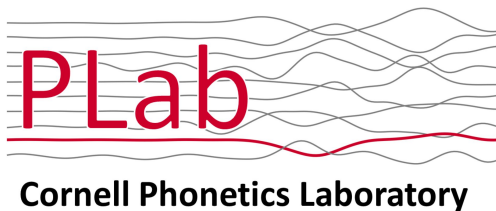


Unifying Initial Geminates and Fortis Stops via Laryngeal Specification

Three case studies from Dunan, Pattani Malay, and Salentino



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Raksit Lau-Preechathammarach^b
Sireemas Maspong^a



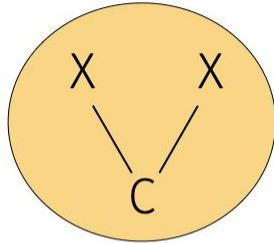
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Overarching Question: Are IGs distinct from fortis consonants?

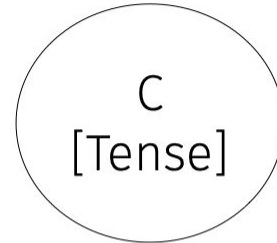
- (1) What are the acoustic correlates of initial geminates (IGs) and how do they unfold in time?
- (2) How do these correlates inform the phonological representation of IGs?

IGs vs fortis are represented as two distinct categories

Initial geminates



Fortis



IGs and Fortis: different representations, but same acoustic cues

Initial Geminates

Fortis Consonants

Phonological
representation

Two timing slots or a mora

Feature(s):
[tense] / [constricted glottis] / [stiff]

Acoustic correlates

↑**duration**, ↑F0, ↑intensity, ↓spectral tilt,
VOT (language dependent)

↑**“articulatory energy”/“resistance”**
↑duration, ↑F0, ↑intensity, ↓spectral tilt,
VOT (language dependent)

(Trubetzkoy 1939; Jakobson, Fant, Halle 1952; Kohler & Dommelen 1987; Cho et al. 2002; Abramson 2003; Idemaru & Guion 2008; Kraehenmann 2011)

A case in point: Korean stops, IGs or fortis?

- Korean has a 3-way fortis, lenis, aspirated contrast
 1. [tense] / [constricted glottis] / [stiff] (summarized in Kang, Schertz, & Han forthcoming)
 2. Phonemic geminates with two timing slots (Ahn & Iverson 2004)
 3. Redundant [tense] feature with two timing slots (Han 1996)
- Acoustic correlates shared with other IG as well as fortis languages (Lee & Jung 2000)

Our view: IGs & fortis consonants are phonologically unified

- Suggested by Ladd & Schmid (2018)
- Rich, unified phonological representation where several cues are available to implement phonological contrast
- These cues are consistently observed in all languages, but their relative weight is language specific
- Geminates are perhaps cases where duration outweighs other cues

3 case studies: Dunan, Pattani Malay & Salentino

Language	IG	Fortis	Other cues
Dunan (Japonic)	✓	✓	↓VOT
Pattani Malay (Austronesian)	✓		↑F0, ↑intensity
Salentino (Indo-European)	✓		

(Abramson 1998; Romano 2003; Bentley 2008; Yamada et al. 2015)

Two types of data

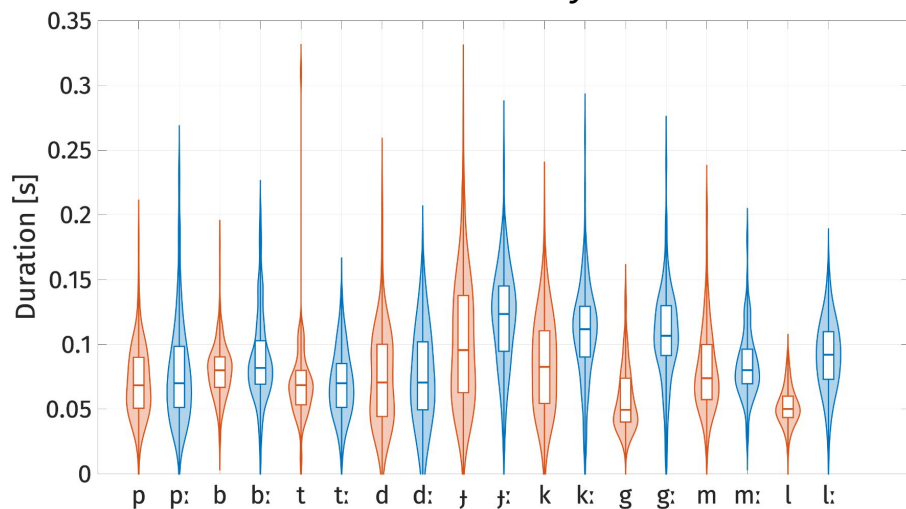
- Controlled data collection: Salentino & Pattani Malay
 - Salentino: 1 speaker x 14 minimal pairs x 11 repetitions (n = 308), carrier sentence
 - Pattani Malay: 14 speakers x 13 minimal pairs x 3 repetitions (n = 1,092) elicited using natural sounding Thai sentences to gather a corpus
- Opportunistic data collection: Dunan
 - Dunan: 1 speaker (n = 2,563)
 - Data from 19 elicitation sessions and stories

Measurements and statistical analyses

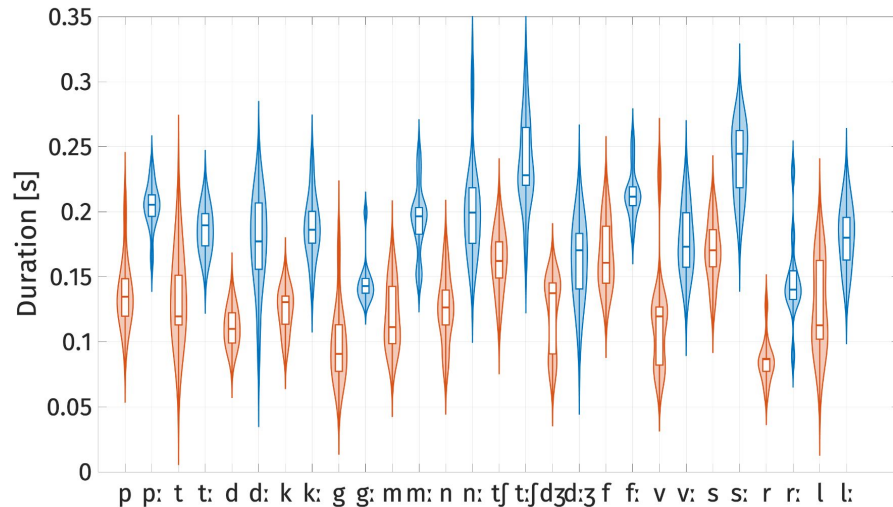
- 3 acoustic properties associated with (initial) gemination
 - 1) Consonant duration (limited to phrase-medial position)
 - 2) F0 contour of vowel
 - 3) Intensity contour of vowel
- **Duration:** Linear mixed effects regression
 - Random effect: consonants
- **f0, Intensity:** 3rd order orthogonal polynomial growth curve analysis
 - Random effect: vowels

Duration: IGs significantly longer in PM and Salentino

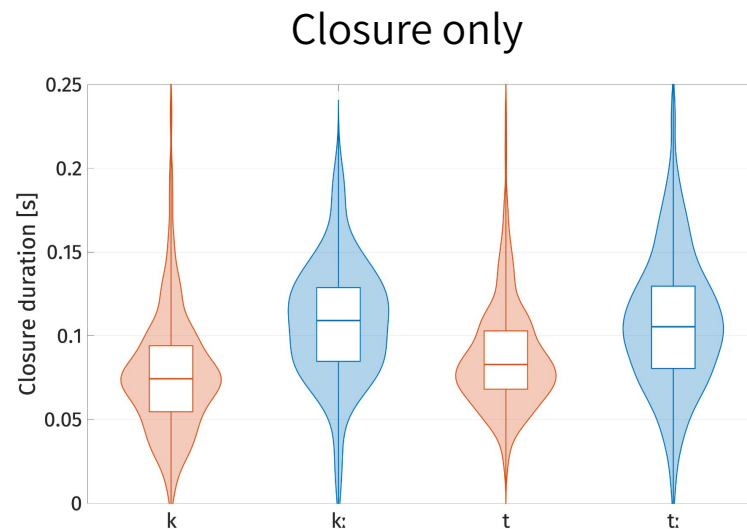
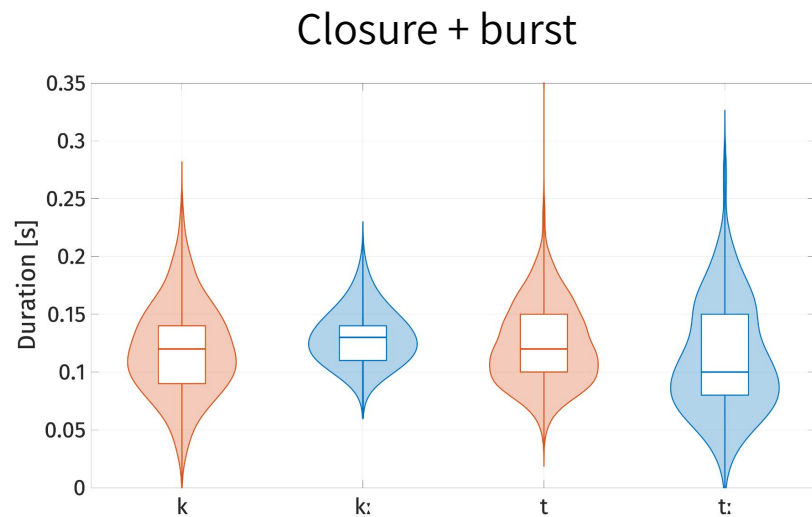
Pattani Malay



Salentino

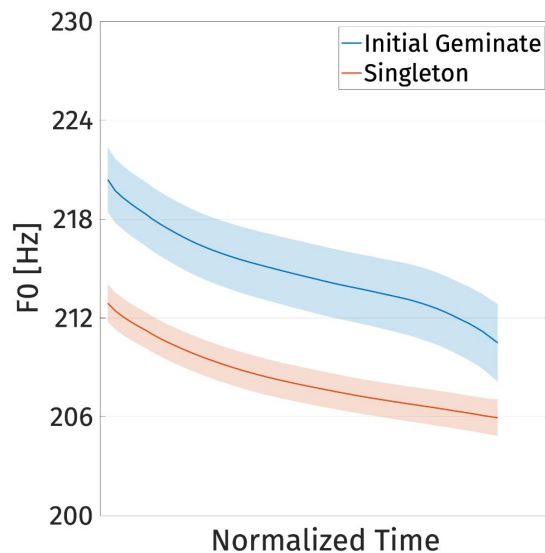


Dunan: IGs have significantly longer closure duration

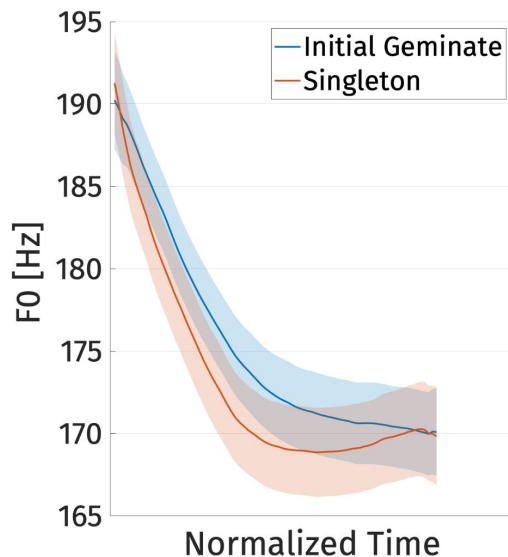


F0 of the following vowel is higher after IGs in all languages

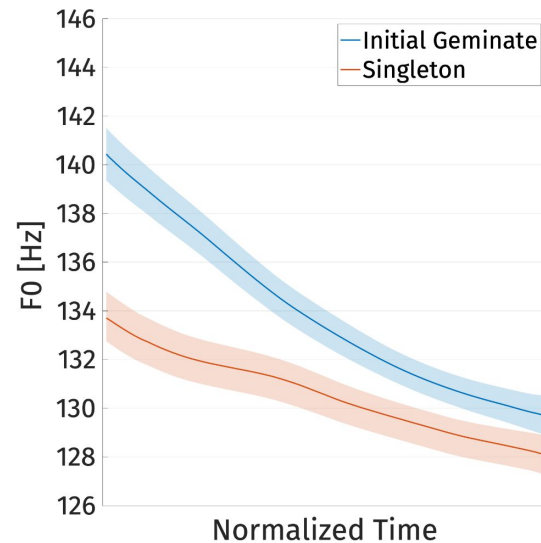
Dunan



Pattani Malay

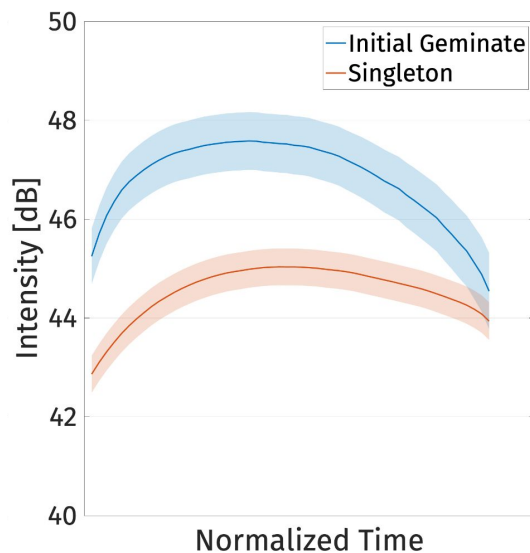


Salentino

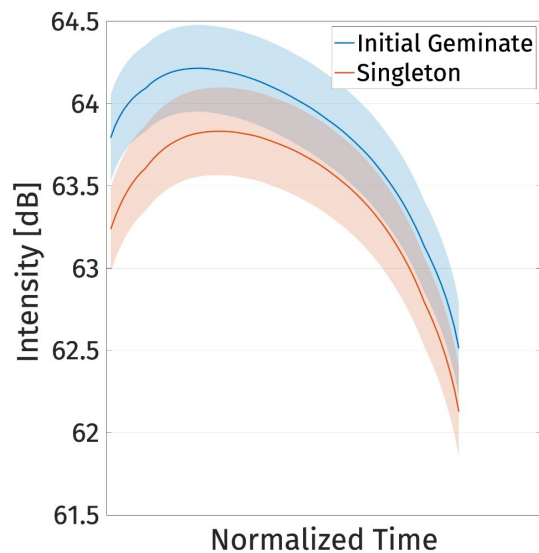


Intensity of the following vowel is higher after IGs

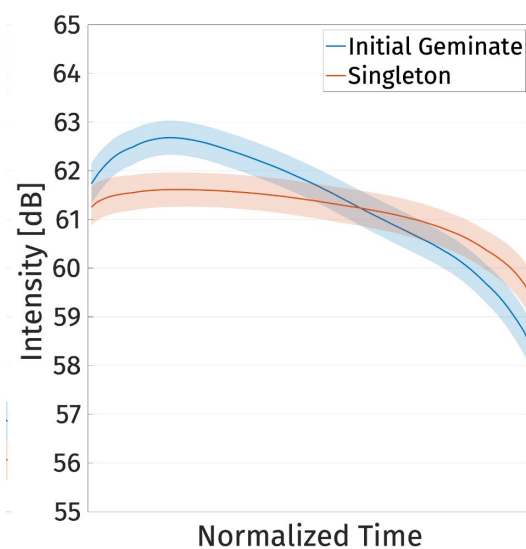
Dunan



Pattani Malay

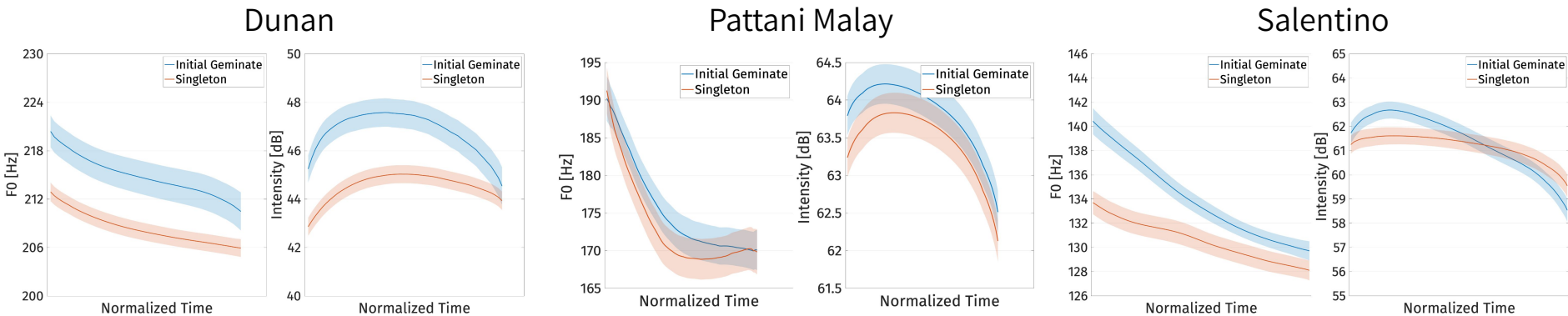


Salentino



Duration is not the only cue in the production of IGs

- F0 and intensity differ much more robustly than generally assumed
- Speakers reliably sustain higher F0 and intensity long after release of IGs



Duration is not the only cue in the production of IGs

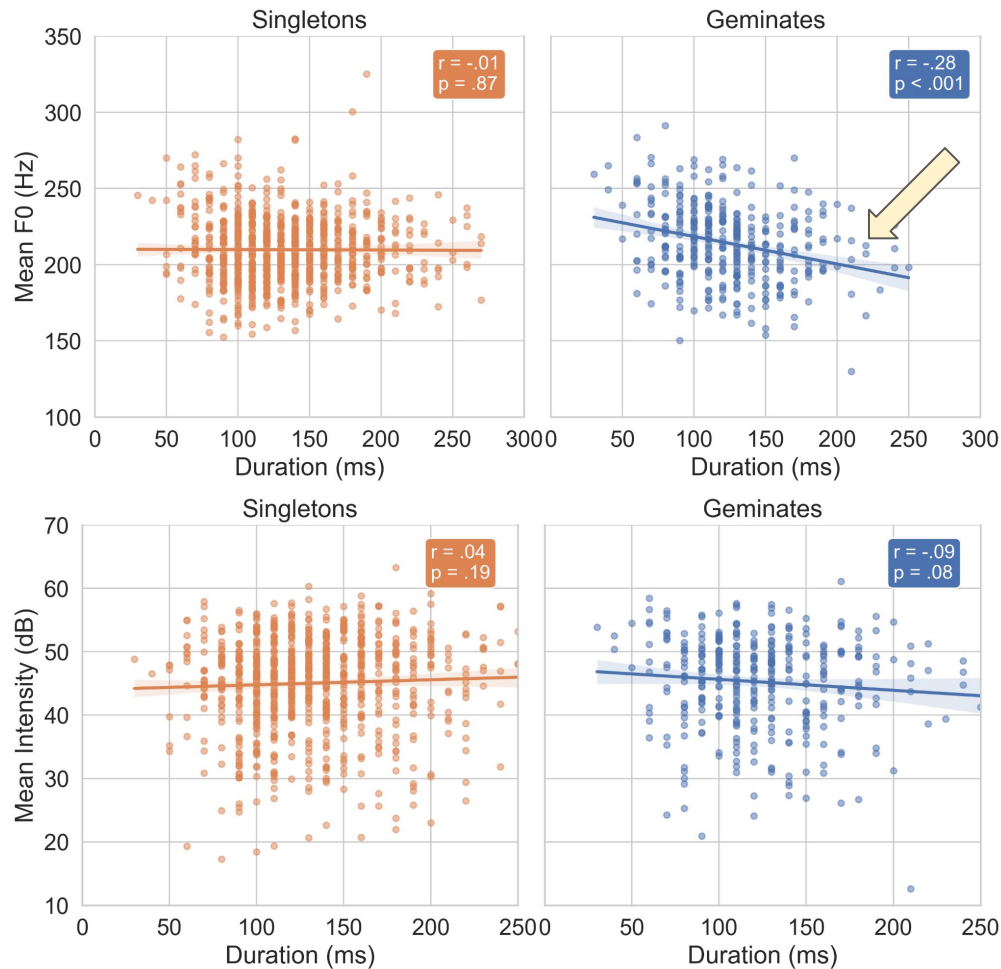
- F0 and intensity differ much more robustly than generally assumed
- Speakers reliably sustain higher F0 and intensity long after release of IGs
- These long lasting effects are unexpected if they are merely a phonetic effect from long closure duration

Cue trade-off: methodology

- Hypothesis: as durational differences decrease (longer singletons, shorter geminates), F0 and intensity differences will increase
- Method
 - Pearson R correlation
 - Mean values of F0 and intensity taken for each token

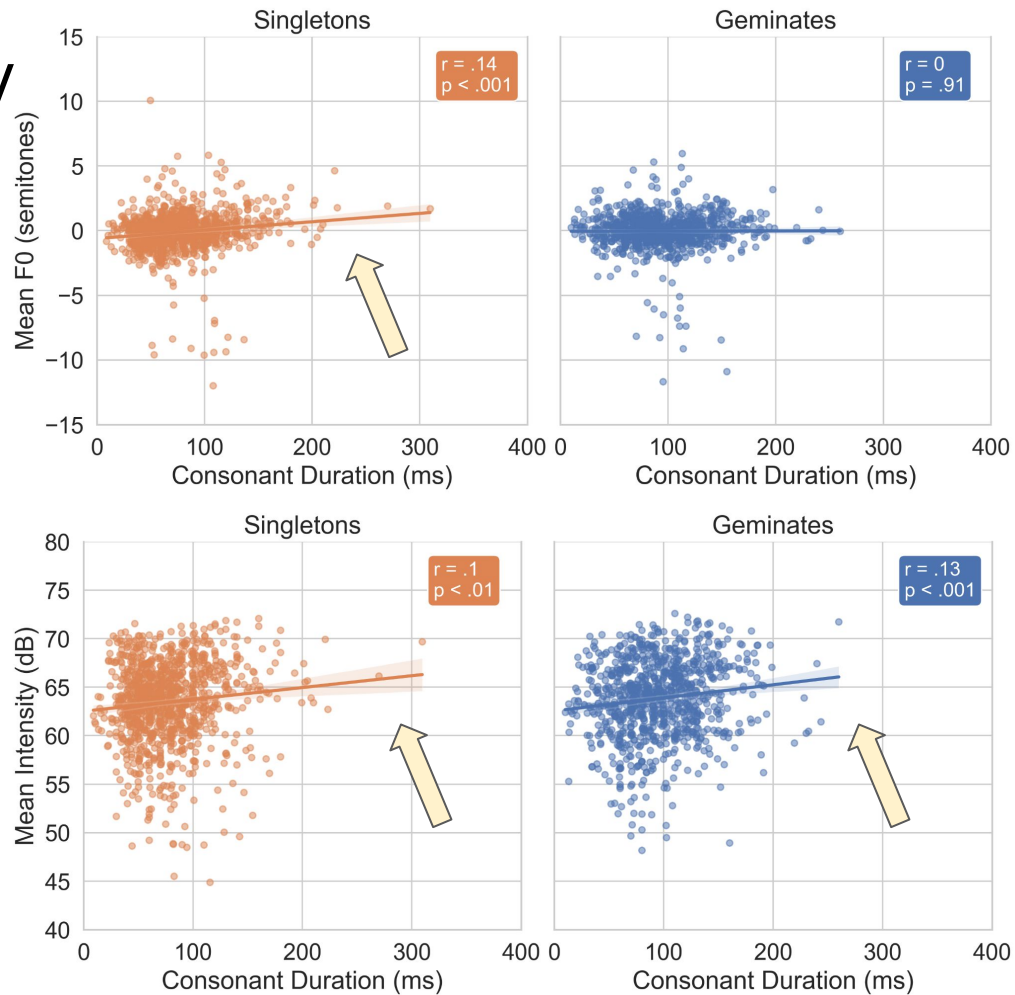
Cue Tradeoff: Dunan

- Negative correlation between IG duration & f_0
- Tradeoff between *duration* cues and f_0 for IGs suggests cue enhancement



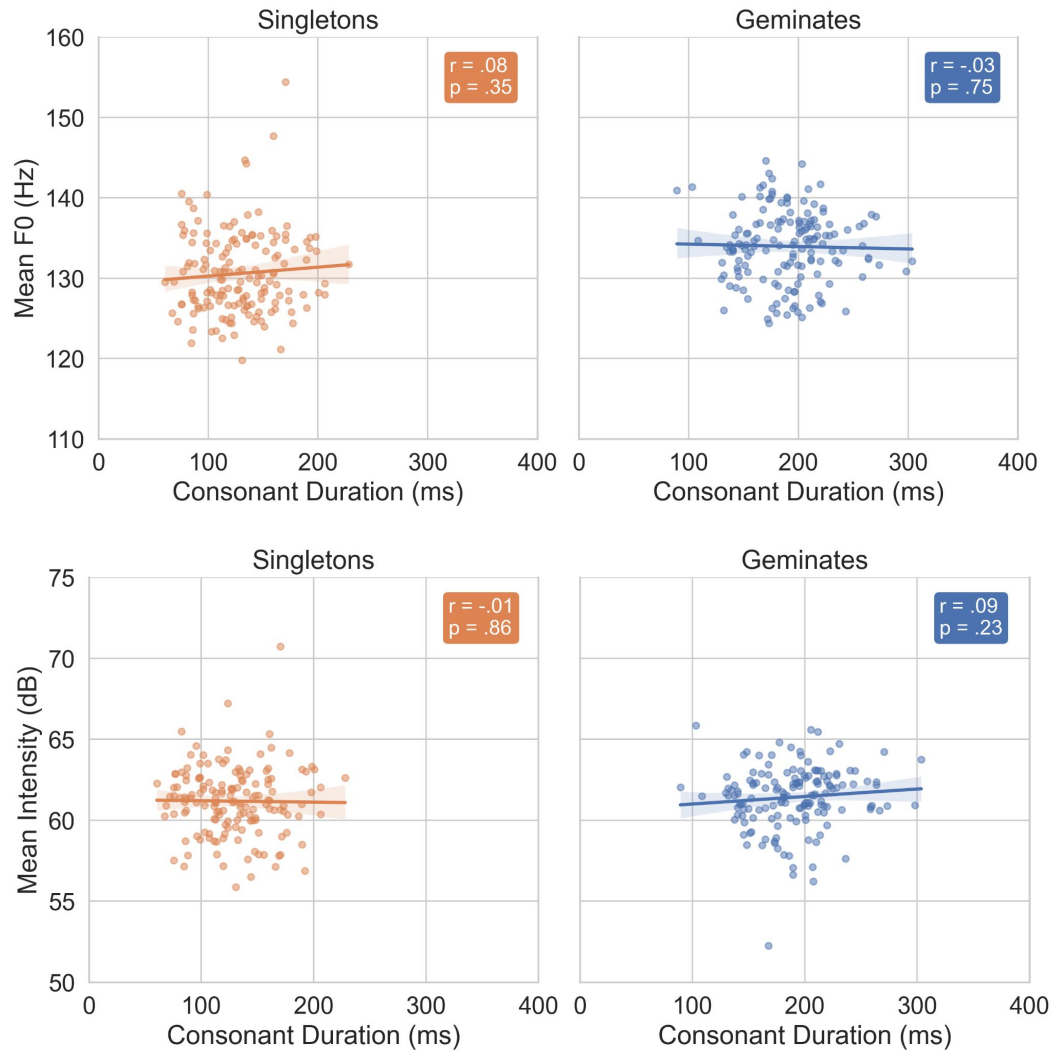
Cue Tradeoff: Pattani Malay

- Weak positive correlations



Cue Tradeoff: Salentino

- No significant correlations



Machine Learning: Classification

- Linear Support Vector Machines (SVM)
- Trained on
 - Duration (Raw, C/ σ Ratio)
 - F0 contours (downsampled to 10 data points)
 - Intensity contours (downsampled to 10 data points)
- Results from a 10-fold cross validation

Dunan Classification

Model	Mean Accuracy	Std Accuracy	
Duration + Intensity + F0	64.7 %	1.5 %	
Intensity + F0	63.4 %	1.1 %	←
F0	60.8 %	1.5 %	
Duration	60.7 %	0.7 %	
Intensity	51.6 %	1.6 %	

Pattani Malay Classification

Model	Mean Accuracy	Std Accuracy
Duration + Intensity + F0	63.7 %	0.4 %
Duration	61.0 %	0.2 %
Intensity + F0	54.0 %	0.4 %
F0	52.8 %	0.1 %
Intensity	52.5 %	0.3 %

Salentino Classification

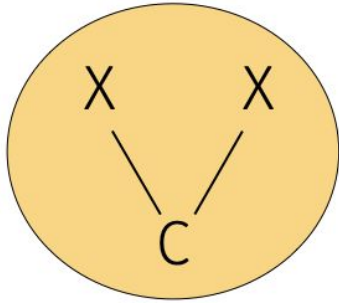
Model	Mean Accuracy	Std Accuracy
Duration + Intensity + F0	81.4 %	0.6 %
Duration	77.8 %	0.4 %
Intensity + F0	74.9 %	1.0 %
F0	72.4 %	0.8 %
Intensity	71.2 %	0.9 %



Summary of the results

- Same acoustic cues appear in different languages:
 - F0 & intensity robust and persist over the following vowel
- Tradeoff:
 - Dunan: F0 trades off with duration
 - No significant correlation in Pattani Malay and Salentino
- Classification:
 - duration + F0 + intensity always perform better than models with each cue alone
 - PM and Salentino: duration > F0 ~ intensity
 - Dunan: F0 ~ duration > intensity (with VOT included)

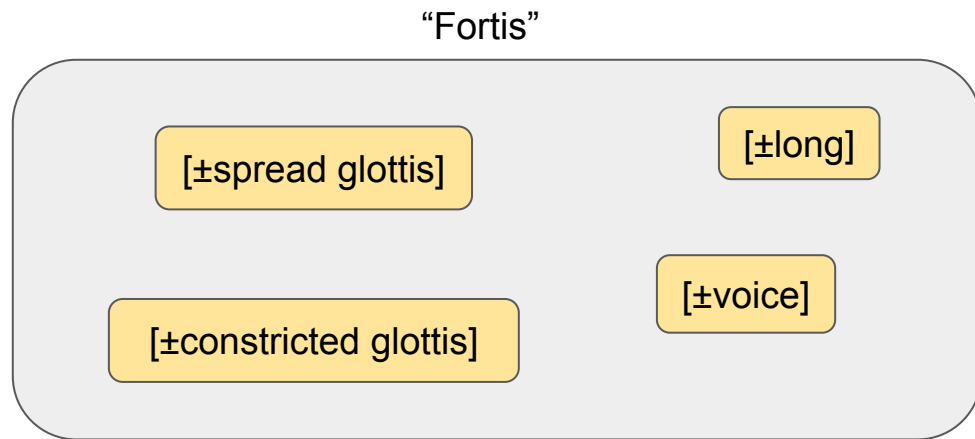
A single feature [+long] or two timing slots are insufficient characterizations of IGs



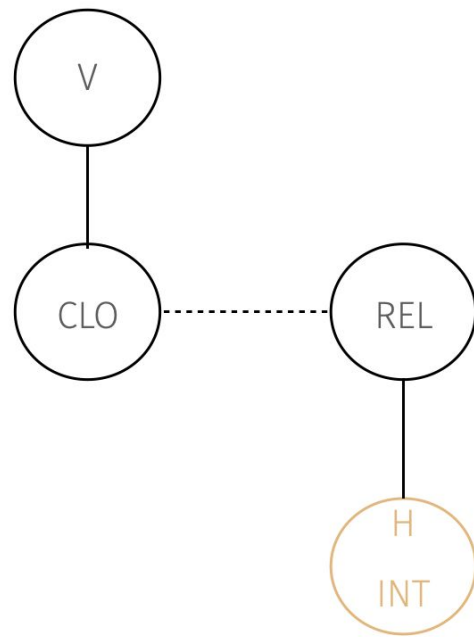
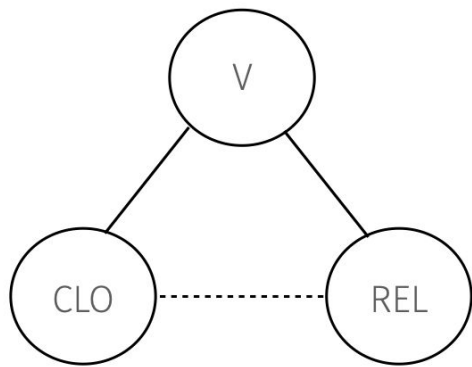
- Potentially capture intensity or F0 differences *close to the release of the consonant*
- But not the sustained higher F0 and intensity long after the release

Constellation of cues capturing a natural class related to (supra)laryngeal activity

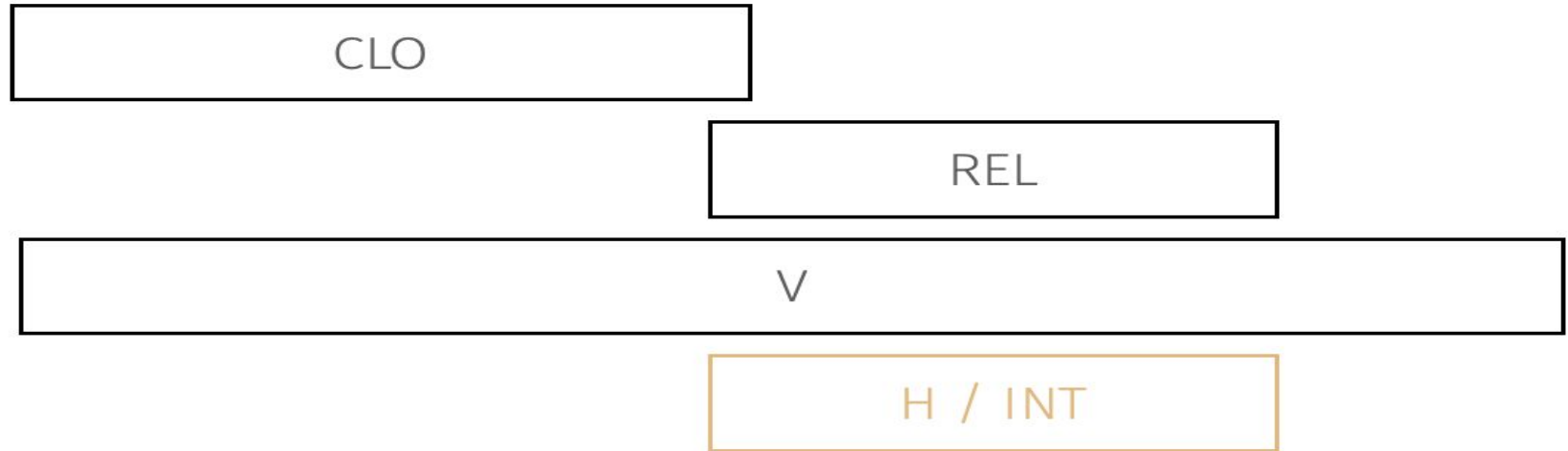
- Longer duration, higher F0 and intensity targets
- Not unlike *register*, which also involves a bundle of cues
- cf. emergent features from acoustic cues (Mielke 2008)



An Articulatory Phonology representation: coupling graphs



IGs are associated with H and INT(ensity) gestures



Conclusions

- Even for “prototypical geminates”, F0/Intensity are more than just “auxiliary”
- Our results show great overlap between cues for IGs and fortis consonants
- Representation
 - Phonologically, constellation of possible phonological specifications (“fortis-like”)
 - IGs show **greater weighting and less variability of durational cues**
- These findings can explain some typologically surprising facts:
 - Voiceless IGs are common, but they are also the hardest to perceive. F0 and Intensity may come into play
 - To our knowledge no language has both IGs and fortis stops

Thank you!

We would like to thank our Dunan, Pattani Malay, and Salentino consultants for providing their time to work with us, the members of the Cornell Phonetics Lab and UC Berkeley's Phorum, Bob Ladd, Susan Lin, Pittayawat Pittayaporn, and three anonymous reviewers for comments on our work, and Pimthip Kochaiyaphum for help in collecting data from Pattani Malay consultants.

Bonus Slides

Dunan IGs

		Labial		Dental		Palatal		Velar		Glottal	
stop	voiceless		pː	t	tː		cː	k	kː		
	voiced		b	d				g			
fricative				s						h	
nasal			m	mː	n	nː		ŋ	ŋː		
tap/trill				r							
glide			w				j				

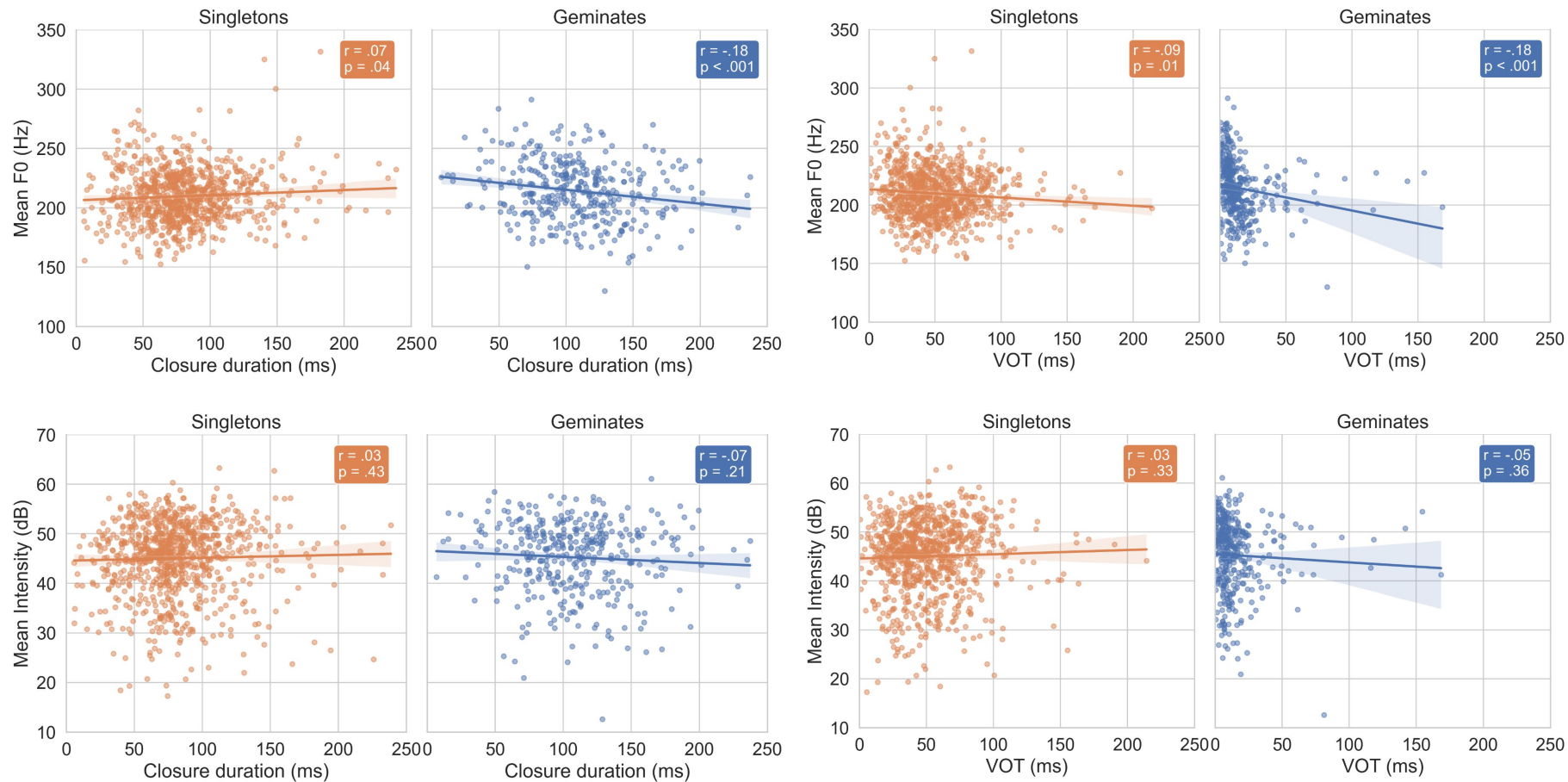
Pattani Malay IGs

		Labial		Alveolar		Palatal		Velar		Glottal	
stop	voiceless	p	p:	t	t:	c	c:	k	k:	ʔ	ʔ:
	voiceless aspirated	p ^h	p ^h :	t ^h	t ^h :	c ^h	c ^h :	k ^h	k ^h :		
	voiced	b	b:	d	d:	ɟ	ɟ:	g	g:		
fricative	voiceless		(f:)	s	s:				(x:)	h	h:
	voiced				z:			ɣ	ɣ:		
nasal		m	m:	n	n:	ɲ	ɲ:	ŋ	ŋ:		
lateral				l	l:						
trill					r:						
glide		w	w:			j	j:				

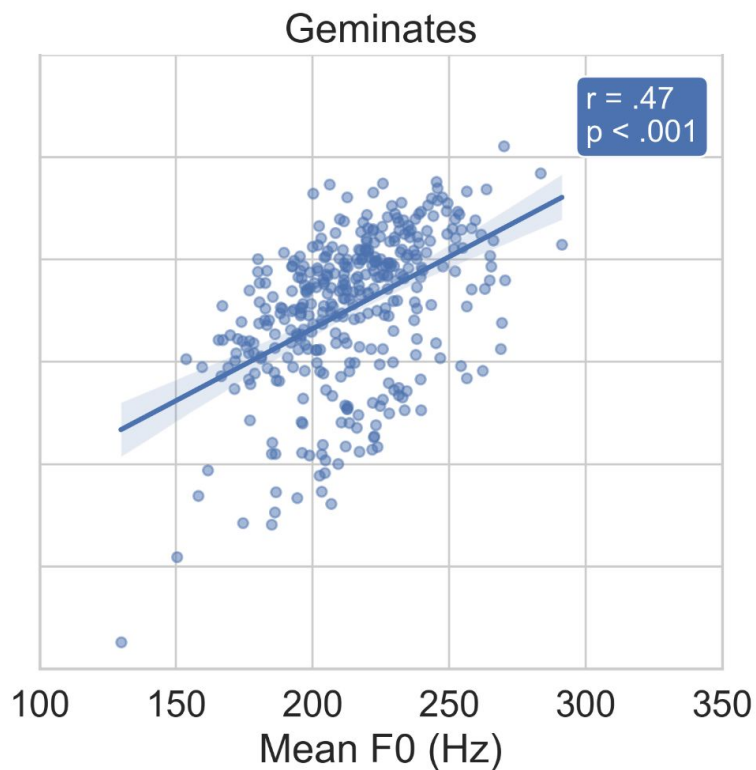
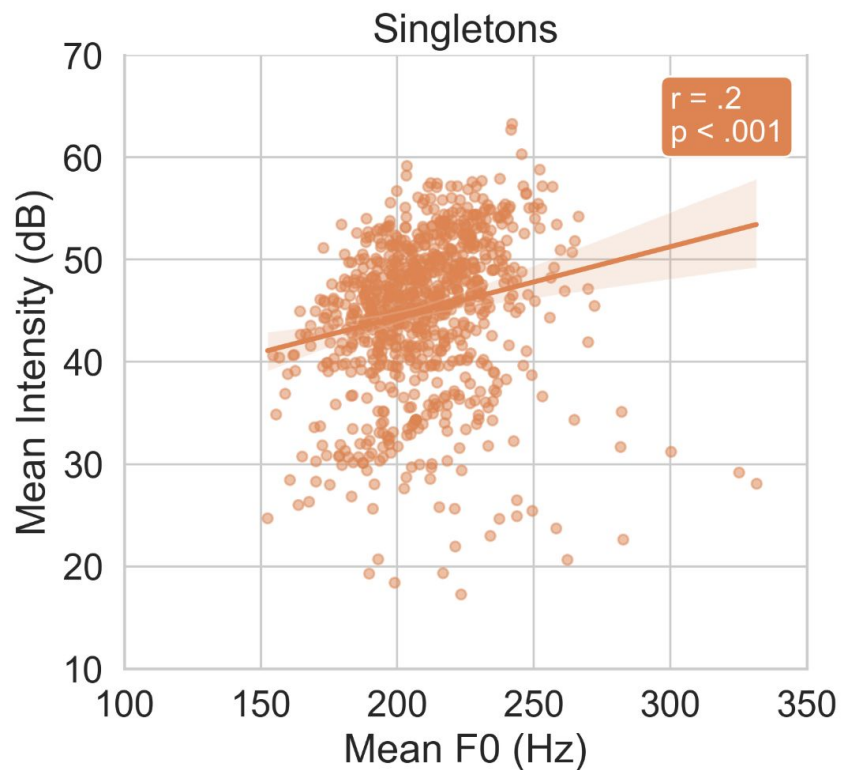
Salentino IGs

		Labial		Alveolar		Palatal		Velar	
stop	voiceless	p	p:	t	t:			k	k:
	voiced		b:	d	d:			g	g:
fricative	voiceless	f	f:	s	s:				
	voiced	v	v:	(z)			ʃ:		
affricate	voiceless			ts		tʃ	tʃ:		
	voiced			dz		dʒ	dʒ:		
nasal		m	m:	n	n:		ɲ:	ŋ	
lateral				l	l:		ʎ:		
trill				r	r:				
glide		w				j			

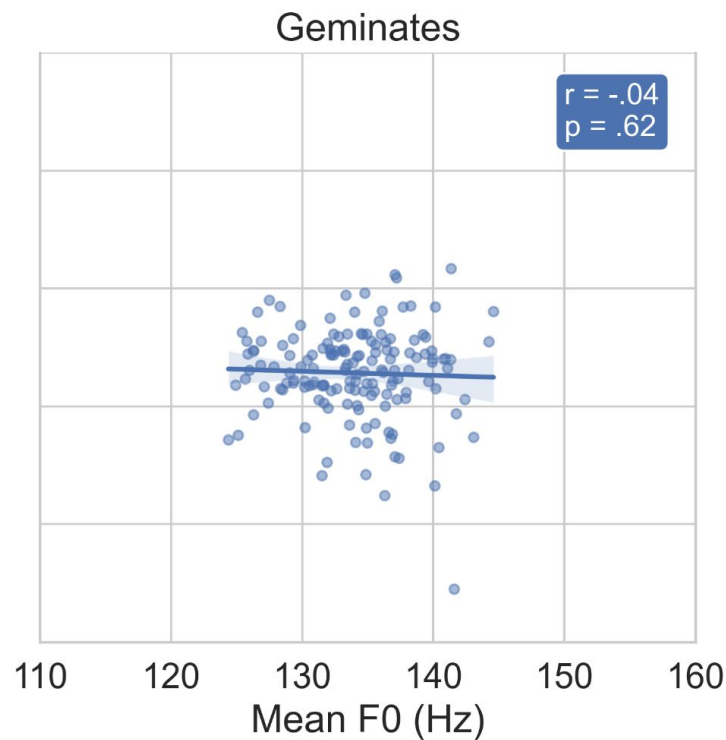
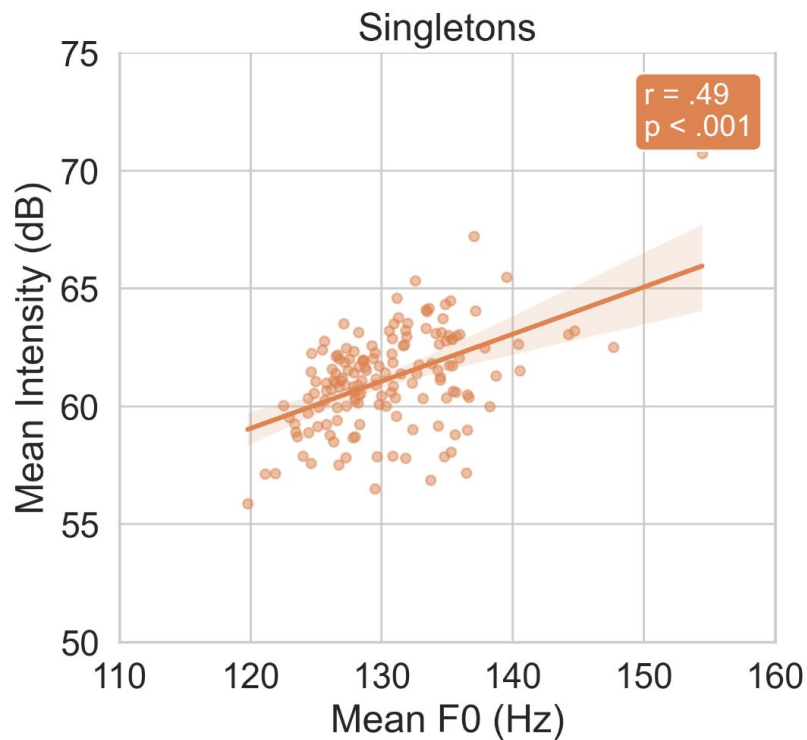
Dunan closure duration & VOT comparisons



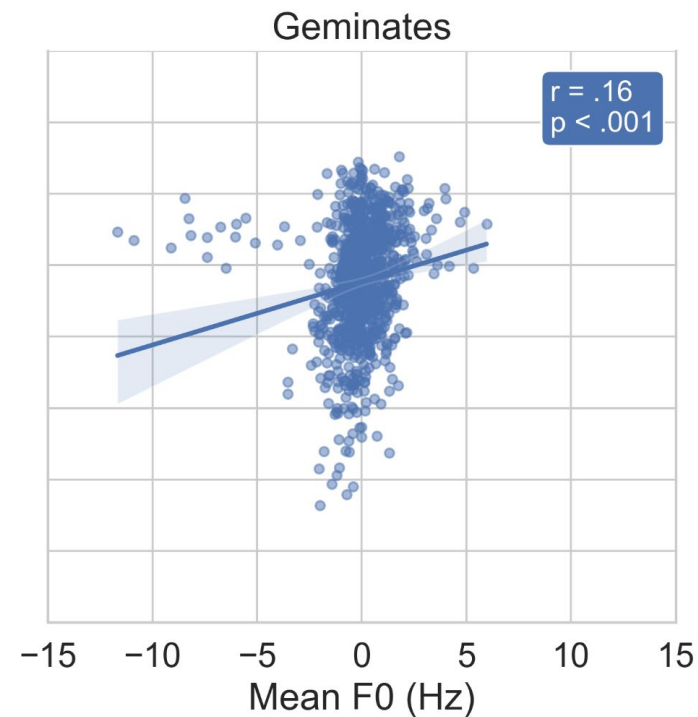
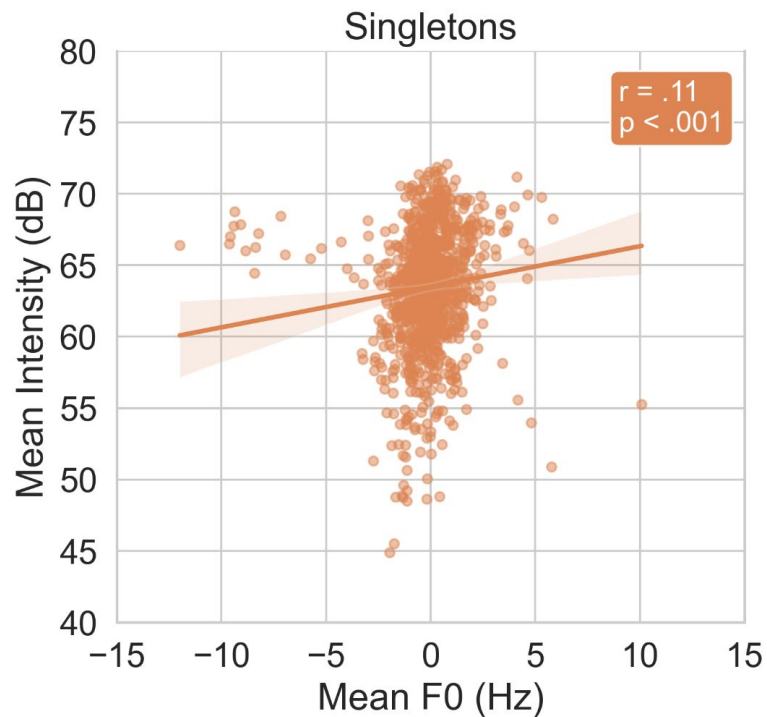
Dunan f0-intensity



Salentino f0-intensity



Pattani Malay f0-intensity



Dunan Classification* (closure duration only)

Model	Mean Accuracy	Std Accuracy	
Duration + Intensity + F0	76.2 %	0.5 %	
Duration	72.0 %	0.4 %	←
Intensity + F0	59.1 %	0.7 %	
F0	52.7 %	0.5 %	
Intensity	51.7 %	1.1 %	

Recordings of Dunan



/tui/ 'bird'



/ttui/ 'one person'

Recordings of Pattani Malay



bunɔ ‘flower’ vs bbunɔ ‘to bloom’
“The flower blooms”

Recordings of Salentino



Sulu



ssulu