Lingual articulation of the Sūzhōu Chinese labial fricative vowels

Matthew Faytak, **Jennifer Kuo**, and **Shunjie Wang** 王顺杰
faytak@ucla.edu

University of California, Los Angeles

ICPhS 19, Melbourne

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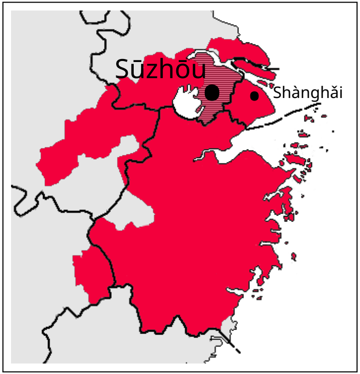
Background

Sūzhōu 苏州 Chinese

A **Wú Chinese** variety, closely related to Shanghainese

» Estimated 2–3 million speakers[1]

» Less well-described compared to some of its neighbors



[1] Yan, 1988; You, 2015; Zhengzhang, 1988.

Labial fricative vowels

Sūzhōu Chinese's vowel system includes both canonical [u] and two **labial "fricative vowels"**[2] (摩擦化元音)

- Vowels with extra supralaryngeal constriction which generates fricative noise and/or dampens formant structure
- **Bilabially compressed** or **labiodental** rather than rounded

More common than one might expect; likely underreported (perceptually similar to [u])

- Chinese dialects, especially Wú, Mandarin[3]
- Tibeto-Burman languages[4]
- Grassfields Bantu and Bantu A languages (Cameroon, Gabon)[5]

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[2] Ling, 2009.

[3] Chen and Gussenhoven, 2015; Yuan, Ling, Shen, and Shi, 2019; Zhu, 2004.

[4] Chirkova, Wang, Chen, Amelot, and Antolík, 2015; Dell, 1981; Edmondson, Esling, and Ziwo, 2017.

[5] Connell, 2007; Faytak, 2017; Medjo Mvé, 1997; Olson and Meynadier, 2015.

Examples from Sūzhōu Chinese

Bilabially compressed [ɯ$^{\beta}$], which must occur after bilabial stops

- Frequently realized with trilling, i.e. [ʙ̩]
- Contrasts with [u]: 补 [pɯ$^{\beta}$] ‘mend’ $\neq$ 播 [pu] ‘broadcast’

Labiodental [ɯ$^{\text{v}}$], which must occur after labiodental fricatives

- Noticeable labiodental frication carries on through vowel
- In complementary distribution with [ɯ$^{\beta}$] (and [u])

[u] [ɯ$^{\beta}$] [ɯ$^{\text{v}}$]

$\rightarrow \rightarrow \rightarrow$ Increasingly small lip aperture $\rightarrow \rightarrow \rightarrow$

Study question

Since labial activity in [ɯ^{β}], [ɯ^{v}] systematically differs from [u], does this condition a systematic difference in **lingual activity**?

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Vowels with simultaneous lingual and labial contributions exhibit **trading relations**, both in regular production and under perturbation[6]

» Inverse relationship between labial and lingual activity

» High back rounded [u] most often investigated, however

[6] Ménard, Perrier, Aubin, Savariaux, and Thibeault, 2008; Perkell, Matthies, Svirsky, and Jordan, 1993; Savariaux, Perrier, and Orliaguet, 1995.

Predictions

From **trading relations**:

Less lingual activity (bunching, backing) during the more heavily lip-constricted vowels [ɯᵝ], [ɯᵛ] compared to [u]

[7] Shadle, Nam, Katsika, Tiede, and Whalen, 2017.
[8] Demolin, 1992; Olson and Meynadier, 2015.

Predictions

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Less lingual activity (bunching, backing) during the more heavily lip-constricted vowels [ɯᵝ], [ɯᵛ] compared to [u]

Aerodynamic properties of consonants similar to [ɯᵝ], [ɯᵛ] make **different predictions** for [ɯᵝ]

» Active lowering of the tongue dorsum during labiodental fricatives[7]: congruent

» Bilabial trills favored near high back vowels such as [u][8]: not congruent

[7] Shadle et al., 2017.

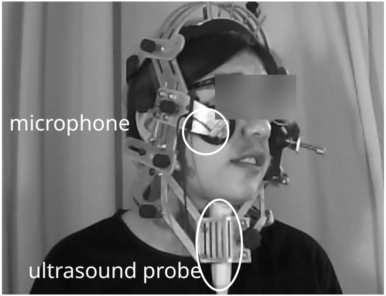
[8] Demolin, 1992; Olson and Meynadier, 2015.

Methods

Location and participants

Lingual ultrasound and **audio** recorded in a quiet room in Gūsū district, Sūzhōu (苏州市姑苏区)

- 15 native Sūzhōu Chinese speakers (13 F), all long-term residents of an urban district of Suzhou[9]
- See appendix for details of ultrasound setup



[9] Gūsū 姑苏区, Hǔqiū 虎丘区, or Wúzhōng 吴中区

Stimuli

Stimuli (after Ling[10]) presented in frame sentence using OpenSesame[11]

Vowel	As in Ling	Stimulus	Gloss
[u]	o	疤 [pu]^{44}	‘scar’
[ɯ$^{\beta}$]	u	播 [pɯ$^{\beta}$]^{44}	‘spread, sow’
[ɯ^{v}]	u	夫 [fɯ^{v}]^{44}	‘husband’
[i]	ı	边 [pi]^{44}	‘side’
[æ]	æ	包 [pæ]^{44}	‘package’

[10] Ling, 2009.

[11] Mathôt, Schreij, and Theeuwes, 2012.

Analysis

Single frame at midpoint of target vowels [u], [ɯ$^{\beta}$], [ɯ$^{\gamma}$] selected; **contours extracted** using EdgeTrak[12]

Separate **SSANOVA** for each speaker's set of frames[13]

» Polar splines re-mapped to cartesian coordinates[14]

» Sanity checking, gross overview of tongue shape and relative position

Discrete Fourier transform of contours also carried out[15]

» Straightforward comparison of **shape properties** of contours across speakers

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[12] Li, Kambhamettu, and Stone, 2005.

[13] Davidson, 2006.

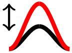
[14] Mielke, 2015.

[15] Dawson, Tiede, and Whalen, 2016.

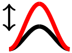
Details: discrete Fourier transform (DFT)

DFT models each tongue surface contour as a combination of sinusoidal **basis functions**

Each coefficient has **two parts** which can be taken to correspond to bunching (height) and frontness differences

- **Real parts**: frontness (**higher** = **more front**) 
- **Imaginary parts**: bunching (**higher** = **more bunched**) 

Coefficient **order**: number of peaks in function

- **First**, imaginary: degree of **simple bunching** 
- **Second**, imaginary: degree of **double bunching** 

Analysis of DFT

To assess differences in tongue contour shape, we submit each of four DFT coefficient-parts to a separate **LMER**

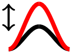
- i.e., first real, first imaginary, second real, second imaginary
- Coefficients of order > 2 do not reflect linguistically important tongue shapes

Model structure:

- coeff.-part $\sim$ vowel $+$ time* $+$ (1 $+$ vowel $+$ time | speaker)

  *time from start of experiment

Predictions in model terms [ɯ$^{\beta}$], [ɯ$^{\text{ʋ}}$] will have **smaller imaginary coefficients** than [u]

- More neutral, less bunched tongue shape
- Coef. 1, imaginary  Coef. 2, imaginary 

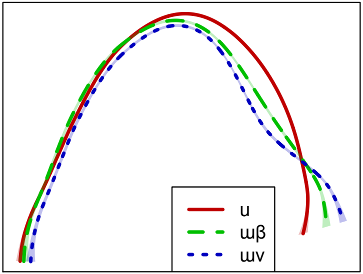
Results

SSANOVA

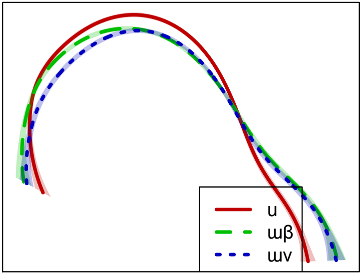
Substantial variation across speakers, but clear patterns in **tongue dorsum height** emerge

» **[u]** generally has a higher tongue dorsum and lower anterodorsum/blade than **[ɯᵝ]** and **[ɯᵛ]**

S03



S07

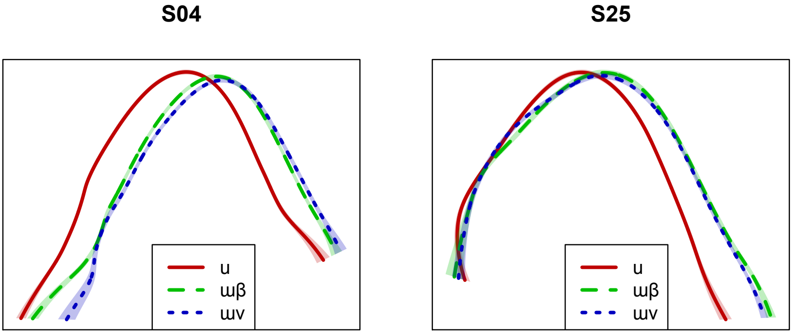


Right is front

SSANOVA

Fronting of [ɯ^{β}], [ɯ^{v}] relative to [u] is also sporadically observed

- Two speakers (S4, S25) produce **[u]** vs. **[ɯ^{β}]**, **[ɯ^{v}]** essentially as a **backness** distinction
- Several others use both strategies simultaneously (e.g. 6)



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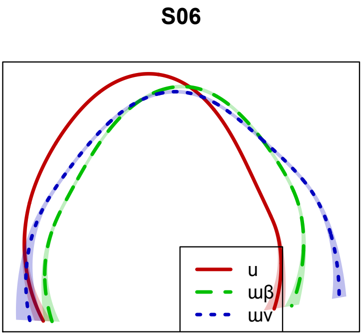

Right is front

DFT models

Effects of **vowel** for both **imaginary parts** reach significance

- First coefficient, imaginary part (p = 0.00025)
  - Substantial effect size (β = -5.9, -3.2 for [ɯ^{v}], [ɯ^{β}])
- Second coefficient, imaginary part (p = 0.03)
  - Smaller effect size (β = -2.9, -1.8 for [ɯ^{v}], [ɯ^{β}])
- Substantial interspeaker variation, in line with SSANOVA: random effects have high SD (1.66–4.38)

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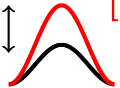
Not significant:

- Effect of **time** for any coefficient-part
- Effect of **vowel** for **real parts**

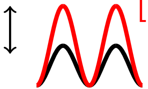
Interpreting DFT model results

The models of DFT coefficients suggest a **more neutral tongue position** for [ɯ^{v}], [ɯ^{β}] compared to [u]

- Lower **first imaginary** coefficient means [ɯ^{v}], [ɯ^{β}] are less bunched (singly) than [u]

or: 
[u] basis fcn.
[ɯ^{v}], [ɯ^{β}] basis fcns.

- Lower **second imaginary** coefficient means [ɯ^{v}, ɯ^{β}] are less doubly-bunched than [u]

or: 
[u] basis fcn.
[ɯ^{v}], [ɯ^{β}] basis fcns.

  - Most likely, extra back-raising for [u] produces slight divot in tongue blade

Discussion

Summary of findings

Sūzhōu Chinese [u] exhibits a **greater back-raising excursion** and thus **higher tongue dorsum position** than [ɯ^{β}] and [ɯ^{v}]

- **Trend toward fronting** of [ɯ^{β}] and [ɯ^{v}] relative to [u] is also visible
- Shown with complementary SSANOVA and DFT analyses

In keeping with known **trading relations** between labial articulation and lingual articulation

- [ɯ^{β}] and [ɯ^{v}] have more consistent and constricted typical labial activity
- Accordingly, the tongue dorsum constriction appears to contribute less to the overall production goal

Aerodynamic considerations

Lingual articulation of [ɯᵛ] may also reflect aerodynamic requirements for **labiodental fricative noise**

- Lowered tongue dorsum ensures airflow is impeded at lips alone[16]
- Congruent with labiodental frication as a **target for production** in [ɯᵛ]

However, tongue dorsum lowering for [ɯᵝ] is at odds with reported characteristics of **bilabial trills**

- Raised tongue dorsum reduces oral cavity volume and makes trilling more likely[17]
- Bilabial trilling in Sūzhōu Chinese [ɯᵝ] could be viewed as a **side effect** of the primary articulatory goal of lip compression

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[16] Shadle et al., 2017.

[17] Demolin, 1992.

谢谢尔笃
Thanks

Contact: faytak@ucla.edu

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Ultrasound details

Device specs

- Telemed EchoB equipped with PV6.5/10/128 Z-3 convex probe
- Probe stabilized using Articulate Instruments headset[18]
- Frame rate $\sim$ 54 Hz

Automatic synchronization of audio and ultrasound signals

- Device's frame strobe signal combined with audio signal using a Scarlett Focusrite 2i2 USB audio interface
- Processed using **ultratils** Python package[19] and custom Python utilities

[18] Scobbie, Wrench, and van der Linden, 2008.

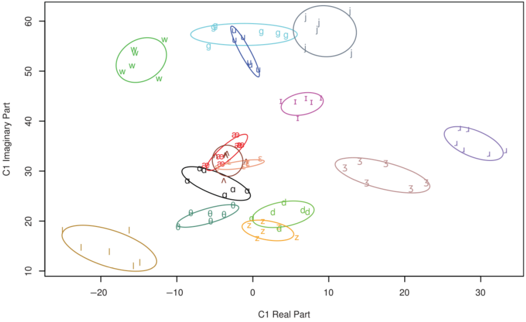
[19] Sprouse and Faytak, 2018.

More DFT details

DFT as implemented in Dawson et al., 2016 is used here

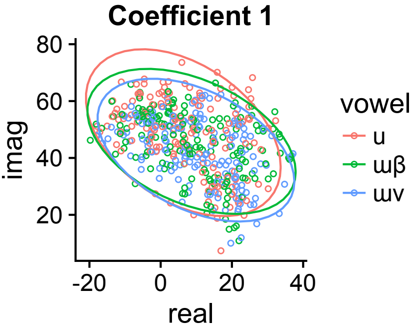
» Gives magnitude of curvature and phase **independent of size, rotation**

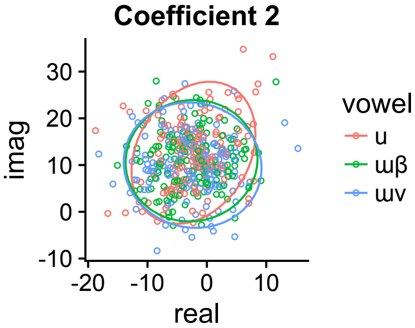
» Has been used to separate tongue contours by degree of bunchedness:



DFT coefficient-parts for all tokens

95% confidence ellipses drawn around each category





DFT models, partial summary

Significant fixed effects; [u] as baseline for “vowel” factor

a. Coefficient 1, imaginary part

	Est.	SE	Rnd. SD	$p(> \chi^2)$
vowel ɯ$^{\beta}$	-3.22	1.16	2.80	$<$**0.001**
ɯ^{v}	-5.90	1.45	4.38	
time	-0.019	0.091	0.28	0.84

b. Coefficient 2, imaginary part

	Est.	SE	Rnd. SD	$p(> \chi^2)$
vowel ɯ$^{\beta}$	-1.82	0.76	1.66	**0.03**
ɯ^{v}	-2.92	1.19	3.94	
time	0.052	0.043	0.092	0.23

DFT models, effects plots

With [u] as baseline, small to moderate effects for imaginary parts