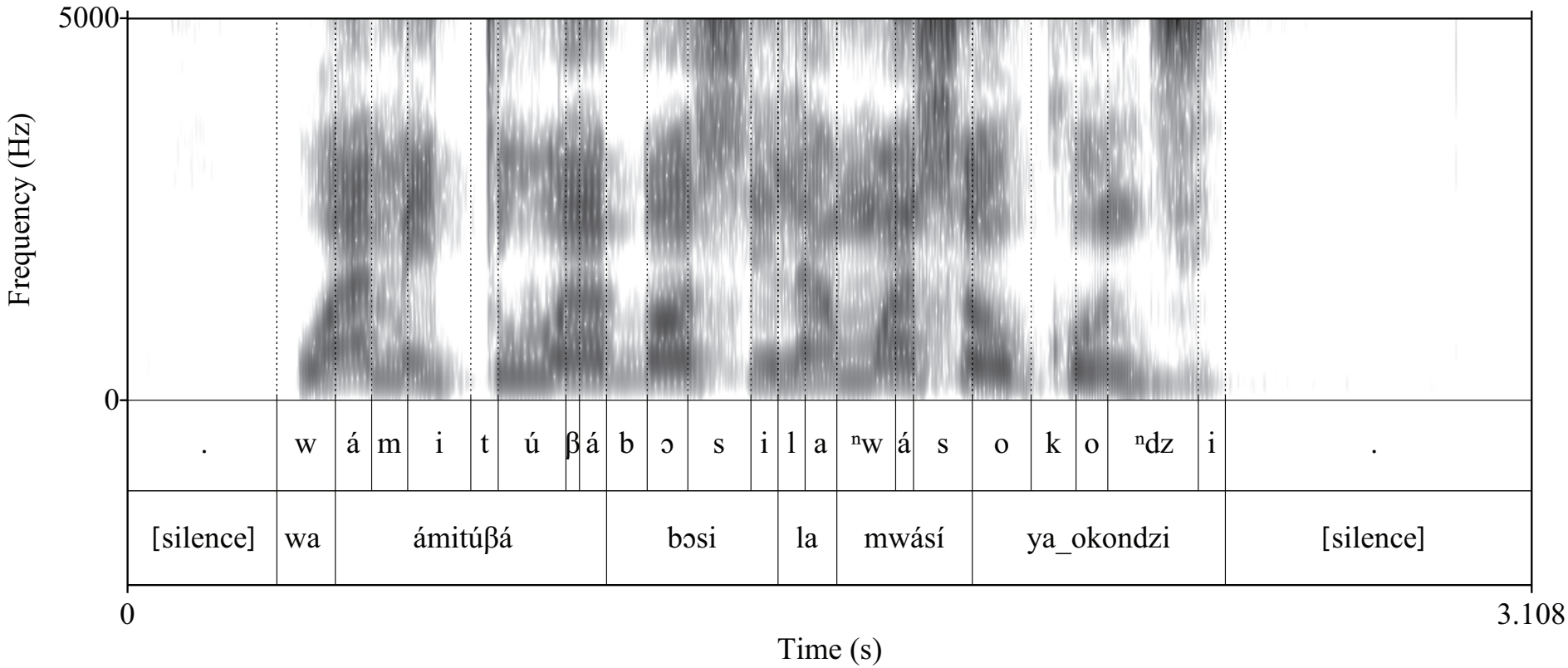
Embosi: vowel/morpheme elision

- Investigate vowel elision and morpheme deletion [Cooper-Leavitt et al, Interspeech 2017]
- Variant rules for elision after Rialland et al., 2012
- Vowel elision at word boundaries: long/short or short/short vowel contact

$$\mathrm{CV}[\mathit{long}, \mathit{HL}]\#\mathrm{V}[\mathit{short}].\mathrm{CV} \rightarrow \mathrm{CV}[\mathit{short}, \mathit{H}]\#\mathrm{V}.\mathrm{CV}$$
$$\mathrm{CV}[\mathit{H}, \mathit{low}]\#\mathrm{V}[\mathit{L}, \mathit{mid}].\mathrm{CV} \rightarrow \mathrm{CV}[\mathit{H}, \mathit{mid}]\#\mathrm{CV}$$

- Compound words introduced to model morpheme deletion

Example: Embosi ya-deletion



Vowel/morpheme elision

Morpheme	n_{del}	n_{del+ve}	$n_{\neg del}$	Total N
ya	83 (35%)	125 (52%)	31 (13%)	239
mo	0	0	8 (100%)	8
ba	0	0	7 (100%)	7
ngá	12 (3%)	6 (1%)	439 (86%)	457
nɔ	13 (8%)	9 (6%)	133 (86%)	155
wa	17 (4%)	14 (3%)	431 (93%)	462

- Pronunciation dictionary permitted vowel or morpheme deletion
- Vowel elision can be attributed to phonetic or phonological processes
- *ya* has highest deletions/vowel elision
- *ya* is most often preserved at the start or end of an utterance (syntactic distribution)

Some Perspectives

- Speech technologies are entering more and more into our daily lives
- Seeing successful applications in different domains, e.g.education, language learning, (Mental) health assessment, rehabilitation
- Linguistic data exploration
  - Our results suggest ASR tools can be of use for large scale phonetic studies
  - Need close collaboration of technologists and linguists
  - Explore and validate linguistic hypotheses
  - Complement with acoustic and perceptual studies
- Help document and characterize languages and variants
  in particular oral languages and small speaker populations
  Bulb `http://www.bulb-project.org`
  Atlas `https://atlas.limsi.fr`

Thank You

- for your attention
- and to many colleagues over the years who have contributed directly or indirectly to this work, including: Gilles Adda, Martine Adda-Decker, Djegdjiga Amazouz, Laurent Besacier, Philippe Boula de Mareüil Maria Candea, Ioana Chitoran, Jamison Cooper-Leavitt, Julien Despres, Thiago Fraga da Silva, Jean-Luc Gauvain, Adèle Jatteau Nidia Hernandez, Viet-Bac Le, Abdel Messaoudi, Oana Niculescu, Annie Rialland, Albert Rilliard, Ioana Vasilescu, Bianca Vieru, Cecile Woehrling, Jane Wottawa, ...

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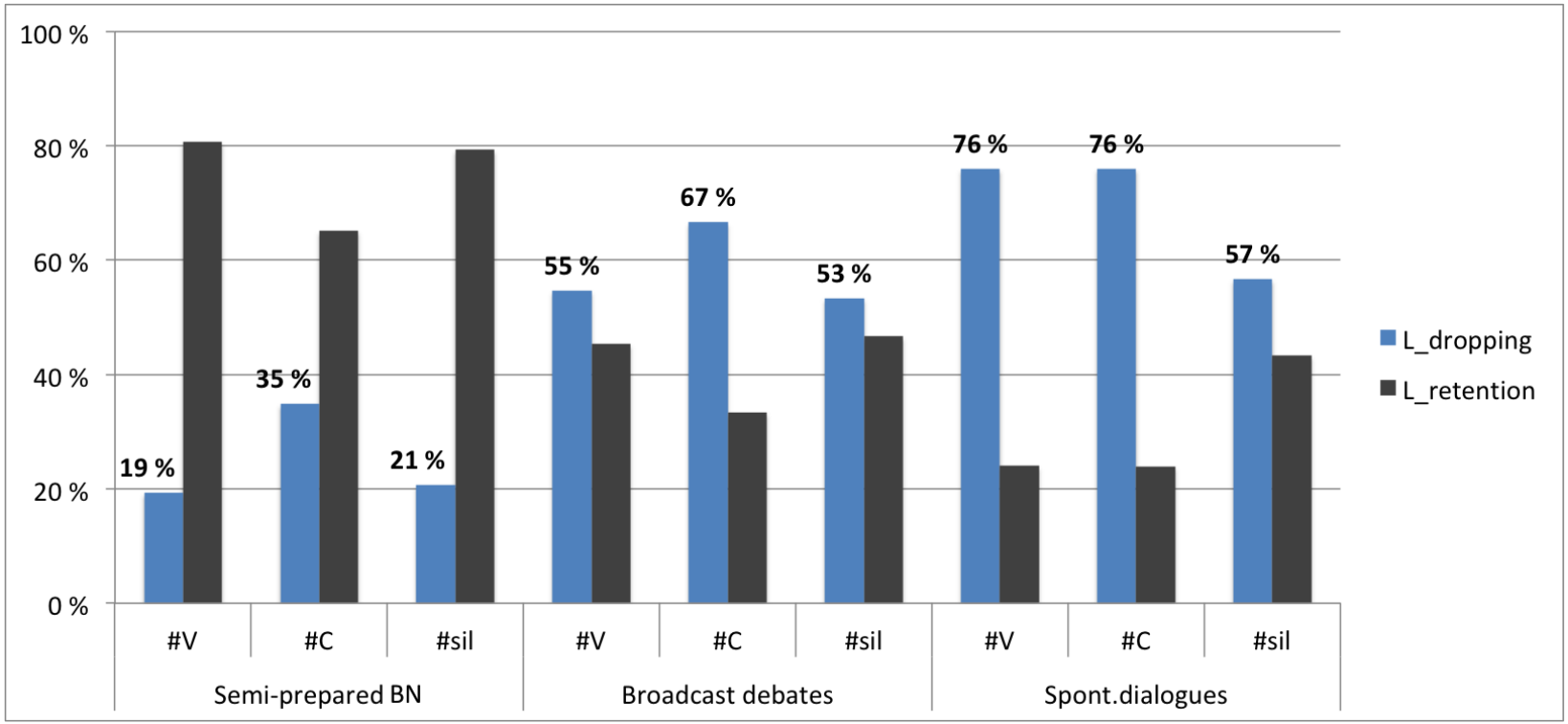
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extra slides

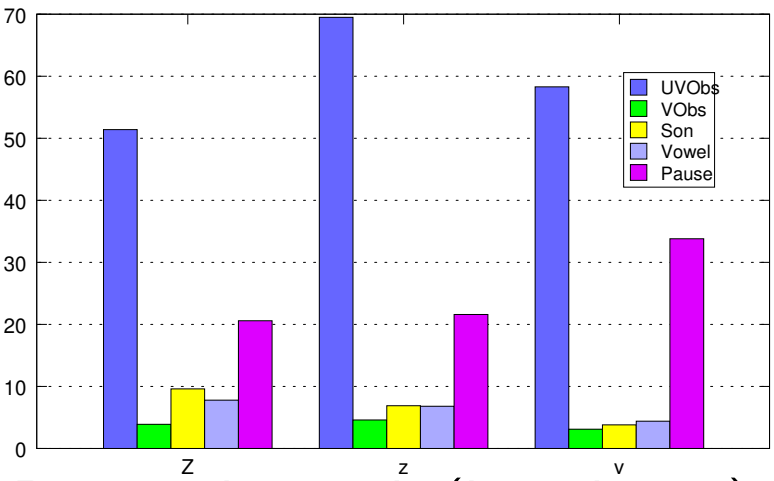


L-dropping/retention vs right context

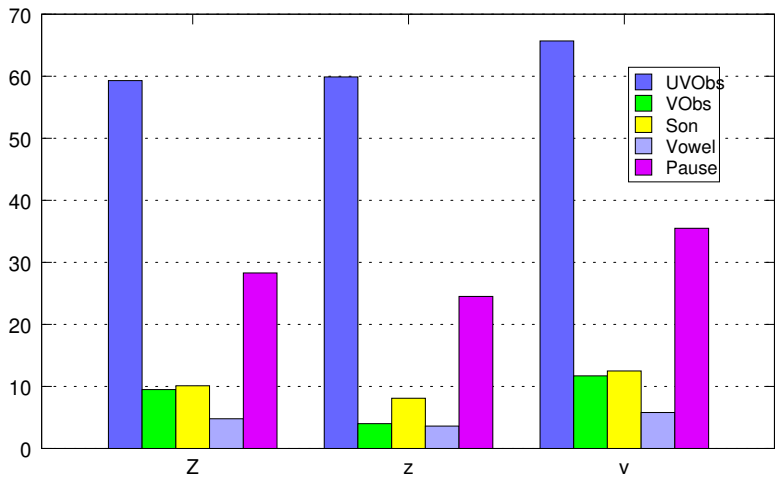


- Tendency for L-retention prepared speech, highest deletion in right #C context
- Highest L-retention for dialogs before silence

Final fricative devoicing - speaking style

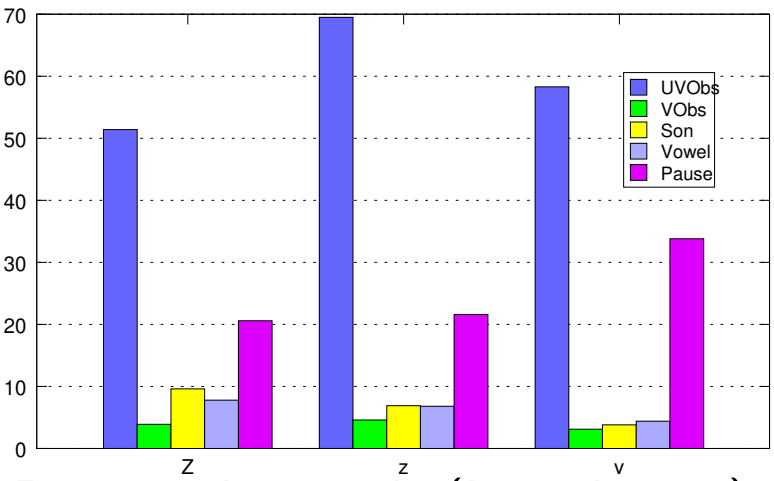


Prepared speech (broadcasts)

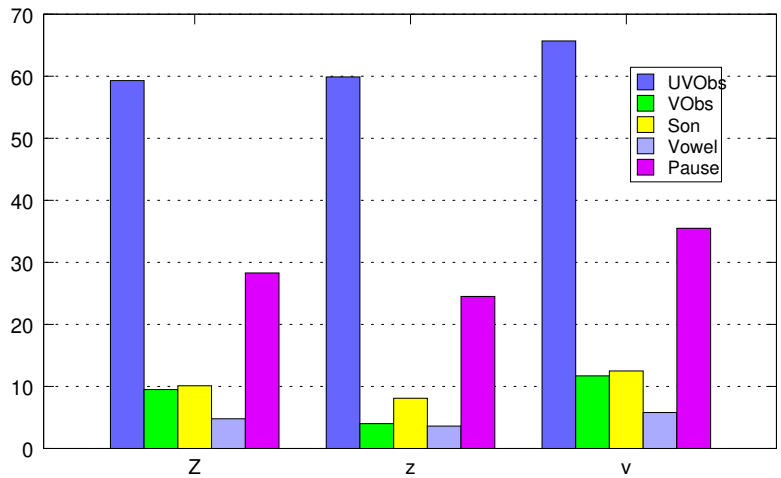


Conversations

Final fricative devoicing - speaking style



Prepared speech (broadcasts)



Conversations

- Observe devoicing, but not voicing before pause

Embosi field trips

- Two 1-month field trips to Brazzaville-Congo
  - Field researcher: GK Kouarata (Kouarata, 2014)
- Collected using the LIG-Aikuma software



1. An initial utterance from the native speaker
2. Followed by a careful re-speaking from the native speaker
3. Followed by a French translation of the original utterance from the native speaker