Uniformity constrains innovative variants of the Sūzhōu Chinese fricative vowels

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Broad argument

Sound change is mediated by a **bias toward uniformity** of speech sounds with other speech sounds

This is a manifestation of a more general tendency in language: speakers prefer **uniformity** in phonetic implementation

- Learners select strategies for producing segments which **use one or more articulators in the same way** as other segments
- Bias towards uniform implementation places a constraint on the **direction of evolution** of sound systems

Narrow arguments

Sūzhōu Chinese **fricative vowels** show uniformity: mainly articulated with a /ɕ/-like tongue shape (in speaker-specific terms)

- Tongue shapes also occasionally resemble /s/ or /i/

Changing patterns of dialect use have led to contact-induced change in Sūzhōu Chinese, the direction of which appears **constrained by uniformity**

- Younger speakers' fricative vowels show **less overall similarity** to /ɕ/
- But their innovative variants of the fricative vowels are often simply **uniform with a new series of segments**, either /s/ or /i/

Overview

Background

- Uniformity
- Fricative vowels
- Suzhou Chinese phonetics and phonology

Details of ultrasound study

- Description of methods
- Results

Discussion

- Young speakers' innovative variants
- Community-wide adoption in nearby dialects

Background: Uniformity

Uniform phonetic implementation

The phonetic implementation of a phonological feature or gesture tends to be **constrained**[1]

- Phonetic outputs **tend towards being identical** on some acoustic or articulatory dimension
- Uniformity operates **within-speaker**: constrains a given speaker's characteristic "target" for a series of sounds

Attested for a variety of acoustic and articulatory parameters

- Timing of aspiration in VOT[2]
- Vowel height (and F1)[3]
- Constriction location[4]

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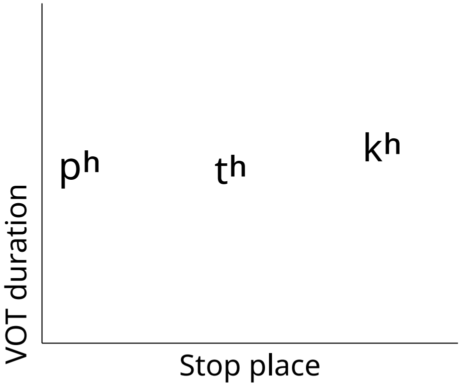
[1] Chodroff, 2017; Faytak, 2018.
[2] Keating, 2003; Chodroff, 2017; Chodroff and Wilson, 2017.
[3] Ménard, Schwartz, and Aubin, 2008.
[4] Maddieson, 1996; Chodroff, 2017.

Example: VOT

Tendency: high mutual predictability within speaker[5]
(speakers may vary in their characteristic VOT)



[5] Chodroff, 2017; Chodroff, Golden, and Wilson, 2019.

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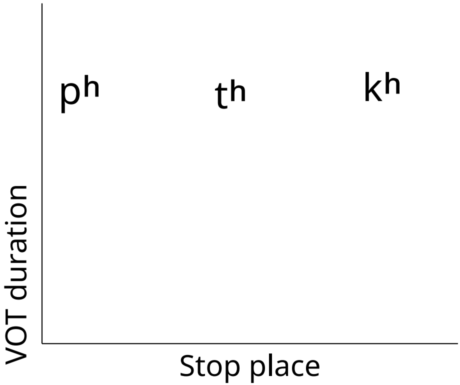

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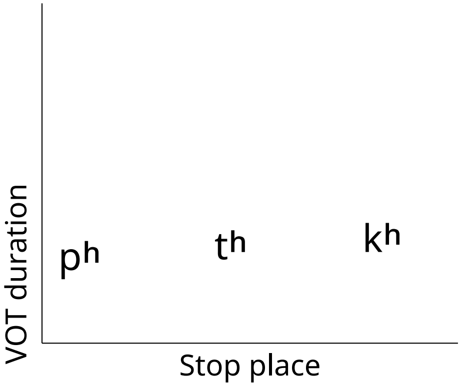
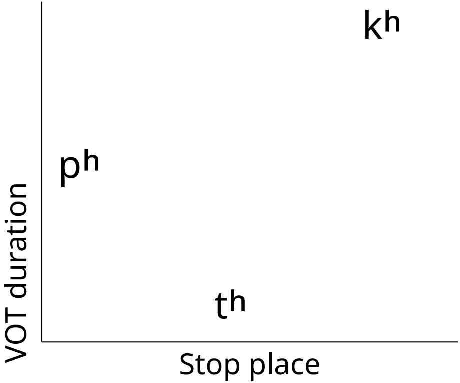


[5] Chodroff, 2017; Chodroff et al., 2019.

Example: VOT

Infrequently attested: little to no mutual predictability within speaker[5]



[5] Chodroff, 2017; Chodroff et al., 2019.

Effects on language evolution

Bias toward uniformity places a constraint on the evolution of sound systems: uniform strategies should come to predominate, other factors held equal[6]

- L1 learners especially favor uniform implementation: **re-use** is better than figuring out from scratch[7]
- **Cumulative effect**: structured variation which may lead to **formation of series**[8]

[6] Faytak, 2018.

[7] Lindblom, 1998; Ménard et al., 2008; Lindblom, Diehl, Park, and Salvi, 2011; Loeb, 2012.

[8] Martinet, 1955; Maddieson, 1996; Clements, 2003.

[9] Keating, 2003.

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- **Cumulative effect**: structured variation which may lead to **formation of series**[8]

But of course, **other factors** may counteract uniformity

- Speakers may idiosyncratically prioritize articulatory ease or other factors over uniformity[9]
- **Contact-induced change** may cause loss of structure

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[6] Faytak, 2018.

[7] Lindblom, 1998; Ménard et al., 2008; Lindblom et al., 2011; Loeb, 2012.

[8] Martinet, 1955; Maddieson, 1996; Clements, 2003.

[9] Keating, 2003.

Background: Fricative vowels

Evolution of fricative vowels

Fricative vowels: fully voiced syllabic segments with light sibilant or shibilant frication

One sound change which uniformity may constrain: **high vowel fricativization**, in which high front vowels ***i**, ***y** develop into fricative vowels[10]

- » Due to phonologization of fricative noise and/or different constriction location
- » Often result in a chain shift in which lower vowels rise to occupy the empty corner of the vowel space

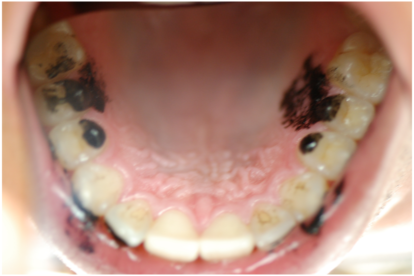
[10] Shi, 1998; Zhao, 2007; Zhu, 2004; Faytak, 2014.

Constriction location

Narrower and more anterior than [i], similar to strident fricative

Static palatography, Chángzhōu 常州 Wú dialect:

[pi] 边 'side'



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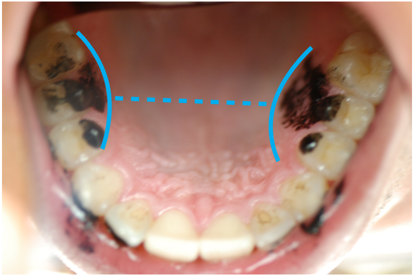

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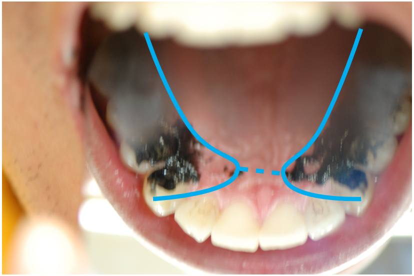

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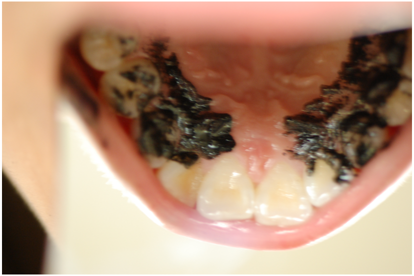

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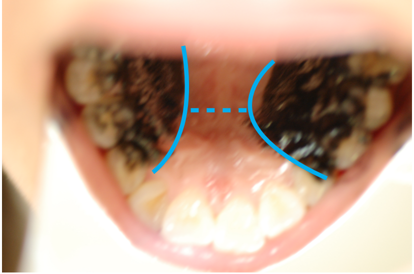

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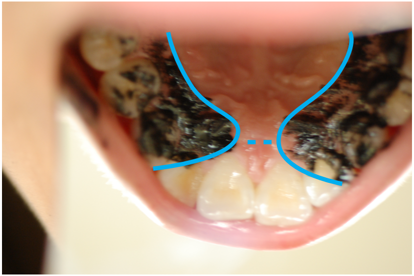
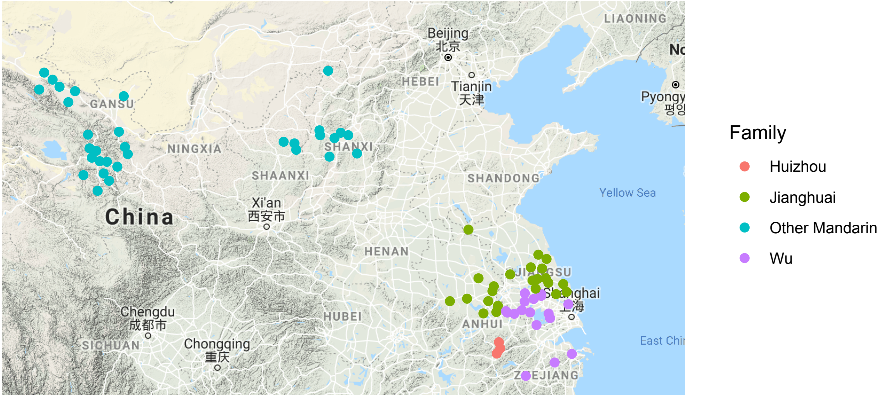


In China

Fricative vowels develop from ***i**, ***y** in many Chinese dialects, mainly Mandarin and Wú[11]



[11] Shi, 1998; Zhao, 2007; Qian, 1992; S. Wang, 2006.

Elsewhere

Fricative vowels from ***i**, ***y**, and sometimes high central vowels, are also attested elsewhere

- Numerous minority languages of southwestern China[12]
- Ryukyuan languages (far southern Japan)[13]
- Grassfields Bantu (Cameroon)[14]
- Debatably, Swedish *Viby-i*[15]

[12] M. Li and Ma, 1983; Chirkova, Wang, Chen, Amelot, and Antolík, 2015.

[13] Aoi, 2012.

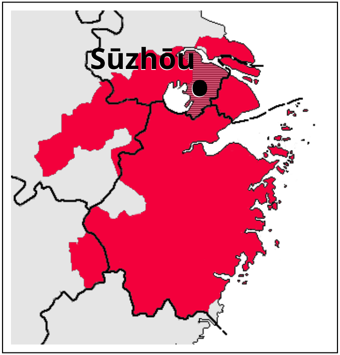
[14] Fiore, 1987; Connell, 2007; Faytak, 2017.

[15] Schötz, Frid, Gustafsson, and Löfqvist, 2014; Westerberg, 2016.

Case study: Sūzhōu Chinese

Sūzhōu Chinese

Northern Wú dialect closely related to Shanghainese



Sūzhōu Chinese

Some local scenery: Master of Nets Garden 网师园

Social situation

Likely 2-3 million speakers in Sūzhōu and the diaspora[16]

- Younger speakers typically described as less fluent or "mixed" with Standard Chinese
- Many younger speakers are not taught the dialect and learn only Standard Chinese in the home
- Usage rates have been declining for younger generations[17]

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[16] Zhengzhang, 1988; Yan, 1988.

[17] P. Wang, 2003.

Vowel system

Canonically, Sūzhōu Chinese has an unusual **six-way distinction** among rounded and unrounded high front vowels, **fricative vowels**, and **apical vowels**[18]

	High front	Fricative	Apical
Place	(Dorso-palatal)	(varies)	(Apico-alveolar)
Unrounded	i	iʑ	ɿ
Rounded	y	yʑ	ʮ

- Can be thought of as a **place contrast** for constriction location
- Apical vowels are more anterior than fricative vowels (apico-alveolar)

[18] Ye, 1988; X. Li, 1998; P. Wang, 2011.

Vowel system

The high front and “fricative” vowels robustly contrast

- With and without alveolopalatal onsets such as /ɕ/
- Other than the apical vowel, the unrounded vowels may co-occur with other onsets (bilabials, labiodentals, alveolars)

	High front	Fricative	Apical
Unrounded	烟 i	衣 iʑ	*ɿ
	‘smoke’	‘clothing’	
Rounded	怨 y	迂 yʑ	*ʮ
	‘complain’	‘winding’	

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	High front	Fricative	Apical
Unrounded	掀 ɕi ‘flip’	稀 ɕiʑ̩ ‘rare’	*ɕɿ
Rounded	休 ɕy ‘rest’	虚 ɕyʑ̩ ‘weak’	*ɕʮ

Vowel system

Contrast between the apical and fricative vowels is more restricted

	High front	Fricative	Apical
Unrounded	鲜 si ‘fresh’	西 $si_{ʑ}$ ‘west’	丝 sɿ ‘thread’
Rounded	*sy	*$sy_{ʑ}$	书 sʮ ‘book’

- » Apical vowels only occur after anterior coronal fricatives and affricates, i.e. /s/, /ts/
- » /y/, /$y_{ʑ}$/ do not co-occur with the /s/ onset, and so the rounded apical and fricative vowels can be treated as allophones

Variation in the fricative vowels

Constrictions for [iʑ] and [yʑ] can be made with **two different tongue postures**, as seen through **linguograms**[19]

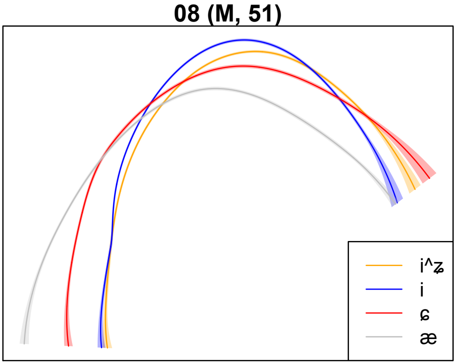
Dorso-postalveolar, further back than fricatives such as [ɕ], but still anterior to [i]

Lamino-(post)alveolar, further front, much more closely resembling [ɕ]

Tongue position

Same configurations can be observed in sagittal ultrasound tongue surface contours[20]

Dorso-postalveolar: not quite **[i]**, not quite **[ɕ]**



[20] Faytak, 2018.

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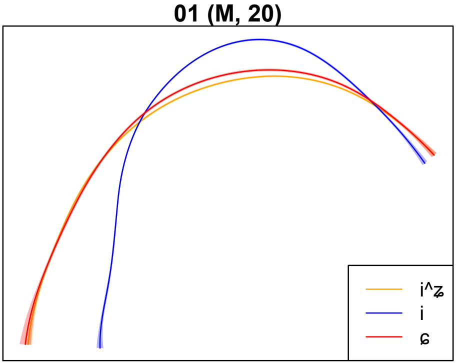
Lamino-postalveolar: nearly identical to **[ɕ]**



[20] Faytak, 2018.

Ultrasound study

Interim summary

What we know:

- Fricative vowels contrast with high front vowels based on anterior constriction and increased fricative noise
- Multiple strategies for speakers to choose from (in Sūzhōu, at least)

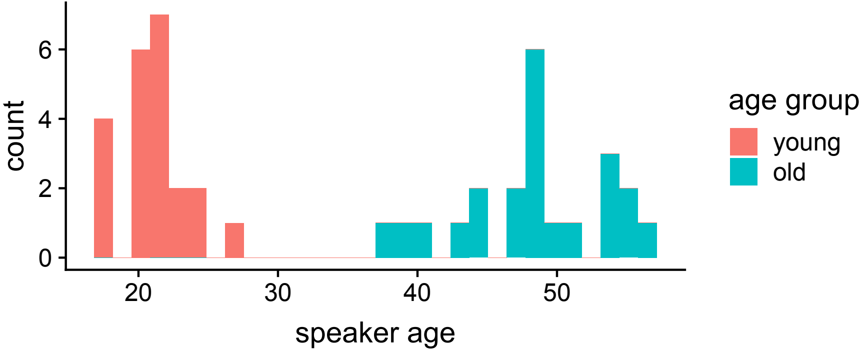
What we **don't know** and would like to find out:

- Which strategies actually predominate (prior study has small sample)
- Whether **uniformity** with [ɕ] plays a role in strategy selection
  - **Uniform, [ɕ]-like** laminal articulator?
  - Or **non-uniform** dorsal articulator?
- How **contact with Standard Chinese** affects this unusual system

Participants

44 speakers (16 male, ages 18-57) recruited in Gūsū district, Sūzhōu (苏州市姑苏区)

- 22 younger than age 30: 11 male, ages 18-27, mean age 21
- 22 older than age 30: 5 male, ages 37–57, mean age 48.3



Participants

Age difference is effectively a **language background** difference

- Older speakers are nearly all **sequential bilinguals**: learned Sūzhōu Chinese in home, then Standard Chinese in primary school
- Younger speakers are nearly all **simultaneous bilinguals**: learned Standard Chinese and Sūzhōu Chinese at the same time, in the home

	Age < 30	Age > 30
Sequential	4	**21**
Simultaneous	**18**	1

Recording method

Ultrasound video recorded using Telemed EchoB

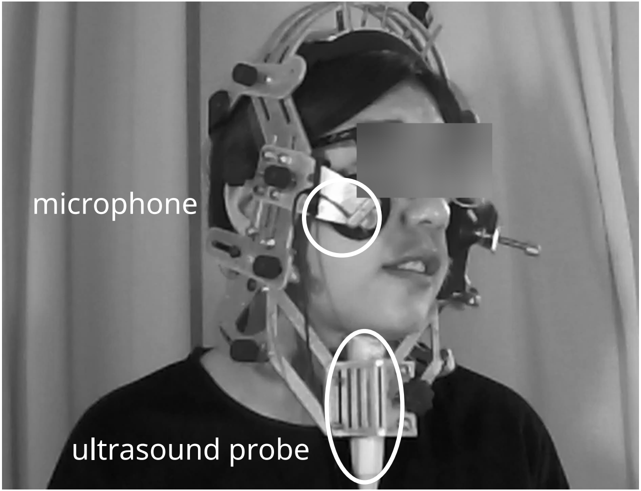
- PV6.5/10/128 Z-3 microconvex probe recording at 54 frames per second
- Probe stabilized with Articulate Instruments headset[21]

Synchronized **audio recordings** collected at the same time

- Sony ECM-77B electret condenser microphone mounted on headset
- 44.1 kHz sampling rate

[21] Articulate Instruments Ltd., 2008.

Recording method



Stimuli

CV syllables which contain target consonants /s/, /ɕ/ and vowels

- All items in upper register, mostly level tone [^{44}] (阴平)
- Items have **fricative onsets** (which are targets) or **non-fricative onsets**
- Contain **high front vowels**, fricative vowels, or apical vowels

		Unrounded	Rounded
fricative	s	si 鲜 'fresh'	*sy
	ɕ	ɕi 掀 'flip'	ɕy 休 'rest'
non-fric.	p	pi 边 'side'	*py
	Ø	i 烟 'smoke'	y 怨 'complain'

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	Ø	iʑ 衣 'clothing'	yʑ 迂 'winding'

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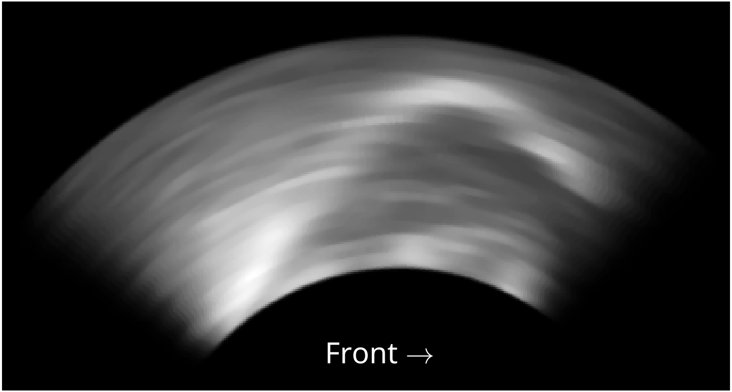
		Unrounded	Rounded
fricative	s	sɿ 丝 ‘silk’	sʮ 书 ‘book’
	ɕ	*ɕɿ	*ɕʮ
non-fric.	p	*pɿ	*pʮ
	Ø	*ɿ	ʮ

Ultrasound data

Midpoint frames of all target segments (fricatives, vowels) extracted, filtered to reduce noise[22]

Pictured: processed [i] from Speaker 13



[22] Mielke, Carignan, and Thomas, 2017.

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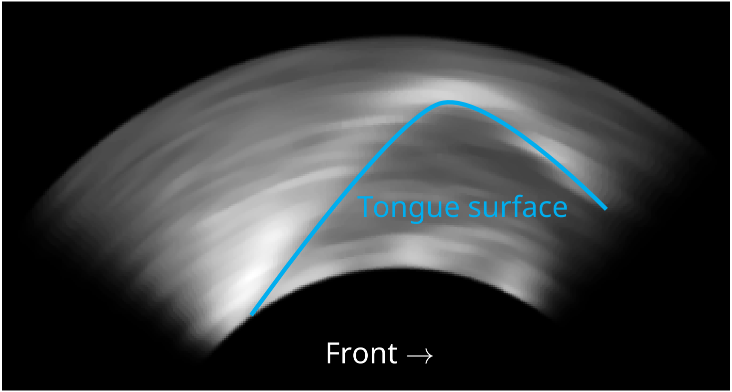

[22] Mielke et al., 2017.

Analysis: dimensionality reduction

Problem: ultrasound image data is noisy and very high-dimensional; feature extraction (i.e. contour extraction) has low reliability and is painfully slow

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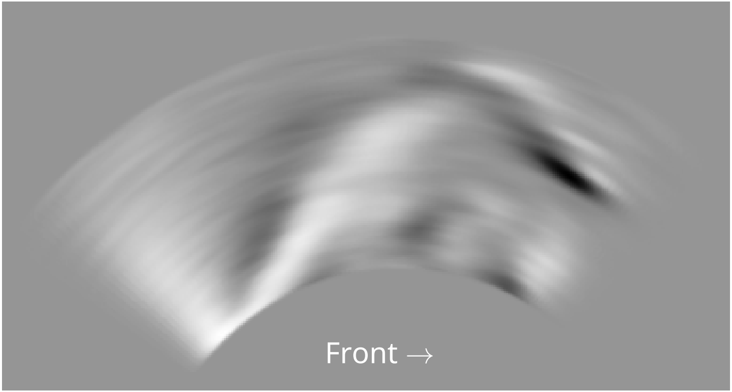
Solution: a two-step **dimensionality reduction** method using principal component analysis (PCA) and linear discriminant analysis (LDA)

- Input data: tens of thousands of pixels for each observation
- PCA result: a much smaller set of PC scores expressing patterns of covariance in the data
- LDA result: score on a single **metric of similarity** to prototype segments /i/, /ɕ/, or /s/

Principal components analysis (PCA)

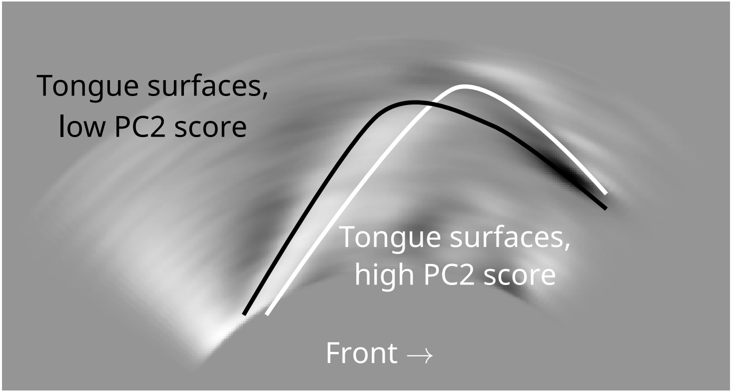
Eigenvectors for ultrasound data represent **covariation in pixel intensity** across the image; sometimes called **eigentongues**[23]



[23] Hueber et al., 2007; Hoole and Pouplier, 2017; Mielke et al., 2017.

Principal components analysis (PCA)

Can be related to basis data through eigenvalues/“PC scores”[23]



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Principal components analysis (PCA)

First **ten PC scores** are retained as a lower-dimensional representation of the data

Separate PCAs are run for **each speaker**, because a single model including all speakers might also capture non-linguistic variation in PC scores:

» Morphological variation (size, palate shape, etc.)

» Ultrasound probe placement variation

» Varying image quality across sessions (is the entire tongue surface visible)

Linear discriminant analyses (LDAs)

Using **PCs 1–10** as input, carry out two **linear discriminant analyses**, both in the following manner

- **Training**, using prototype segments with **known articulation** as the classes
- **Testing**:
  - Transform **data not used in training** into linear discriminant space
  - Provides insights on segments with **unknown articulation**: which classes they resemble

Linear discriminant analyses (LDA)

Training and testing phases of LDA both yield two useful types of data

- **Classification** of each observation as **one of the training categories**
  - Training phase: self-classification (is the LDA working?)
  - Testing phase: classification of test data **in terms of training data**
  - Can be used as **index of uniformity**: more unanimous classifications are more uniform
- Linear discriminant (LD) scores for each observation (a continuous measure)
  - Can be used to **quantitatively assess degree of similarity** of training and test data

Three-class *vs* two-class LDA

One of two LDAs carried out on the PCA data: use ***/i/, /ɕ/, /s/*** as training data

- Test data: **fricative vowels** and **apical vowels** as a test case (known to be /s/-like)
- Mostly for **exploratory purposes**: hard to compare models across participants
- This space is used to **classify the fricative vowels**

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The other, for **for statistical analysis**: simpler training set consisting of ***/i/, /ɕ/***

- Test data: only **fricative vowels**
- Low end is always ***/i/*-like**, high end is always ***/ɕ/*-like**, in **speaker-specific terms**
- Can compare across speakers if range-normalized

Predictions

Classification of fricative vowels /iʑ/, /yʑ/ should mostly be as /ɕ/

- In both three-class and two-class LDAs
- Regardless of presence of onset fricative

LD for fricative vowels /iʑ/, /yʑ/ should **correlate** with LD for /ɕ/

- In other words, fricative vowel tongue shapes are **predictable within speaker** given /ɕ/ tongue shapes
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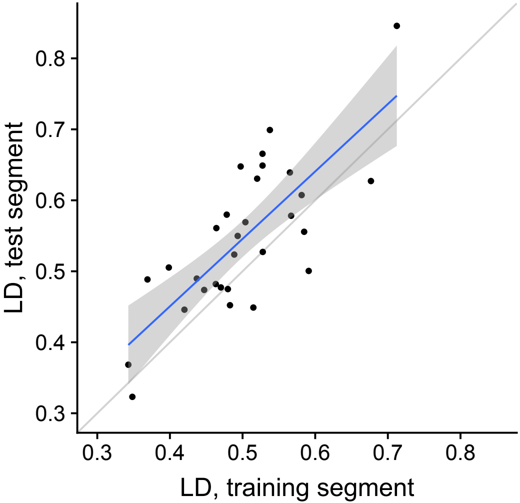
May vary by **age group**, due to changing contact situation

Predictions, as a plot

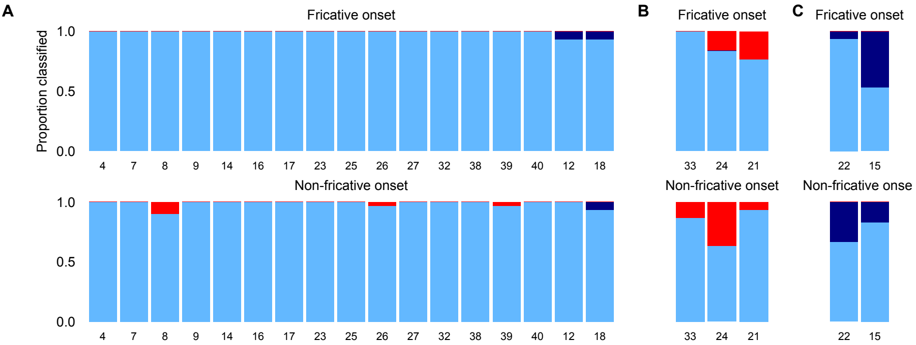
Training segment's LD versus test segment's LD



Results:
Speakers older than 30

Three-class LDA: classification ■ /i/ ■ /ɕ/ ■ /s/

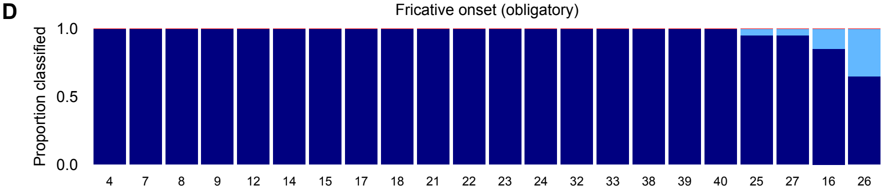
Fricative vowels are mostly **/ɕ/-like**, whether adjacent to a fricative (top) or not (bottom)



Groups: A, never less than 90% /ɕ/; **B**, more than 10% /i/ in some context; **C**, more than 10% /s/ in some context

Three-class LDA: classification /i/ /ɕ/ /s/

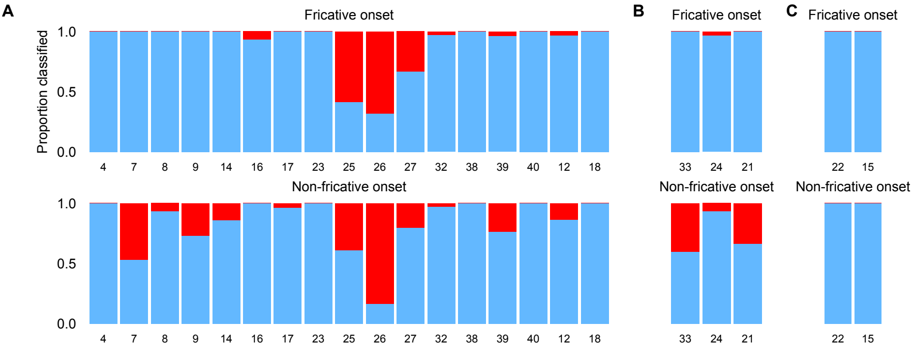
Apical vowels are almost entirely **/s/-like**



- This reassures us that our PCA/LDA method is detecting real similarity
- Apical vowels are known to have /s/-like tongue shapes

Two-class LDA: classification /i/ /ɕ/

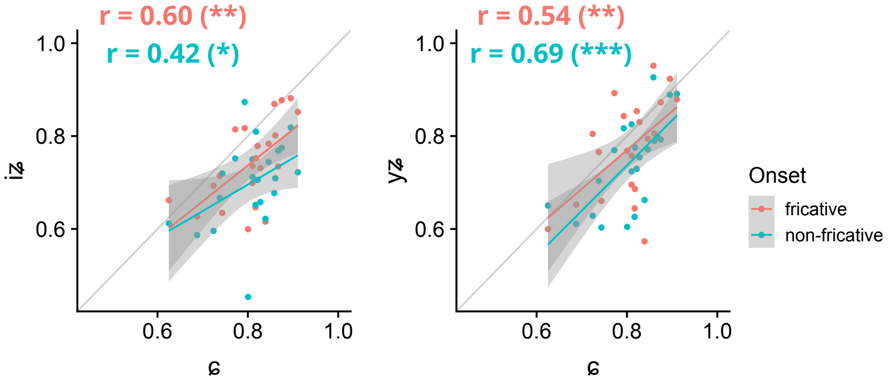
Fricative vowels are mostly **/ɕ/-like**, but note speaker 26: resolves as essentially /i/-like



Groups arranged as in three-class LDA

Two-class LDA: autocorrelation on LD

Moderate to strong correlations in LD which reach significance for both vowels (in both contexts) with /ɕ/'s LD ($r = 0.4$ to 0.6)



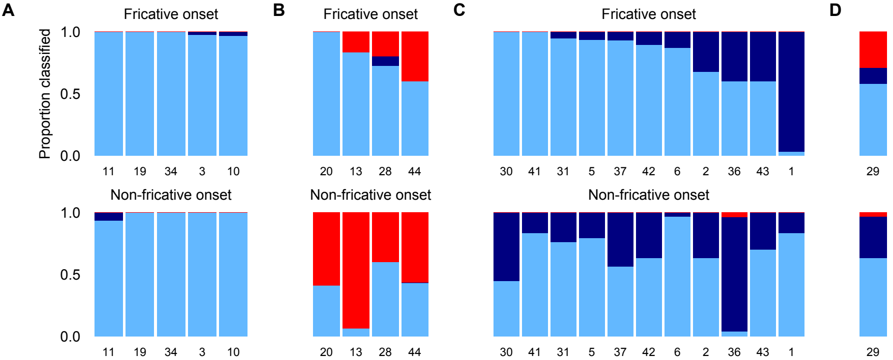
Correlations with median /i/ LD do not reach significance

Results:
Speakers younger than 30

Three-class LDA: classification

/i/ /ɕ/ /s/

Much more varied than older group; notably more speakers with /s/-like classification outcomes

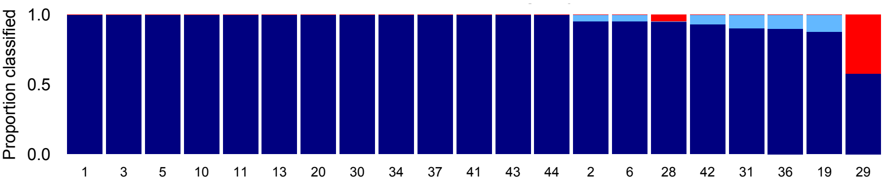


Note speaker 13 (in group B) and speakers 36 and 1 (in group C)

Three-class LDA: classification

/i/ /ɕ/ /s/

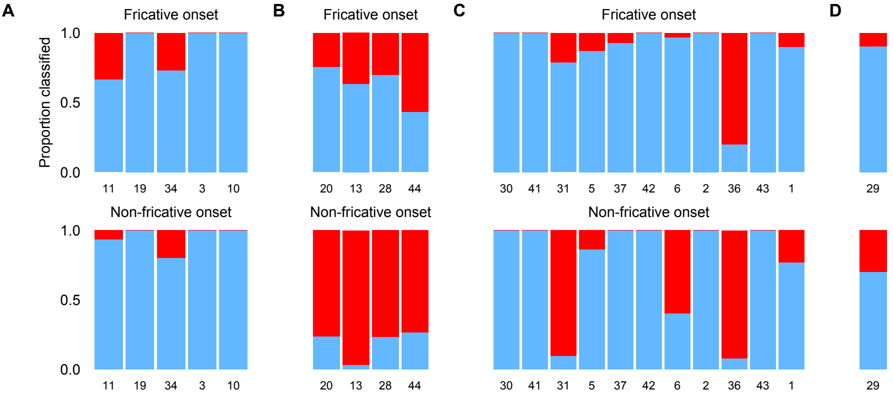
Apical vowels still classify overwhelmingly as /s/-like



» For speakers 36 and 1, fricative vowels and apical vowels are essentially the same in one context

Two-class LDA: classification /i/ /ɕ/

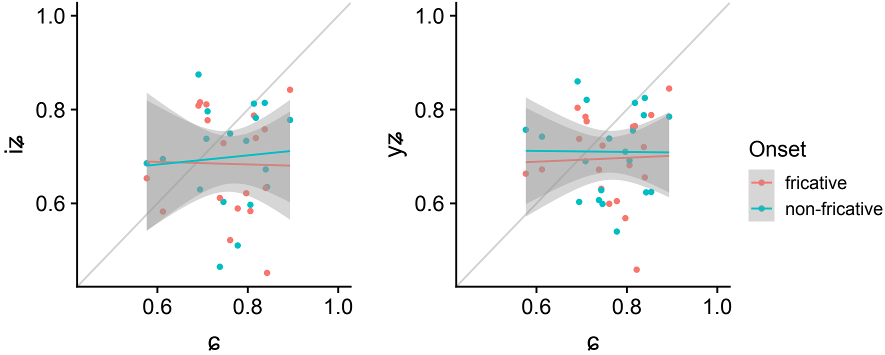
Young speakers classify as less strongly /ɕ/-like than old speakers



Note Speaker 31 resolves as essentially /i/-like with non-fricative onsets

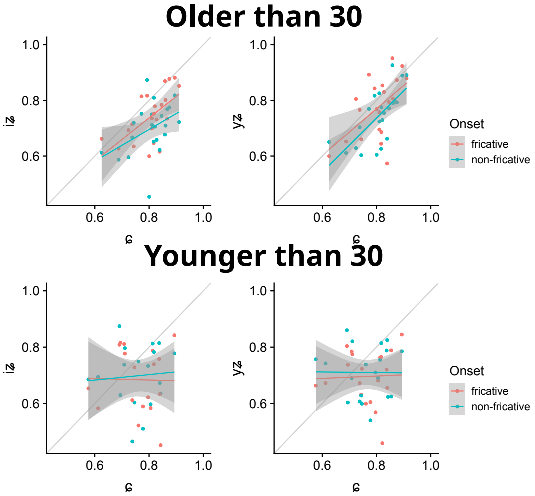
Correlation

Young speakers' correlations with /ɕ/ (and /i/) **do not reach significance**



Correlation

For both segments in both contexts, older speakers have a stronger correlation with /ɕ/



Discussion

Fricative vowels are *mostly* uniform

Fricative vowel variants **qualitatively similar to /ɕ/** predominate

- Much more **structure** than if speakers were randomly selecting from known, apparently equivalent strategies
- Suggests the influence of speaker-side uniformity bias

Some exceptions:

- A minority of speakers across both age groups have less uniform fricative vowels (mixed classification)
- Younger speakers show **similarity to /s/** at a much greater rate

Younger speakers

Many younger speakers do not adhere to this pattern

- Intensified contact disrupts the structured variation which typically holds (fewer unanimous classifications)
- **Factors other than uniformity bias** appear to influence strategy selection for these speakers

In some individual cases, new variants appear to be **mediated by existing structures**, leading to **new patterns of structured variation**

- Can be thought of as **uniform with different segments** rather than with /ɕ/
- Four or five out of 22 younger speakers (including speaker 35)
- **Uniform implementation mediates which strategies a speaker picks**

Community-level change

The individual innovations discussed here are **“micro” sound changes**[24]

» Sound change in the broader speech community can be conceptualized as a shift in the “pool of variation” as a whole

We might ask ourselves: is there evidence for corresponding “macro” changes **at the community level**?

[24] Ohala, 1989.

Community-level change

The individual innovations discussed here are **“micro” sound changes**[24]

» Sound change in the broader speech community can be conceptualized as a shift in the “pool of variation” as a whole

We might ask ourselves: is there evidence for corresponding “macro” changes **at the community level**?

Yes! Evolution of fricative vowels in neighboring dialects has frequently resulted in:

» Merger with high front vowels

» Neutralization (but not merger!) with apical vowels

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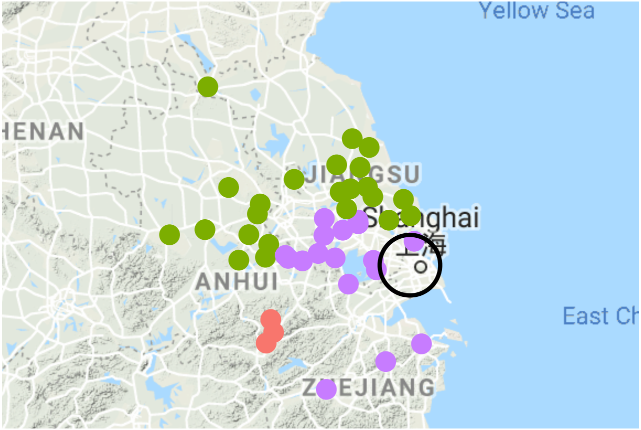
[24] Ohala, 1989.

Shànghǎi and surrounding areas



Shànghǎi and surrounding areas

Greater Shànghǎi area has merged fricative vowels with high front vowels[25]

» Proliferation of /i/-like fricative vowel variants would encourage this

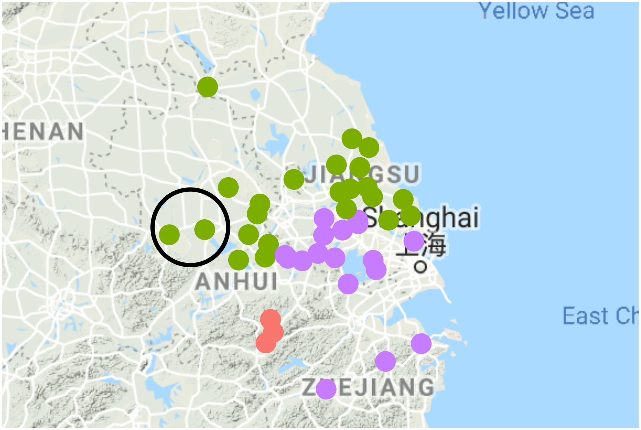
Proto-Wú[26]			mid-1900s[27]		post-1980
衣 'clothing'	*i	>	*i$_{ʑ}$	>	i
烟 'smoke'	*iẽ		...	>	i
迂 'winding'	*y	>	*y$_{ʑ}$	>	y
怨 'blame'	*yø̃		...	>	y

[25] Zhu, 2006; Qian and Shen, 1991.

[26] Ballard, 1969.

[27] Zhu, 2006; Chen and Gussenhoven, 2015.

Héféi and surrounding areas



Héféi and surrounding areas

In Héféi 合肥 and nearby cities such as Lù'ān 六安, fricative vowels and apical vowels are produced identically[28]

» Proliferation of /s/-like fricative vowel variants would encourage this

椅 'chair'	*i	>	*i$_{\text{ʑ}}$	>	(z)ɿ
丝 'thread'	*sɿ		...	>	sɿ
雨 'rain'	*y	>	*y$_{\text{ʑ}}$	>	(z)ʮ

» "Apicalization" of fricative vowels turns out to be quite common (perhaps because it is more easily detectable)[29]

[28] Wu, 1995; Hou, 2009; Kong, Wu, and Li, 2019.
[29] Zhao, 2007; Hu and Ling, 2019.

Héféi and surrounding areas

The resulting structural effects are **more complex** than in Shànghǎi: not precisely merger

- Before: apical vowels after apico-alveolar onsets /s ts ts^h/, fricative vowels overlapping and elsewhere
- After: apical vowels extend to all of these contexts

Héféi and surrounding areas

The resulting structural effects are **more complex** than in Shànghǎi: not precisely merger

» Before: apical vowels after apico-alveolar onsets /s ts tsʰ/, fricative vowels overlapping and elsewhere
» After: apical vowels extend to all of these contexts

Available evidence also suggests that [ʮ] did not exist before "apicalization"

» Pre-existing /ɿ/ may have influenced the development of *yʑ

Concluding notes

Innovative variants of fricative vowels observed in Sūzhōu Chinese can be connected to **community-level change** in nearby dialects

- "Isolated"[30] sounds are not observed at community level
- If no series with /ɕ/, then a series with /s/ or /i/

Uniformity bias appears to mediate the development of these innovative variants

- At the "micro" level
- Possibly in the selection of variants which propagate to the community

[30] Martinet, 1955.

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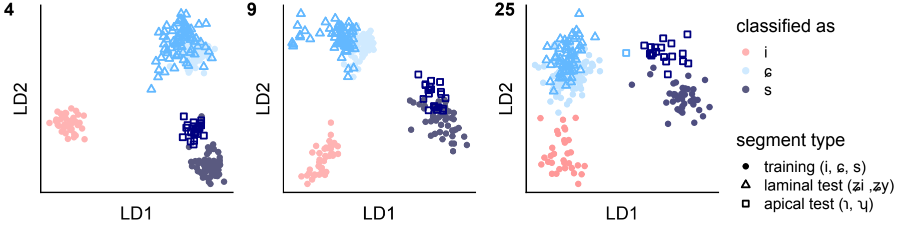
Heterogeneity of three-class LDA solutions

Multiple LDs are **not comparable across participants**: no guarantee that variation encoded in a given LD is between the same two prototypes

- » Contrast 4 versus 9, 25



LD over time, all speakers

What happened in about 1985?