

ACOUSTIC AMBIGUITY LEADS TO ARTICULATORY RE-ANALYSIS: AFFRICATE PALATALIZATION IN HONG KONG CANTONESE

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INTRODUCTION

Phonemically, Hong Kong Cantonese (HKC) has three sibilants: /s, ts, ts^h/

Studies suggest HKC affricates /ts/ and /ts^h/ (but not the fricative /s/) are becoming palatalized in certain linguistic environments (Yu 2016, Chan 2007, Liu 2010, Lan 2017)

Sound change in progress?

INTRODUCTION

Old system:

- All three sibilants have only one allophone [ts, ts^h, s]

New system:

- /ts/ and /ts^h/ have two allophones while/s/ has one:
  - /ts, ts^h/: Alveolar [ts, ts^h] vs. post-alveolar [tʃ, $tʃ^h$]
  - /s/: only alveolar [s]

What is the **conditioning environment** for palatalization?

INTRODUCTION

Conditioning environment?

- Before **rounded** vowels: /ts, ts^h/ > [tʃ, $tʃ^h$] / _ [+round] (Chan 2007, Liu 2010)
- Before **back** vowels: /ts, ts^h/ > [tʃ, $tʃ^h$] / _ [+back] (Lan 2017)

However, not supported by any acoustic or articulatory data

- All previous studies relied on impressionistic judgement
- Contrary findings in articulatory study: no difference in place of articulation across different vowel contexts, always alveolar (Lee & Zee 2010)

OBJECTIVES

- Investigate **affricate palatalization**, an ongoing sound change in HKC through **acoustic** and **articulatory** analysis
- Research questions:
  - Is affricate palatalization indeed an ongoing sound change in HKC?
  - What is the conditioning environment of the affricate allophones?
  - How are the allophones realized in terms of their articulation?
  - What are the possible phonetic motivations of such a change?

METHODOLOGY

1. Audio recording
   - Acoustic analysis
   - Does the acoustics of affricates differ by **linguistic environment** and by **age and gender** of speakers?
   - Examine whether there is a sound change



METHODOLOGY

2. Ultrasound tongue imaging
   - Measure tongue position
   - Examine lingual articulation of affricate allophones
3. Video recording
   - Measure lip movements
   - Examine labial articulation of affricate allophones



METHODOLOGY

Materials:

- 126 disyllabic words that start with sibilants: 42 /s/, 45 /ts/, 39 /ts^{h}/
- All attested **sibilant** + monophthong CV combinations tested
  - Vowels: [aː, ɐ, ɛː, œː, ɵ, iː, ɪ, yː, ʊ, ɔː]
  - Coda consonants: /#, t, n, k, ŋ/
  - Tone: 1 /˥/ (high level) or 3 (mid level) /˧/
- 44 filler items to obscure aim of study

METHODOLOGY

Participants:

- 12 native speakers of HKC, born between 1956-2001
- No previous history of speech or hearing impairments

Four groups by age and gender:

- 6 older speakers (born 1956-1962)
- 6 younger speakers (born 1997-2001)
- 6 female, 6 male

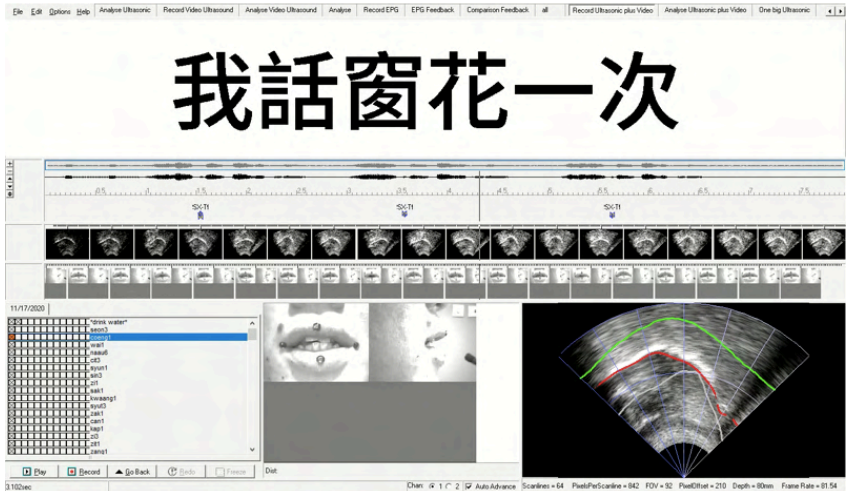
Age group	Female	Male
Older	3	3
Younger	3	3

METHODOLOGY

Procedure:

- Data collected at the University of Hong Kong
- Words embedded in carrier phrase [ŋɔ:˩˧ wa:˧] ___ [jɐt̚ tsʰi:˧] "I say ___ once"
- Words presented to each participant in unique randomized order
- Each word presented once, repeated three times
- 378 target tokens per participant, total of 4,536 tokens across all participants prior to exclusion of mispronounced words etc.

METHODOLOGY



Recording:

- Simultaneous audio, ultrasound, and video recording
- Ultrasound: High speed (84 fps) SonoSpeech Micro ultrasound system, 20mm radius probe
- Audio: Recorded at 22kHz/16-bit with Sennheiser MKE2-P-C Microphone
- Video: coronal and sagittal view of speaker's lips recorded at 60 fps
- Synchronized in Articulate Assistant Advanced (AAA) (Articulate Instruments Ltd. 2012)

METHODOLOGY

Audio: 20ms Hamming window, centered at the 75% point between onset of sibilant and end of frication, high-pass filtered at 500Hz in Praat (Boersma & Weenink 2021)

Centre of gravity (COG) measured: indicator of sibilant place of articulation (Jongman et al. 2000)

- ↑ Higher value: more fronted alveolar place, lip spreading
- ↓ Lower value: more backed post-alveolar place, lip rounding

METHODOLOGY

- Mixed-effect regression model in R with *lmerTest* (Kuznetsova et al. 2020)
- Fixed effects: following vowel (roundedness, height, backness), type of sibilant, coda, tone, duration, age group, gender
  - Random effects: speaker, word, repetition
  - *M* ~ type * roundedness * age group * gender + height + backness + tone + coda + duration + (1 | speaker) + (1 | word) + (1 | repetition)

RESULTS

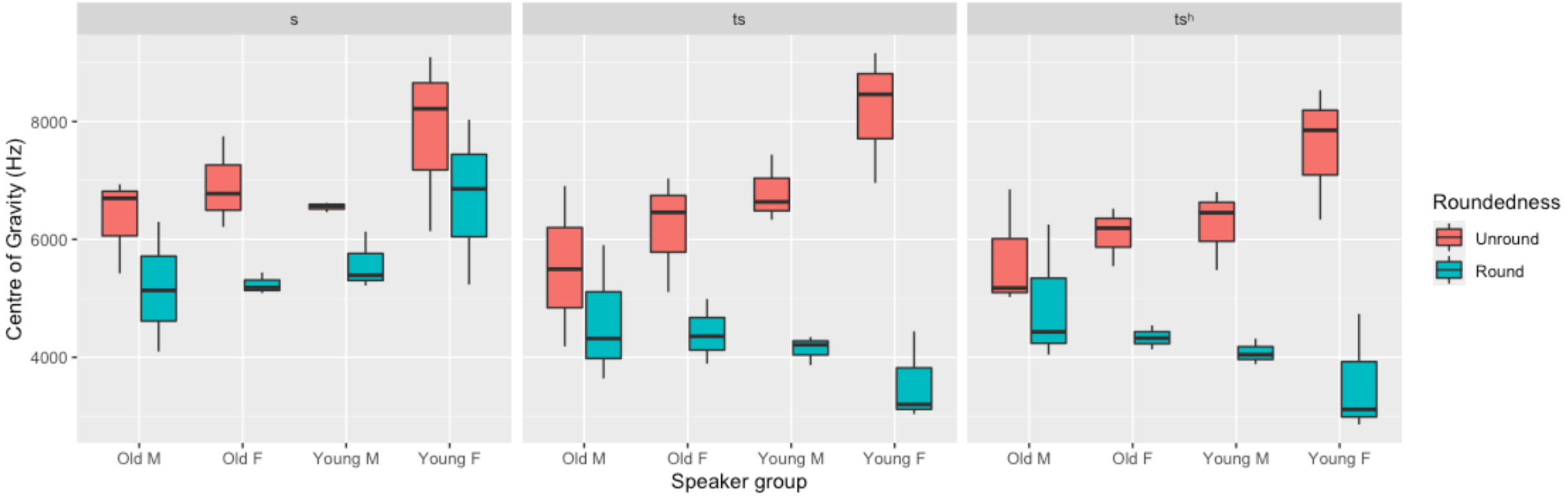


Figure 1. COG (in Hz) of HKC sibilants by age group and gender

RESULTS

Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	
roundedness (round)	-1362.8225	106.7232	371.0189	-12.77	**< 2E-16**	***
height (low)	-435.5149	83.1643	104.9933	-5.237	**8.45E-07**	***
height (mid)	11.155	48.3761	107.7861	0.231	0.818072	
backness (front)	-188.7609	60.667	106.9728	-3.111	**0.002388**	**

Effect of following vowel:

- Significant effect of vowel roundedness, **rounded** vowels **lower** COG
- Significant effect of vowel height and backness, low vowels and front vowels lower COG

RESULTS

Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	
round * age (young) * /ts/	-1897.3421	166.2484	4240.1867	-11.413	**< 2E-16**	***
* /ts^h/	-1515.3525	172.7982	4239.9851	-8.769	**< 2E-16**	***
* gender (F) * /ts/	-373.8218	166.634	4243.1425	-2.243	**2.49E-02**	*
* /ts^h/	-465.1248	173.0502	4241.8786	-2.688	**0.00722**	**
* age (young) * gender (F) * /ts/	-1432.938	234.6275	4244.6985	-6.107	**1.10E-09**	***
*/ts^h/	-1260.5438	244.2515	4245.9021	-5.161	**2.57E-07**	***

Significant interaction between type of sibilant, roundedness and age/gender:

- COG of /ts, ts^h/ **lower** before rounded vowels for **younger** speakers, **female** speakers, **younger female** speakers

RESULTS

Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	
round * age (young)	135.7872	119.8423	4240.6129	1.133	0.257258	
* gender (F)	-526.562	120.584	4245.8832	-4.367	**1.29E-05**	***
* age (young) * gender (F)	395.282	169.7052	4251.4845	2.329	**0.019894**	*

Significant interaction between roundedness of following vowel and gender

- COG of sibilants **lower** for **female** speakers before **rounded** vowels

Significant interaction between roundedness, age and gender

- COG of sibilants **higher** for **younger female** speakers before **rounded** vowels

RESULTS

Fixed effects:	Estimate	Std. Error	df	t value	Pr(>|t|)	
round * /ts/	244.8829	137.1287	519.1839	1.786	0.074717	
* /ts^{h}/	351.8602	141.9413	509.4451	2.479	**0.013501**	*

- Significant interaction between type of sibilant and roundedness of following vowel
- COG of /ts^{h}/ **higher** when followed by **rounded** vowels

DISCUSSION

- **Roundedness** (not backness or height) of the following vowel conditions acoustics of sibilants
  - Consistent with Chan (2007) and Liu (2010)
- In general, sibilants more palatalized/labialized before **rounded** vowels
  - Palatalization, or co-articulatory effect of vowel rounding?

DISCUSSION

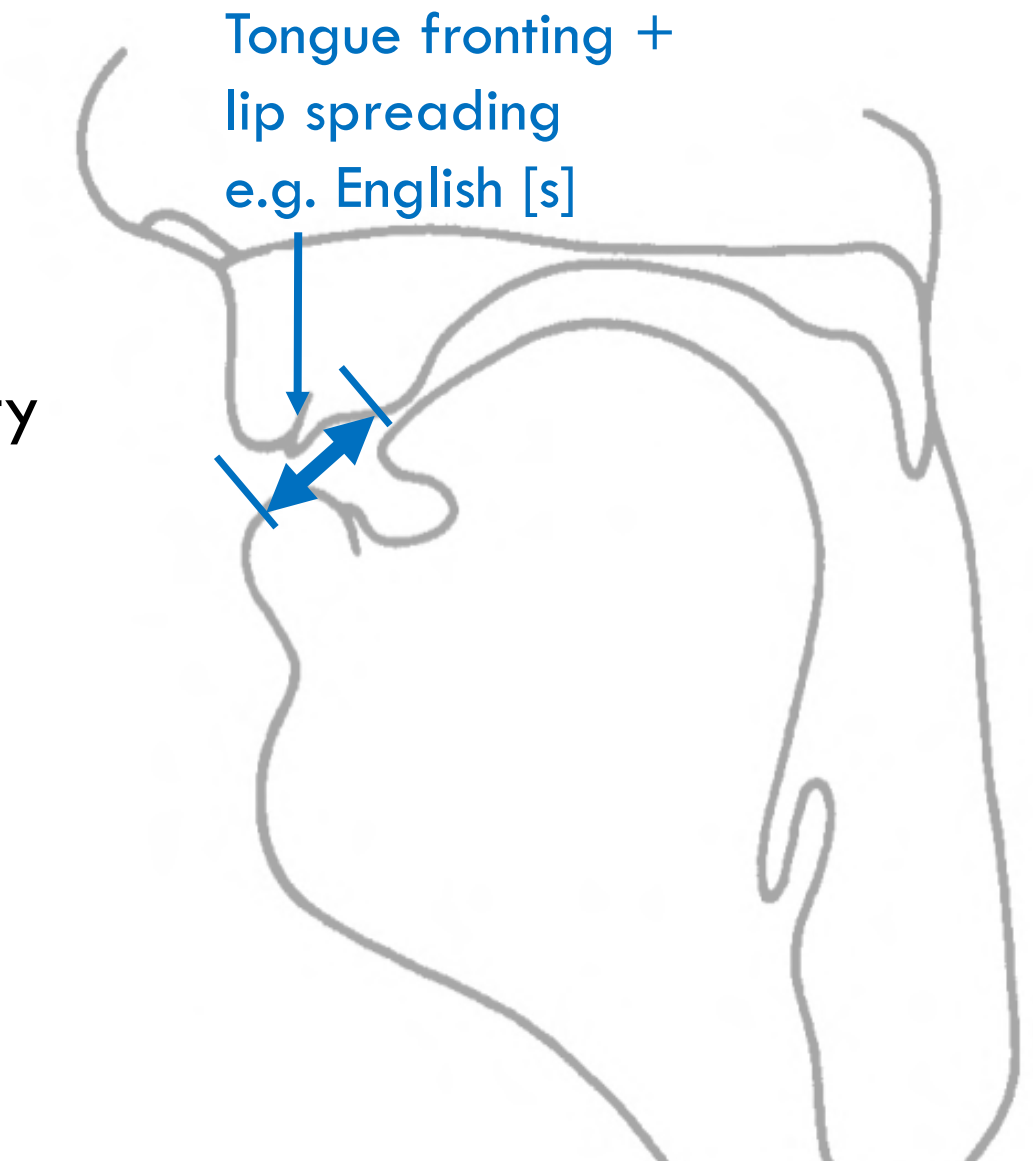
- **Affricates** /ts, ts^h/ more palatalized/labialized than fricative /s/ before **rounded** vowels for **younger** and **female** speakers
- Younger females tend to be innovative speakers. Their speech pattern may indicate direction of sound change (Labov 1990)
  - Consistent with Chan (2007) and Liu (2010)
  - Change from co-articulatory effect to phonologization of allophones?
  - Palatalization or labialization?

DISCUSSION

Differences in COG can be result of any gestures that changes length of front cavity of vocal tract

Both tongue and lip configuration change length of front cavity:

- **Tongue fronting** or **lip spreading**, front cavity shortens, **higher** COG



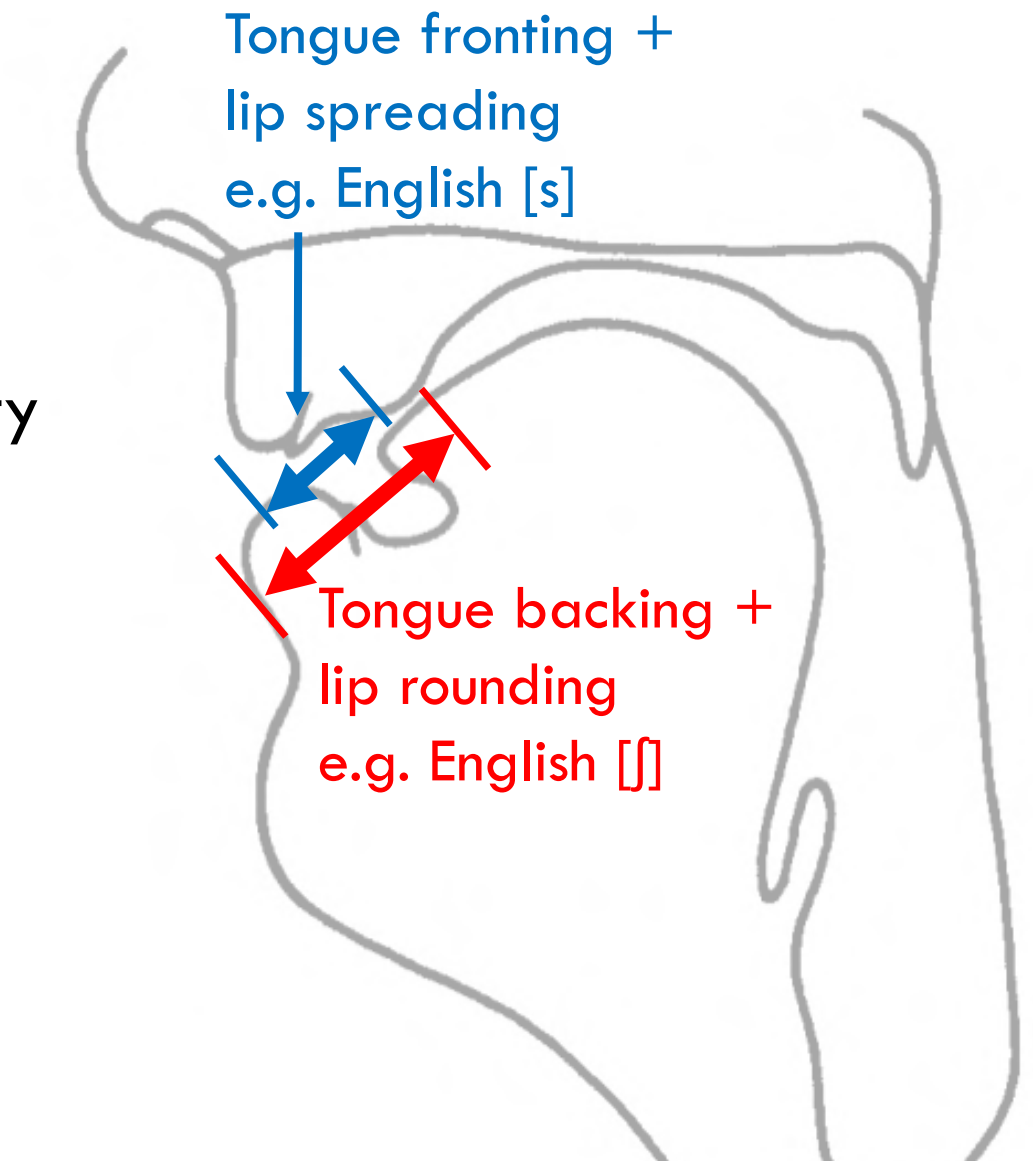
Figures adapted from Ladefoged & Johnson (2010)

DISCUSSION

Differences in COG can be result of any gestures that changes length of front cavity of vocal tract

Both tongue and lip configuration change length of front cavity:

- **Tongue fronting** or **lip spreading**, front cavity shortens, **higher** COG
- **Tongue backing** or **lip rounding**, front cavity lengthens, **lower** COG



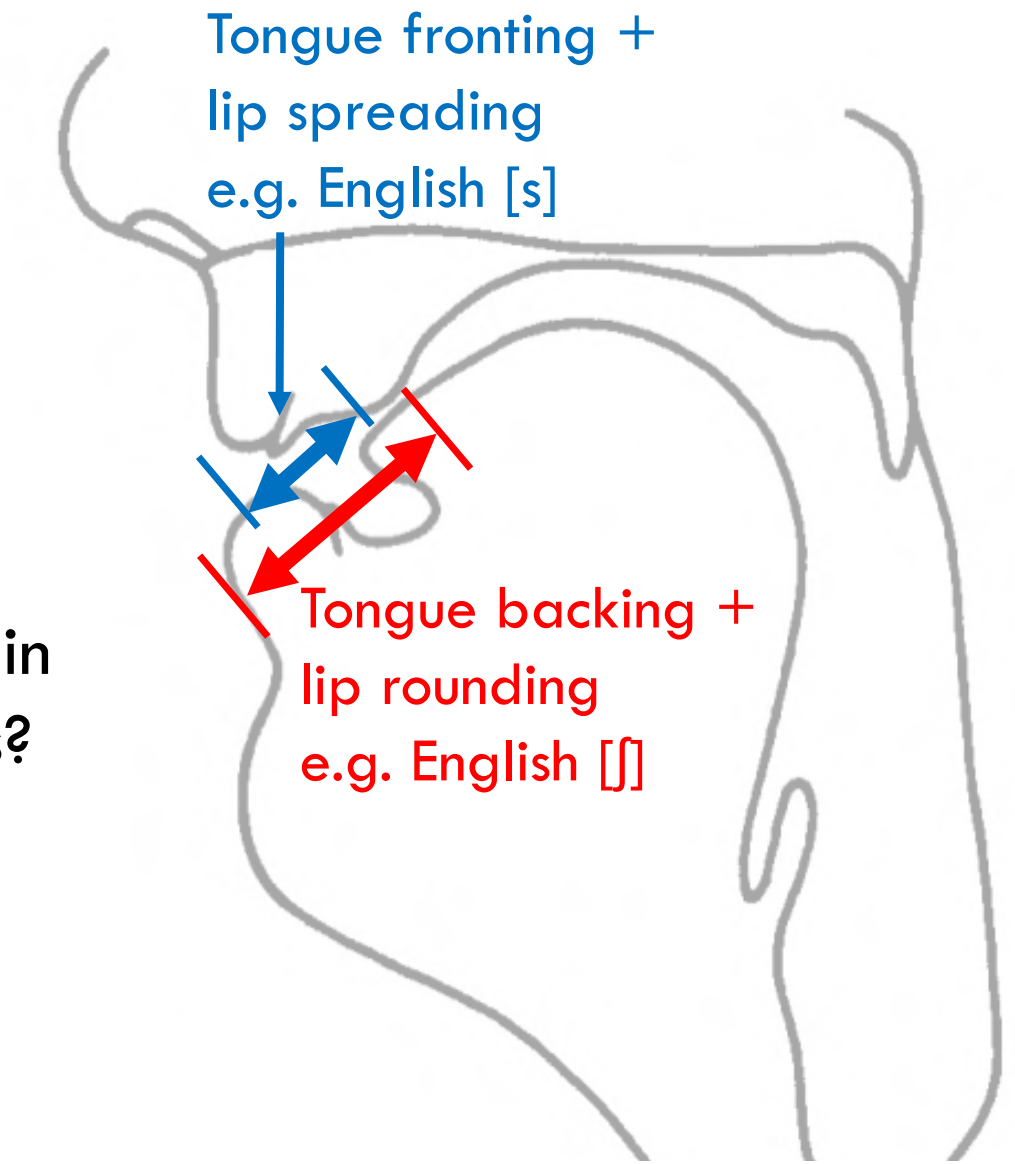
Figures adapted from Ladefoged & Johnson (2010)

DISCUSSION

Acoustic analysis alone **cannot** disambiguate effect of tongue and lip in the articulation of sibilants

What causes age and gender differences in sibilant articulation before rounded vowels?

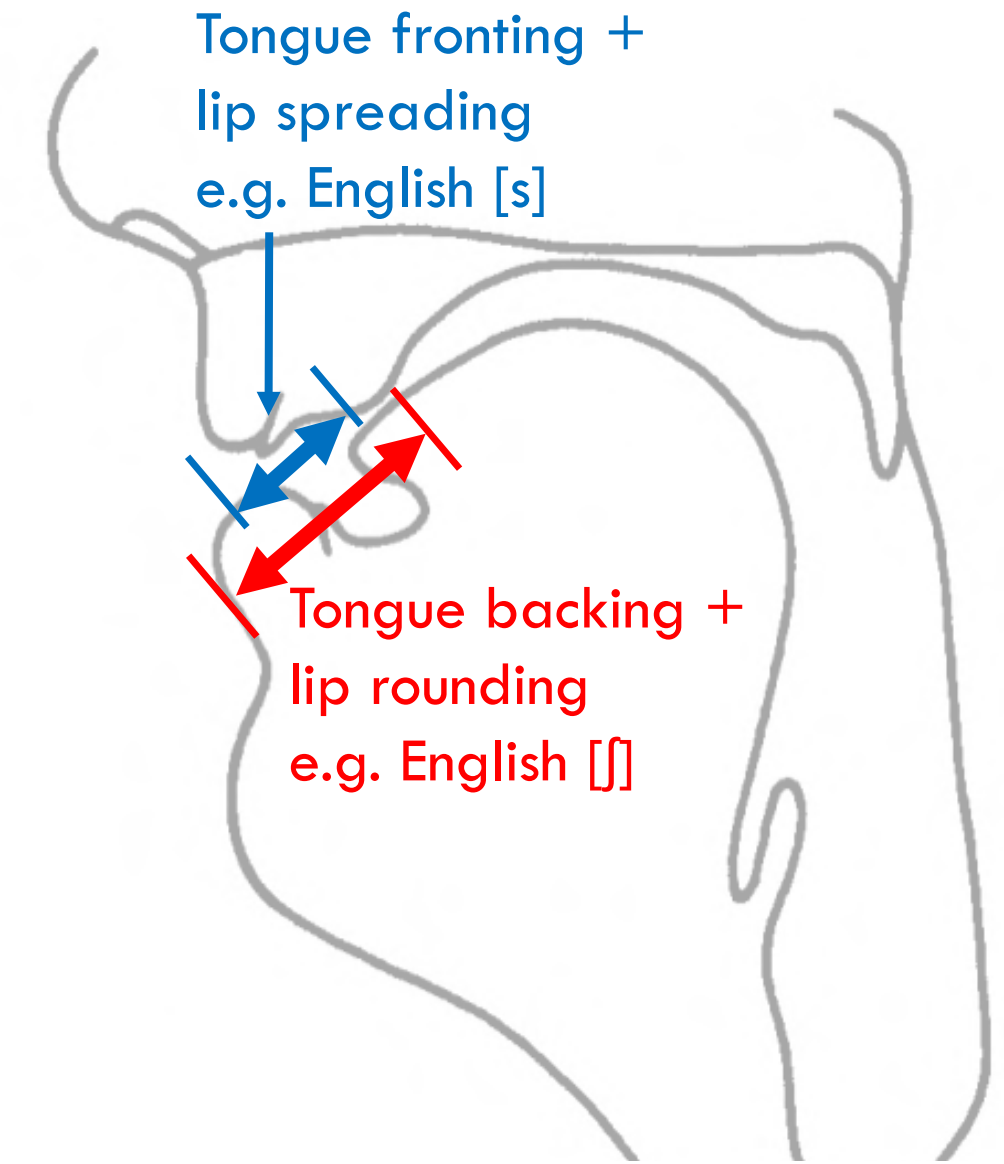
Articulatory measurement with **ultrasound tongue imaging** and **lip video** necessary



Figures adapted from Ladefoged & Johnson (2010)

DISCUSSION

- Lip rounding only?
  - Hypothesis 1: co-articulatory effect, anticipatory lip rounding
  - Hypothesis 2: phonologization of labialized allophones [ts^{w}, ts^{hw}]
- Tongue backing?
  - Hypothesis 3: phonologization of post-alveolar allophones [tʃ, tʃ^{h}]



Figures adapted from Ladefoged & Johnson (2010)

METHODOLOGY

Lip measurement:

Beads affixed to upper lip, lower lip and two corners of the mouth to track movement of lips

Every other video frames from onset of sibilant to mid-point of following vowel extracted and measured

33.3ms interval in between frames

29,969 frames entered analysis in total



METHODOLOGY

Measure of lip protrusion: Horizontal distance between left edge of video frame and upper lip

- Longer distance: more protruded (round)
- Shorter distance: less protruded (unround)

Movement of upper lip independent of that of other articulators, better reflects labial gestures (Farnetani 1999)

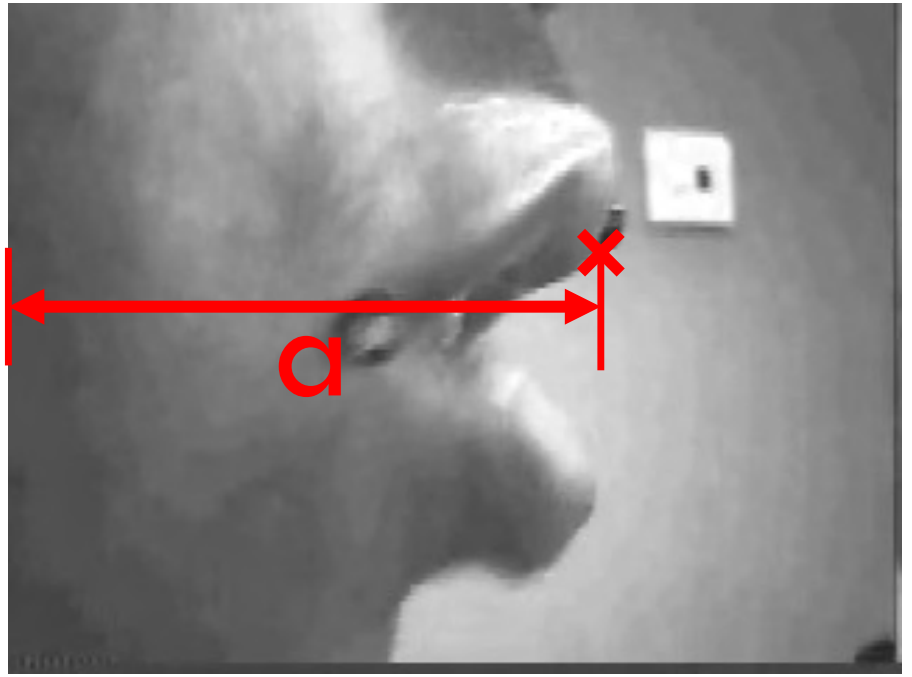


Figure 2. Articulatory measurements for lip protrusion. The degree of protrusion is defined as (a)

METHODOLOGY

Horizontal distance of upper lip z-score normalized by speaker

Generalized additive mixed modelling (GAMMs) in R

Factors A, B, C

RESULTS

Significant difference in lip movement for sibilants before rounded vs. sibilants before unrounded vowels

- More protruded for rounded vowels than unrounded vowels

No difference in timing or degree of lip protrusion across three sibilants

- For sibilants followed by unrounded vowels, lip remains retracted
- For sibilants followed by round vowels, lip protrusion maximum aligned with onset of vowel for all sibilants

RESULTS

No diachronic change in timing or magnitude of lip rounding gesture

Thus, results do not support hypothesis 2

- No evidence for phonologization of labialized allophones [ts^{w}, ts^{hw}]
- Rounding remains the result of anticipatory lip rounding before round vowels

METHODOLOGY

Ultrasound tongue imaging:

All ultrasound frames from onset of sibilant to end of frication extracted and measured

11.9ms interval in between frames

55,732 frames entered analysis in total

Tongue spline of each speaker rotated bas on occlusal plane and distance from probe z-score normalized

Generalized additive mixed modelling (GAMMs) in R

Factors A, B, C

RESULTS

Speaker 9 (**Older male**):

- **Same** tongue position before rounded vs. unrounded vowels for all three sibilants
- **Different** tongue positions for affricates and fricative
- /s/ more **fronted,** /ts, ts^h/ more **backed**

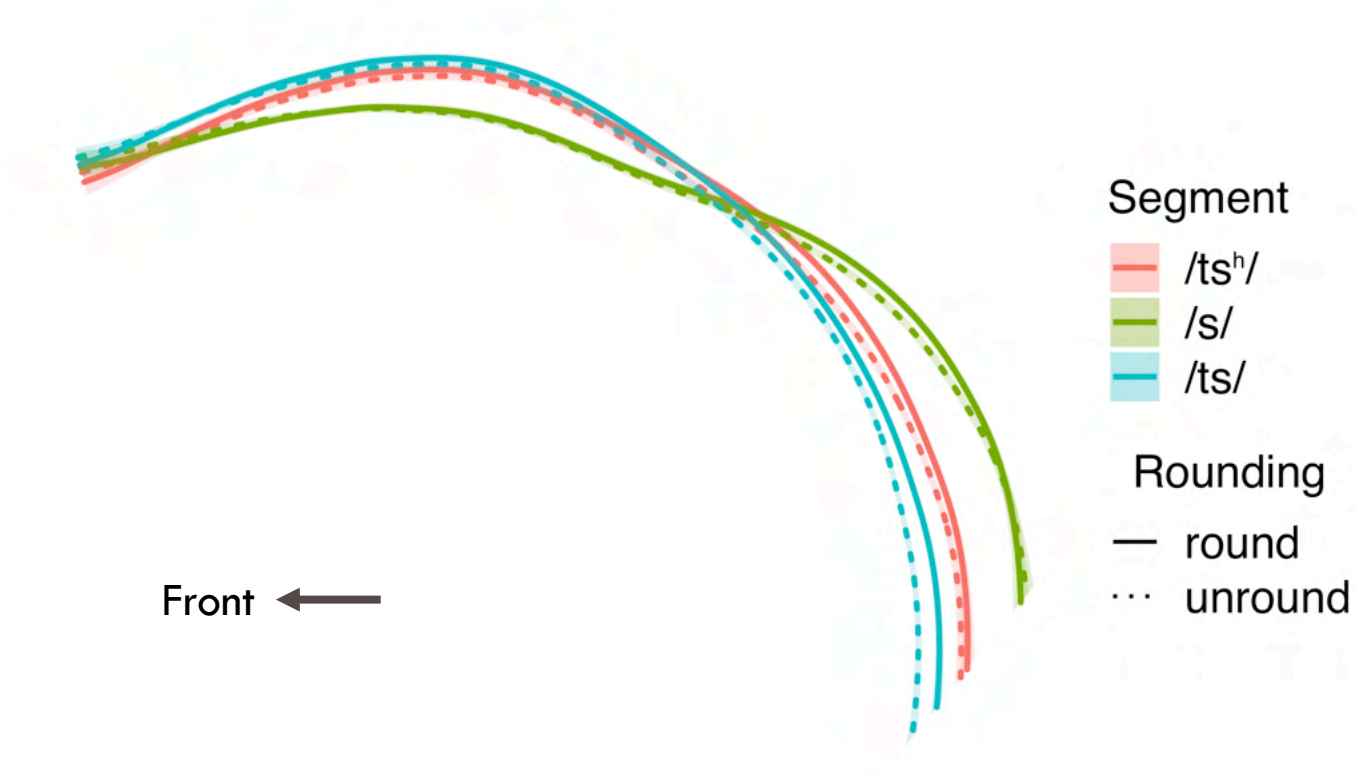


Figure 2. Polar SSANOVA tongue contours of sibilants by rounding for speaker 9 (Older male)

RESULTS

Speaker 5 (**Younger female**):

- **Different** tongue positions before rounded vs. unrounded vowels for /ts, ts^h/
- **Fronted** before **unrounded** vowels
- **Backed** before **rounded** vowels

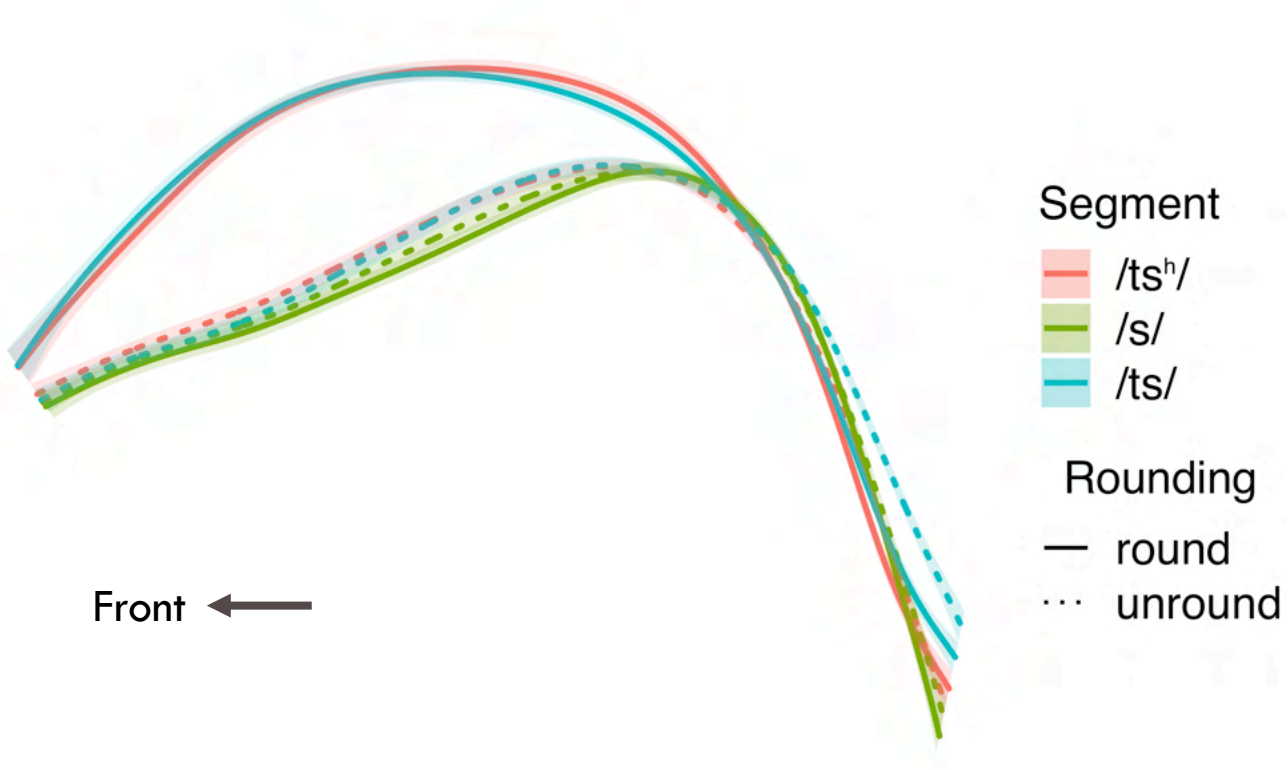


Figure 5. Polar SSANOVA tongue contours of sibilants by rounding for speaker 5 (Younger female)

RESULTS

Speaker 5 (**Younger female**):

- **Same** tongue positions before rounded vs. unrounded vowels for /s/
- **Same** tongue position for affricates before unrounded vowel and fricative

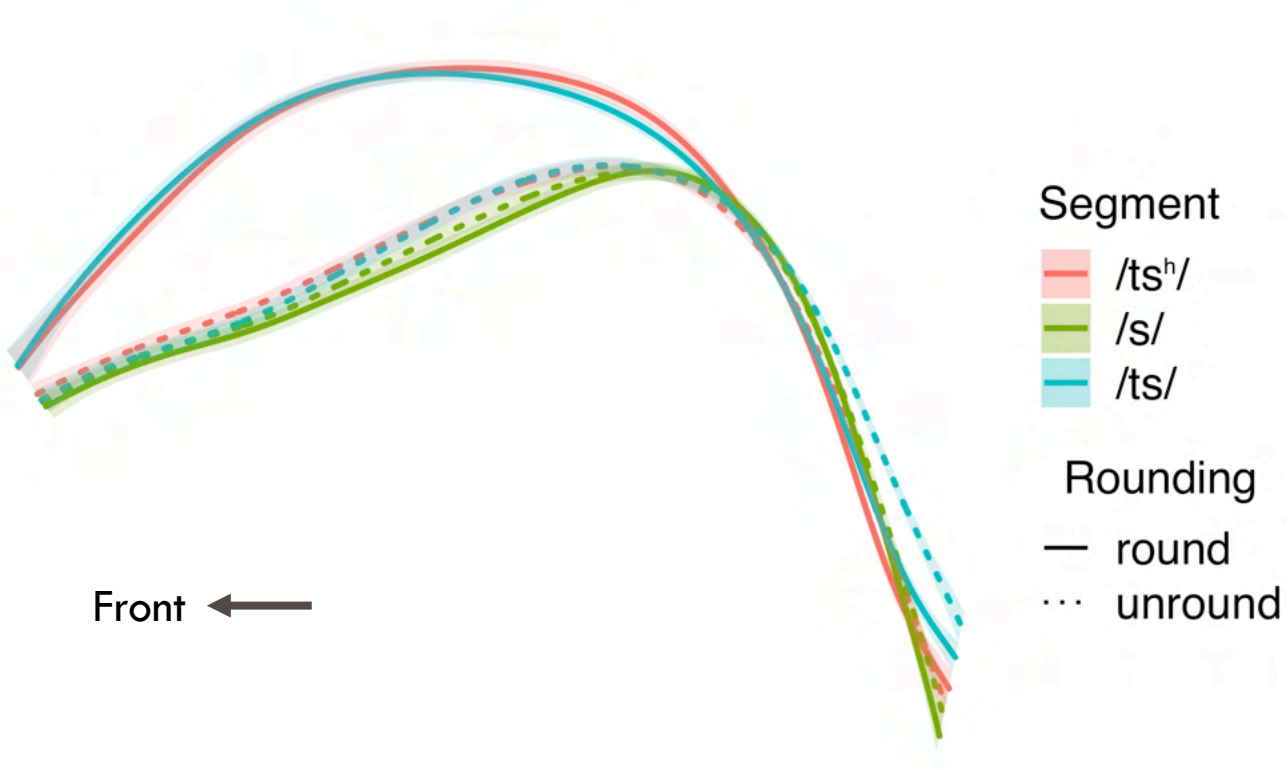


Figure 5. Polar SSANOVA tongue contours of sibilants by rounding for speaker 5 (Younger female)

RESULTS

Affricates /ts, ts^h/ vary in tongue position by roundedness of following vowel among **younger** speakers, consistent with acoustic measurements

Before unrounded vowels: alveolar [ts, ts^h]

Before rounded vowels: (palatalized) post-alveolar [tʃ, $tʃ^h$]

Older speakers: same tongue position for affricates regardless of roundedness of following vowel

Gender: female speakers > male speakers

RESULTS

No palatalization of fricative /s/

- For all speakers, tongue position of /s/ remains the **same** regardless of roundedness of following vowel
- Consistent with Yu (2016)

DISCUSSION

Results of both **acoustic** and **articulatory** analyses support the hypothesis of affricate allophone phonologization in HKC

Conservative system: /ts, ts^h/ as [ts, ts^h] in all contexts

Innovative system: /ts, ts^h/ > [tʃ, $tʃ^h$] / _ [+round]

DISCUSSION

Is affricate allophonic restructuring induced by **language contact**?

Liu (2010) and Lan (2017): Influence of English

- Onset of change coincide with the period when Cantonese-English bilingualism became widespread in HK (late 20th century)
- The only phonemic affricates in English are post-alveolar /tʃ, dʒ/

DISCUSSION

Yet, does not explain why palatalization only occurs **before rounded vowels** but not in other environments

- English /tʃ, dʒ/ post-alveolar in all linguistic environments
- e.g. cheese vs. choose, check vs. chalk
- Phonetic motivation for restructuring of affricate allophonic system?

DISCUSSION

Lip rounding and tongue backing share similar acoustic effect

- Both lower spectral peak and COG

- Younger speakers reinterpret lowering of COG from anticipatory lip rounding as tongue backing (palatalization)

- Hypo-correction: accentuate articulatory difference between affricates before rounded vs. unrounded vowels

- Palatalization became feature of affricates, two allophones formed

DISCUSSION

Why palatalization targets **affricates only** but not fricative?

- Under **articulatory phonology**-style approach (Browman & Goldstein 1989), affricates and fricatives might be affected by vowel co-articulation to a different extent

DISCUSSION

Frication phase of affricates shorter than that of fricatives, more gestural overlap with following vowel

Anticipatory lip rounding affects a greater proportion of frication for affricates vs. fricatives

Thus, precondition for sound change more pronounced for affricates

DISCUSSION

Supported by our acoustic and articulatory data

Timing and degree of anticipatory lip rounding do not differ by type of sibilant

However, the frication portion of /s/ much longer than that of /ts, ts^h/

Hence, listeners may recover information on place of articulation from first half of /s/ but not from /ts, ts^h/



THANK YOU!

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