Ultrasound as a tool for language documentation: Production of the labiocoronal fricative in Setswana

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Overview

- The labio-coronal fricative [ɸ͡ʃ] is reported to occur in Setswana (Cole, 1955; Tlale, 2005), contra Ladefoged & Maddieson (1996).
- We investigate the production of labio-coronal fricatives in two dialects of Setswana: **Sengwato** (spoken in Shoshong) and **Sekgatla** (spoken in Oodi).
- Instrumental phonetic data from fieldwork in Botswana: Ultrasound, video, and audio.
- The labio-coronal fricative is best analyzed as the labialized counterpart of the palato-alveolar fricative, not as a sequence or as double articulation.

Language Background

Setswana is a Southern Bantu language in the Sotho-Tswana group (S30):

- Spoken by ~4.5 million speakers in Botswana, South Africa, and Zimbabwe (Simons & Fennig, 2017).
- Most widely-spoken language in Botswana; predominant language used in education and media (Zsiga & Boyer, 2017).

Language Background

	bilabial	dental/ alveolar	(alveo-) palatal	velar	glottal	labio-coronal
stop	p^h, p, b	t^h, t, (d) t^{hw}, t^w		k^h, k k^{hw}, k^w		
fricative	ɸ	s, s^w	ʃ	x, x^w	h	$\widehat{ɸʃ}$
affricate		$\widehat{ts^h}$, $\widehat{ts}$ $\widehat{ts^{hw}}$, $\widehat{ts^w}$	$\widehat{tʃ^h}$, $\widehat{tʃ}$, $\widehat{dʒ}$	$\widehat{kx^h}$, $\widehat{kx^{hw}}$		$\widehat{pʃ^h}$, $\widehat{pʃ}$, $\widehat{bʒ}$
nasal	m	n, n^w	ɲ, $ɲ^w$	ŋ, $ŋ^w$		
approx.	(ß)	r, l				
glide	w		j			
click		ŋ|	ŋ‖			

Table 1: Consonant inventory of Setswana, Sengwato dialect (Zsiga & Boyer, 2017).

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fricative	ɸ	s, s^w	ʃ	x, x^w	h	$\widehat{\phi\int}$
affricate		$\widehat{ts}^h$, $\widehat{ts}$ $\widehat{ts}^{hw}$, $\widehat{ts}^w$	$\widehat{t\int}^h$, $\widehat{t\int}$, $\widehat{d\text{ʒ}}$	$\widehat{kx}^h$, $\widehat{kx}^{hw}$		$\widehat{p\int}^h$, $\widehat{p\int}$, $\widehat{b\text{ʒ}}$
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Language Background

Setswana exhibits contrastively round alveolars and velars (Tlale, 2005):

(1) a. [tʰaɲa] 'wake up'
b. [tʰʷaɲa] 'crackle'

(2) a. [t͡sala] 'friend'
b. [t͡sʷala] 'dress' (v.)

(3) a. [kala] 'tree branch'
b. [kʷala] 'write'

(4) a. [ak͡xʰa] 'dangle'
b. [ak͡xʰʷa] 'be dangled'

And a round palatal nasal:

(5) [ɲʷaba] 'a riddle'

Language Background

Labio-coronal fricatives and affricates reported for some dialects of Setswana (Cole, 1955; Tlale, 2005):

(6)
a. [ma$\widehat{\phi\int}$i] 'milk'
b. [$\widehat{\phi\int}$a] 'burn'
c. [m$\widehat{p\int}$a] 'dog'
d. [$\widehat{b\text{ʒ}}$ala] 'sow (v.)'

- Found in two dialects, Sengwato and Sekgatla, and in a neighboring language, Sebirwa (Chebanne, 2000).
- In other dialects, the labio-coronals are realized as simple alveopalatals: [maʃi] 'milk', [n$\widehat{t\int}$a] 'dog'.

Language Background

The labio-coronals derive historically from Proto-Bantu **pi*, **pu*, **bi*, and **bu* sequences:

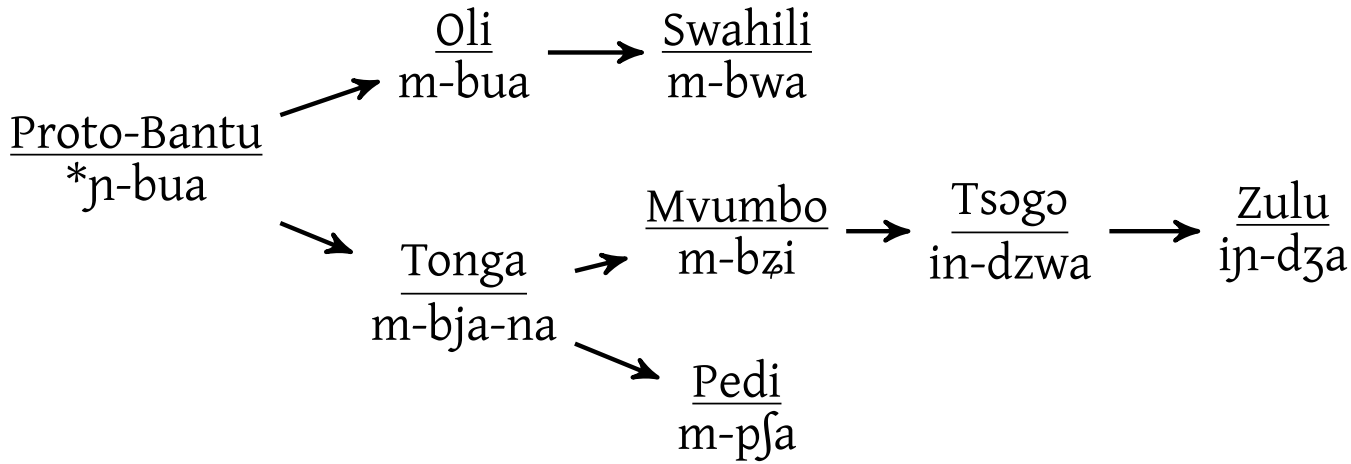


Figure 1: Reflexes of Proto-Bantu *ɲ-bua 'dog'. Adapted from Ohala 1978.

Language Background

Modern Setswana exhibits alternations between labials and palatals in certain morphophonological contexts:

(7) Palatalization of labials in the diminutive (Cole, 1955):

a. /tɬʰapi-ana/	→	[tɬʰatʃʷana]	‘small fish’
b. /tsʰɛpʰɛ-ana/	→	[tsʰɛtʃʰʷana]	‘small springbok’
c. /mʊχʊbɪ-ana/	→	[mʊχʊdʒʷana]	‘small pan’
d. /mʊraɸɪ-ana/	→	[mʊratʃʰʷana]	‘small nation’

Language Background

Bateman (2007, 2010): The change from labial to palatal occurred as a series of changes (telescoping):

(8) Stages of labial palatalization in the causative:

-lap- + ja	→	-lapja	→	-lapʃa	→	-laptʃʷa	→	[-latʃʷa]	'make sb. tired'
-leoɸ- + ja	→	-leoɸja	→	-leoɸʃa	→	-leɸtʃʷa	→	[-leotʃʷa]	'make sb. sin'

The labio-coronal fricative is a more conservative form of the fully palatalized fricatives and affricates observed in other dialects of Setswana.

Doubly articulated fricatives?

Ladefoged & Maddieson (1996): doubly articulated fricatives are perceptually and articulatorily problematic.

- Insufficient airflow to generate frication at two places of articulation.
- One source of noise would overwhelm the other.

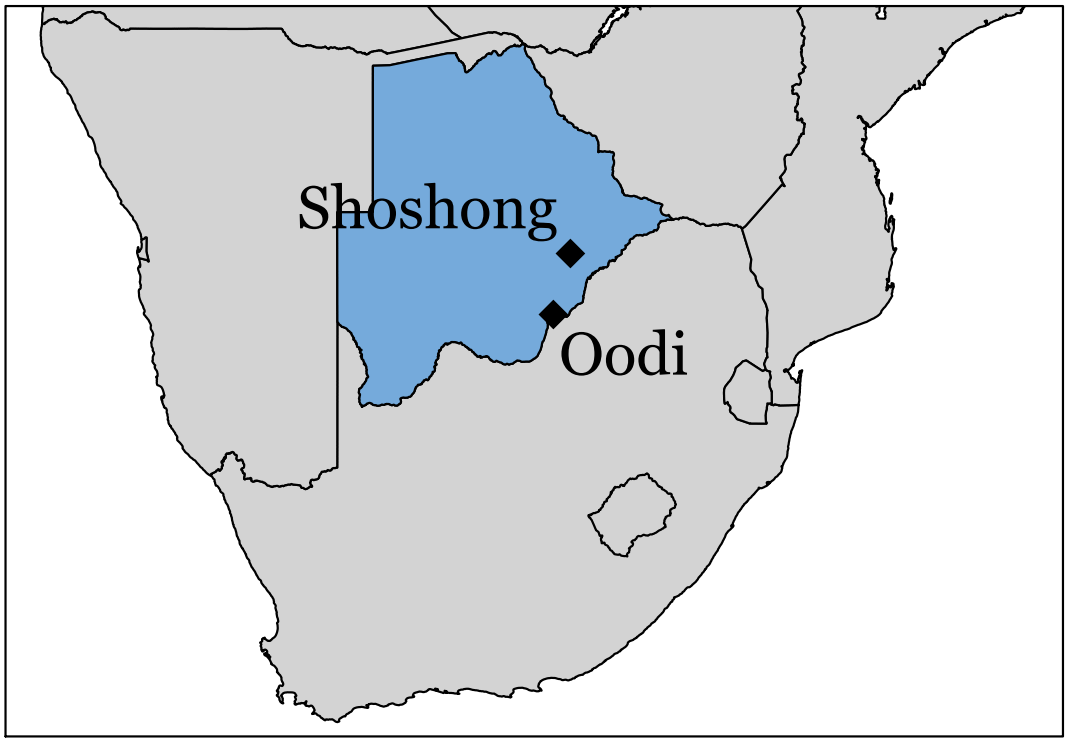
Reported cases can be analyzed as sequences or lack true double frication:

- Sepedi: [fs] sequenced like English *off**s**et*
- Swedish: [ʃ͡ʃ] exhibits wide range of variation, not clear that it actually exhibits double frication

Research Questions

- Which of the following analyses best characterizes the labio-coronal fricative of Setswana:
  - Articulatory sequence ([ɸ + ʃ])
  - Complex secondary articulation ([ɸ^{j}] or [ʃ^{w}])
  - True double articulation ([$\widehat{\text{ɸʃ}}$])
- What is the relationship of the labio-coronal fricative to whistled fricatives found in other Southern Bantu languages (Shosted, 2006, 2011)?

Participants



- Five speakers (three women) of **Sengwato**, spoken in Shoshong.
- Four speakers (two men) of **Sekgatla**, spoken in Oodi.

Methods: Recording

- Three repetitions of words containing [ɸ/h, s, s^w, ʃ, $\widehat{ɸʃ}$, x], in word-initial position before the vowels [a] and [e].
- Simultaneous audio, ultrasound, and video recording in quiet room in participant or neighbor's home.
- Acoustic data recorded with Marantz PMD660 solid state recorder and Sennheiser headset condenser microphone.
- Video data recorded with a Sony camcorder at 30 fps.
    - Lip configuration measured by calculating vertical and horizontal aperture dimensions.

Methods: Ultrasound

- Ultrasound: SonoSite M-Turbo with C60x 5–2 MHz transducer at depth of 9.2 or 11 cm.
- 30 fps NTSC output synchronized with audio using Elgato Video Capture device.
- Head and probe movement mitigated with headrest and articulated arm mounted to table (cf. Stone et al. 1988.)
- Tongue contours extracted at point of maximum constriction and traced in EdgeTrak (Li et al., 2005).
- Modeled with polar smoothing spline ANOVA (Gu, 2002; Davidson, 2006; Mielke, 2015) in R.

Methods: Ultrasound

Figure 2: Ultrasound recording setup

Acoustic data

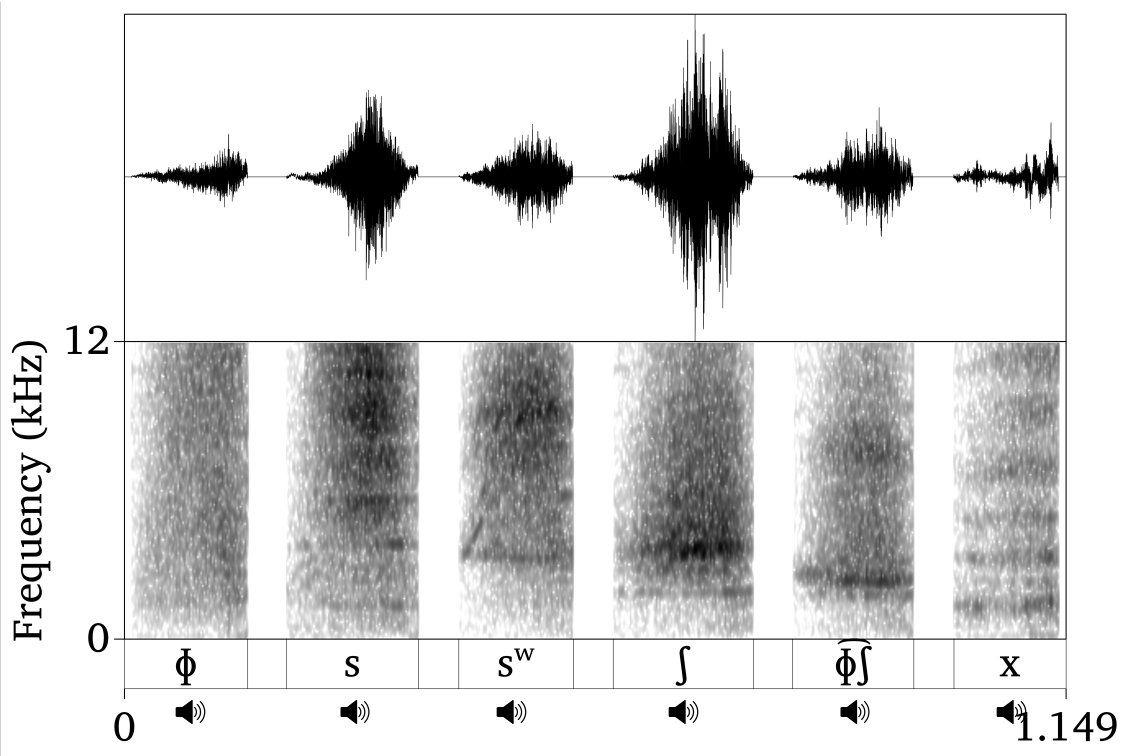


Figure 3: Waveform and Spectrogram for Sekgatla fricatives

- Reduced amplitude for [sʷ] and [$\widehat{\phi\int}$].
- No sequential change over the course of the [$\widehat{\phi\int}$] fricative.

Acoustic data

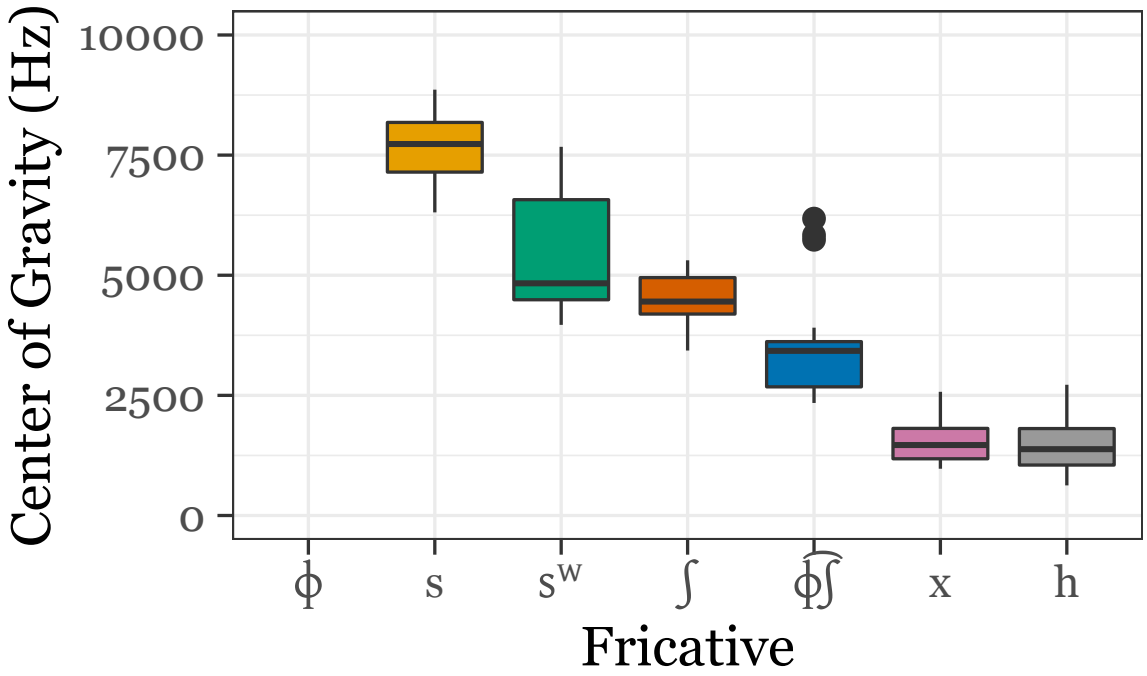


Figure 4: Mean center of gravity for Sengwato fricatives.

- Lower COG for [sʷ] and [ɸ͡ʃ] vs. [s] and [ʃ].

Acoustic data

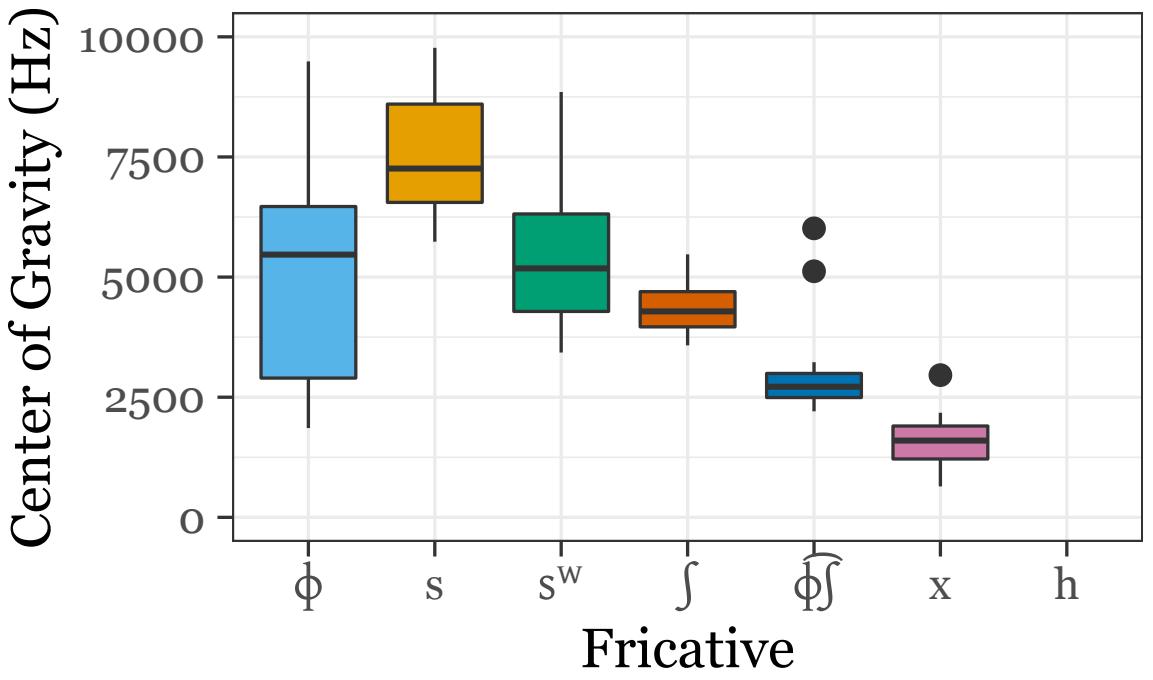
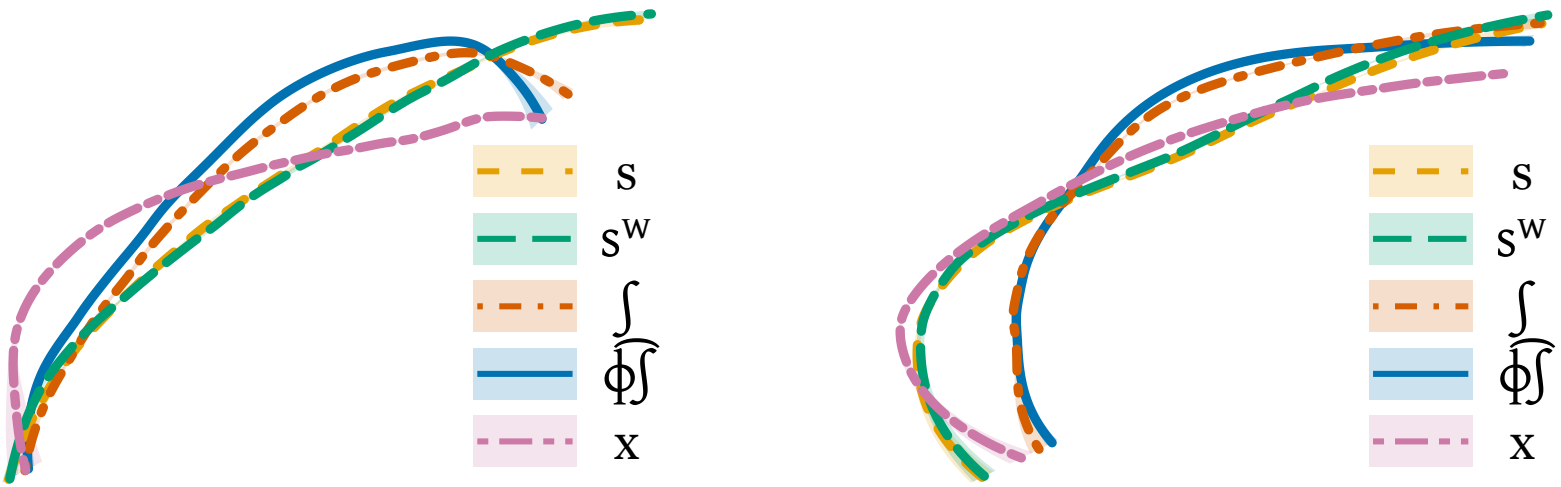


Figure 5: Mean center of gravity for Sekgatla fricatives.

Ultrasound results

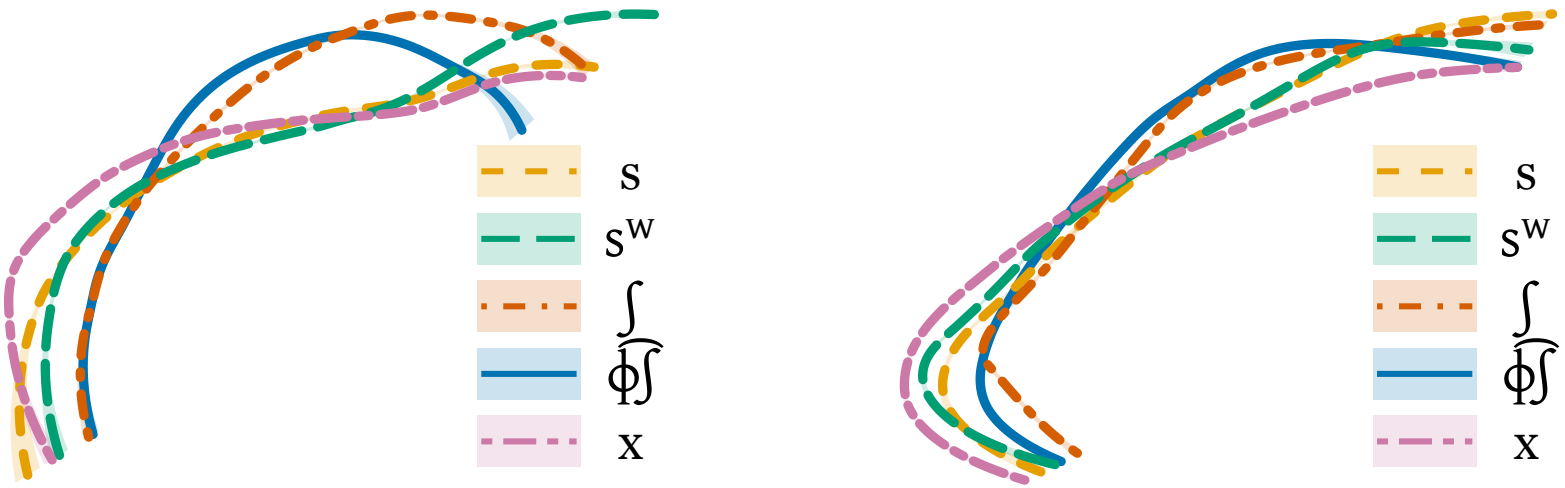


(a) Sekgatla Speaker 1

(b) Sekgatla Speaker 2

Figure 6: Polar SSANOVA tongue contours for Sekgatla speakers

Ultrasound results



(a) Sengwato Speaker 1

(b) Sengwato Speaker 2

Figure 7: Polar SSANOVA tongue contours for Sengwato speakers

Lip configuration

(a) [ɸ]

(b) [s]

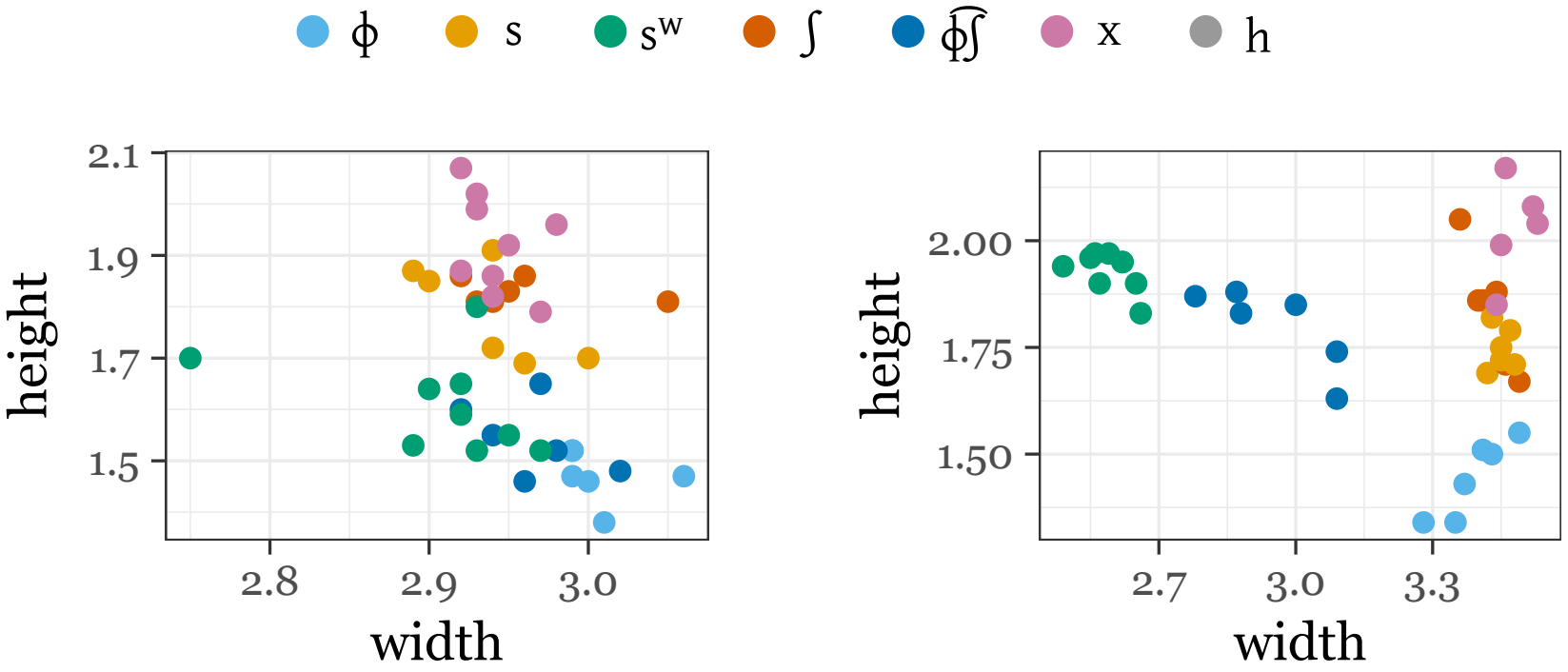
(c) [sʷ]

(d) [ʃ]

(e) [ɸ͡ʃ]

Figure 8: Lip configurations for Setswana fricatives

Lip configuration

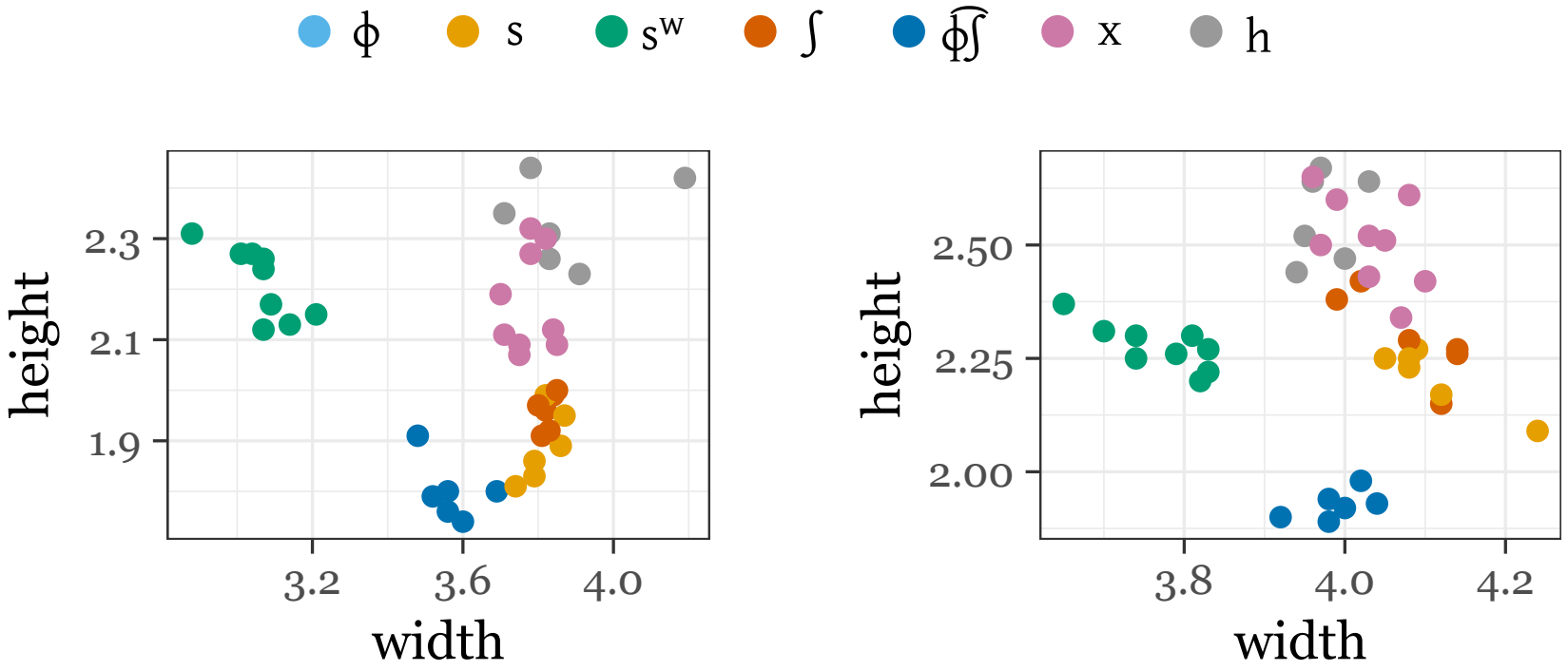


(a) Sekgatla Speaker 1

(b) Sekgatla Speaker 2

Figure 9: Lip video measurements for Sekgatla speakers.

Lip configuration



(a) Sengwato Speaker 1

(b) Sengwato Speaker 2

Figure 10: Lip video measurements for Sengwato speakers.

Discussion

Is [$\widehat{\phi\int}$] a sequence of fricatives?

- No, acoustic data reveal no sequential change over fricative's duration.

Is [$\widehat{\phi\int}$] a true doubly articulated fricative?

- Aerodynamic data don't support this analysis; no buildup of pressure behind the lips for most tokens.
- Ladefoged & Maddieson (1996): "Although doubly articulated fricatives are not impossible to produce, we suspect that they do not normally play any contrastive role in linguistic phonetics."

Discussion

Labio-coronal fricatives are best characterized as palato-alveolars with secondary labialization: [ʃᶲ]

- The labio-coronals are the palato-alveolar counterparts of the round alveolars and velars.

Revised Inventory

	bilabial	dental/ alveolar	(alveo-) palatal	velar	glottal
stop	p^h, p, b	t^h, t, (d) t^{hw}, t^w		k^h, k k^{hw}, k^w	
fricative	ɸ	s, s^w	ʃ, ʃɸ	x, x^w	h
affricate		$\widehat{ts}^h$, $\widehat{ts}$ $\widehat{ts}^{hw}$, $\widehat{ts}^w$	$\widehat{tʃ}^h$, $\widehat{tʃ}$, $\widehat{dʒ}$ $\widehat{pʃ}^h$, $\widehat{pʃ}$, $\widehat{bʒ}$	$\widehat{kx}^h$, $\widehat{kx}^{hw}$	
nasal	m	n, n^w	ɲ, $ɲ^w$	ŋ, $ŋ^w$	
approx.	(ß)	r, l			
glide	w		j		
click		ŋ|	ŋ‖		

Table 2: Revised Consonant inventory of Setswana.

Featural Representation

Does Setswana exhibit a [compressed]/[round] contrast, like Swedish and Norwegian (Lindau, 1978; Linker, 1982; Ladefoged & Maddieson, 1996)?

- The difference between [ʃᵠ] and [sʷ] is not consistently one of protrusion.
- The articulatory correlates of labialization are variable within and across dialects.

Featural Representation

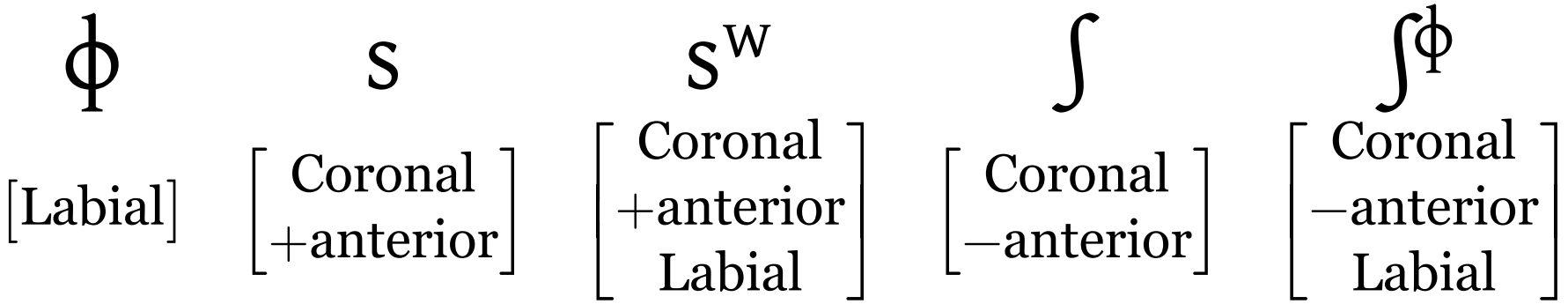


Figure 11: Featural representation of Setswana fricatives.

Whistled fricatives?

What relationship does the labio-coronal fricative have to the whistled fricatives of the Shona and Tshwa-Ronga groups of Southern Bantu?

- Maddieson (2003): whistled fricatives involve "vertical narrowing of the lips with little or no protrusion"
- Hannan (1987): Shona whistled fricatives derive historically from Proto-Bantu *pi̯ and *bi̯ sequences

Whistled fricatives?

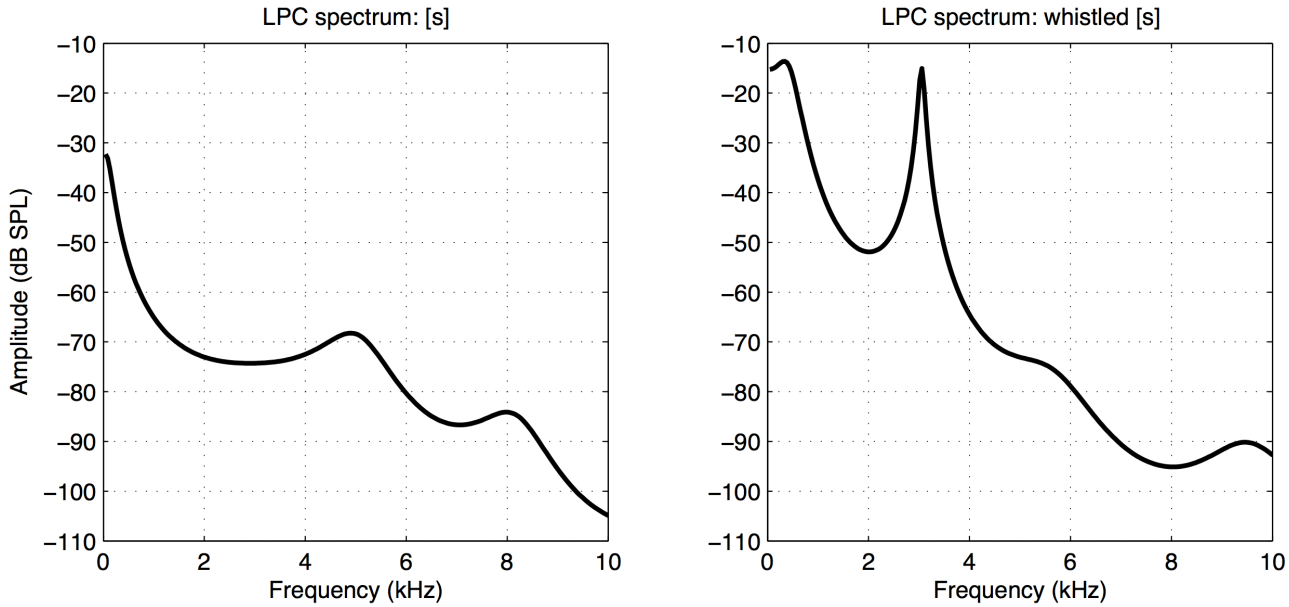
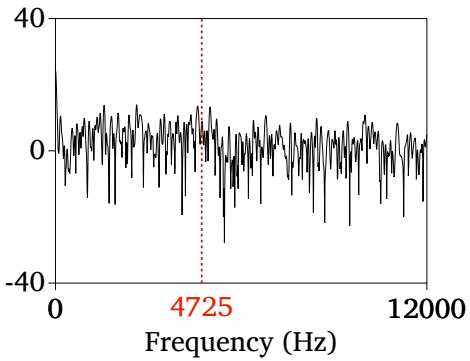


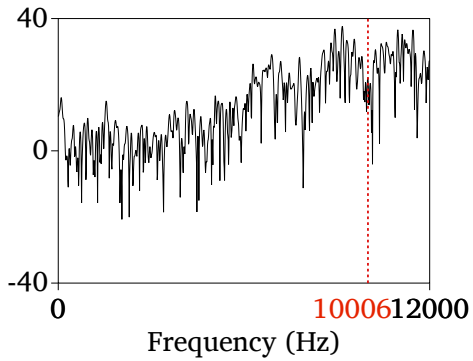
Figure 12: LPC Spectra of Tshwa sibilants. From Shosted (2006).

- Whistled fricatives exhibit narrow spectral peak, while labio-coronals involve reduced amplitude and center of gravity.

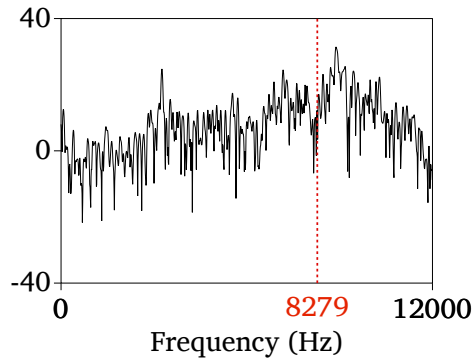
Whistled fricatives?



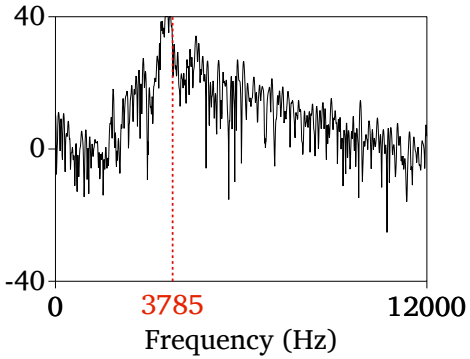
(a) [ɸ]



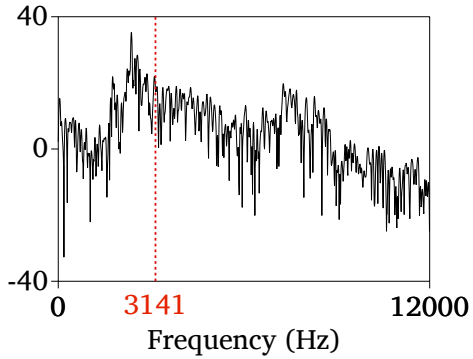
(b) [s]



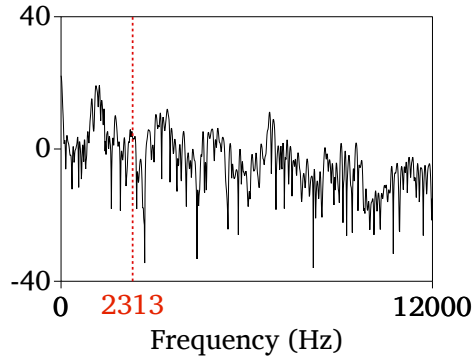
(c) [sʷ]



(d) [ʃ]



(e) [ɸ͡ʃ]



(f) [x]

Figure 13: FFT spectra with center of gravity for Setswana fricatives

Whistled fricatives?

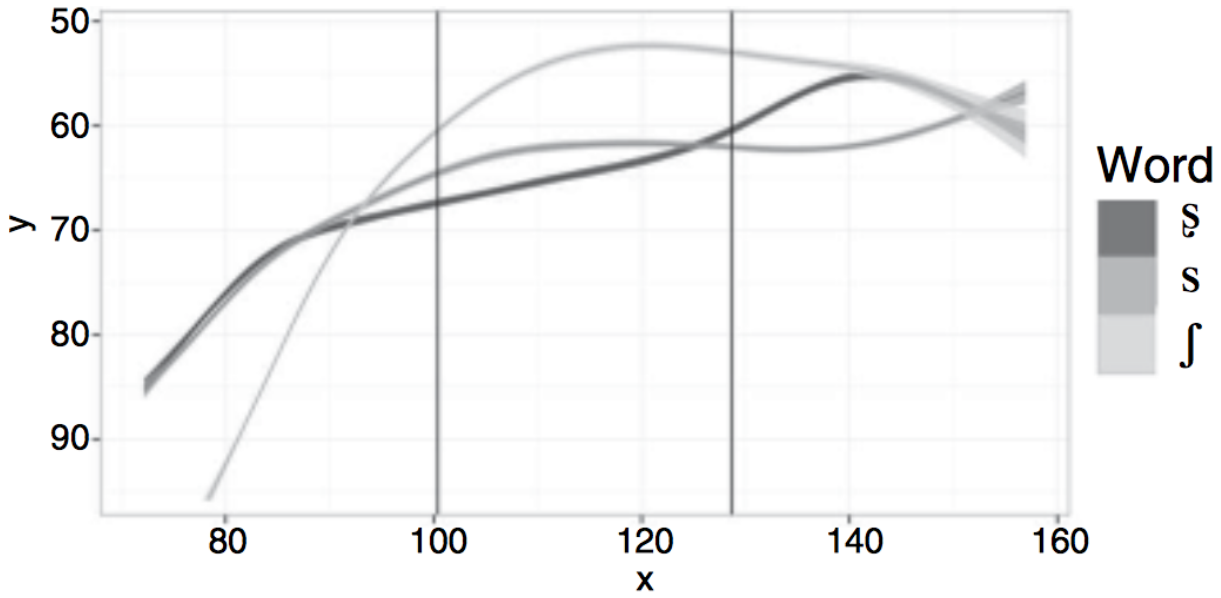


Figure 14: Tongue contours for [sa], [ʂa], [ʃa]. From Lee-Kim et al. (2014).

- Whistled fricatives involve retroflex articulation, while labio-coronals exhibit laminal palato-alveolar constriction Shosted (2011); Lee-Kim et al. (2014).

Conclusions

- Acoustically, the labio-coronal fricative is realized with a lowered center of gravity and reduced amplitude.
- In terms of articulation, the labio-coronal fricative exhibits a range of variation in both tongue shape and lip configuration.
- The articulatory variability observed is not reflected in the acoustic signal.
- Taking portable ultrasound into the field offers an opportunity to investigate unusual sounds for which instrumental phonetic data is lacking.

Thank you!

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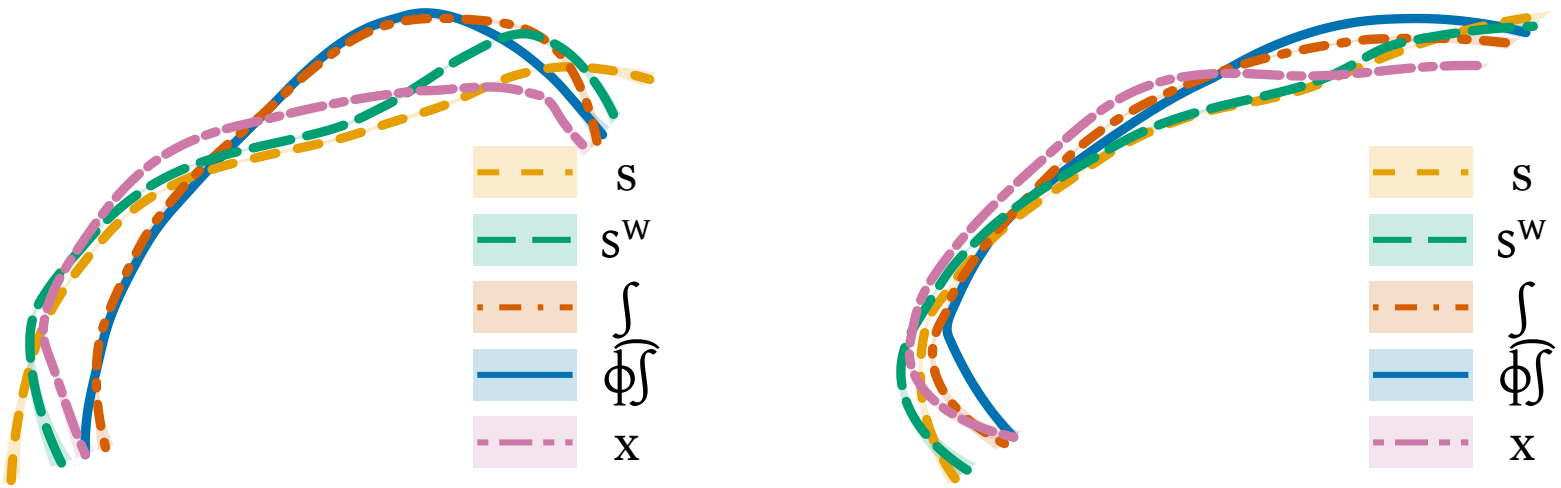
More ultrasound results

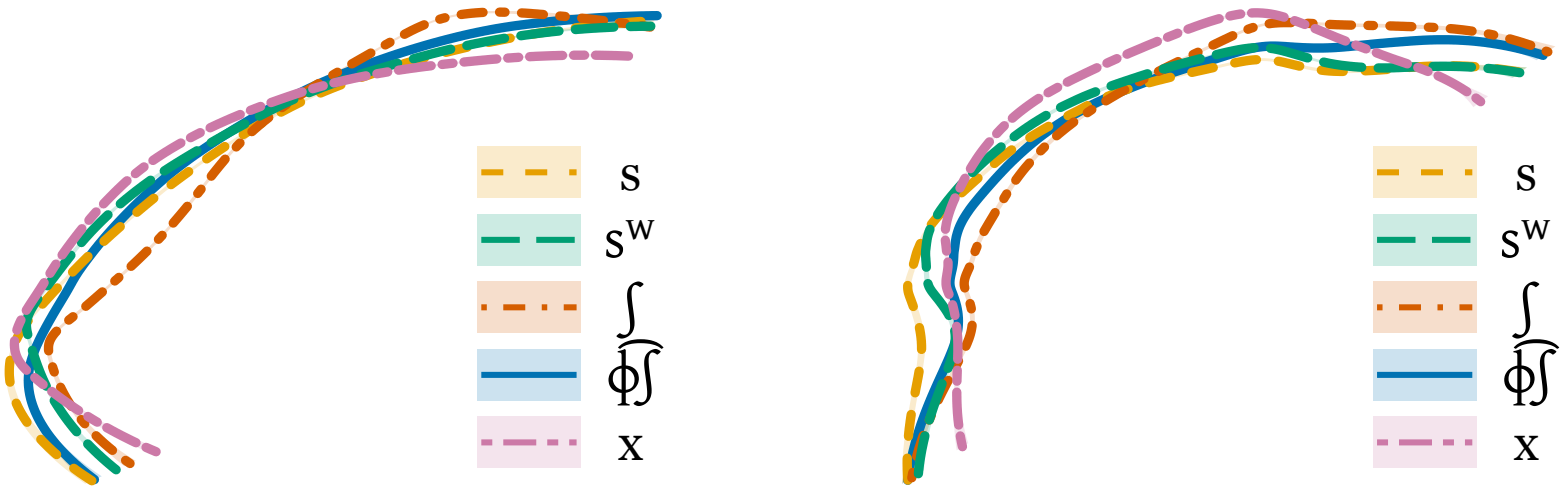


(a) Sekgatla Speaker 3

(b) Sekgatla Speaker 4

Figure 15: Polar SSANOVA tongue contours for Sekgatla speakers

More ultrasound results

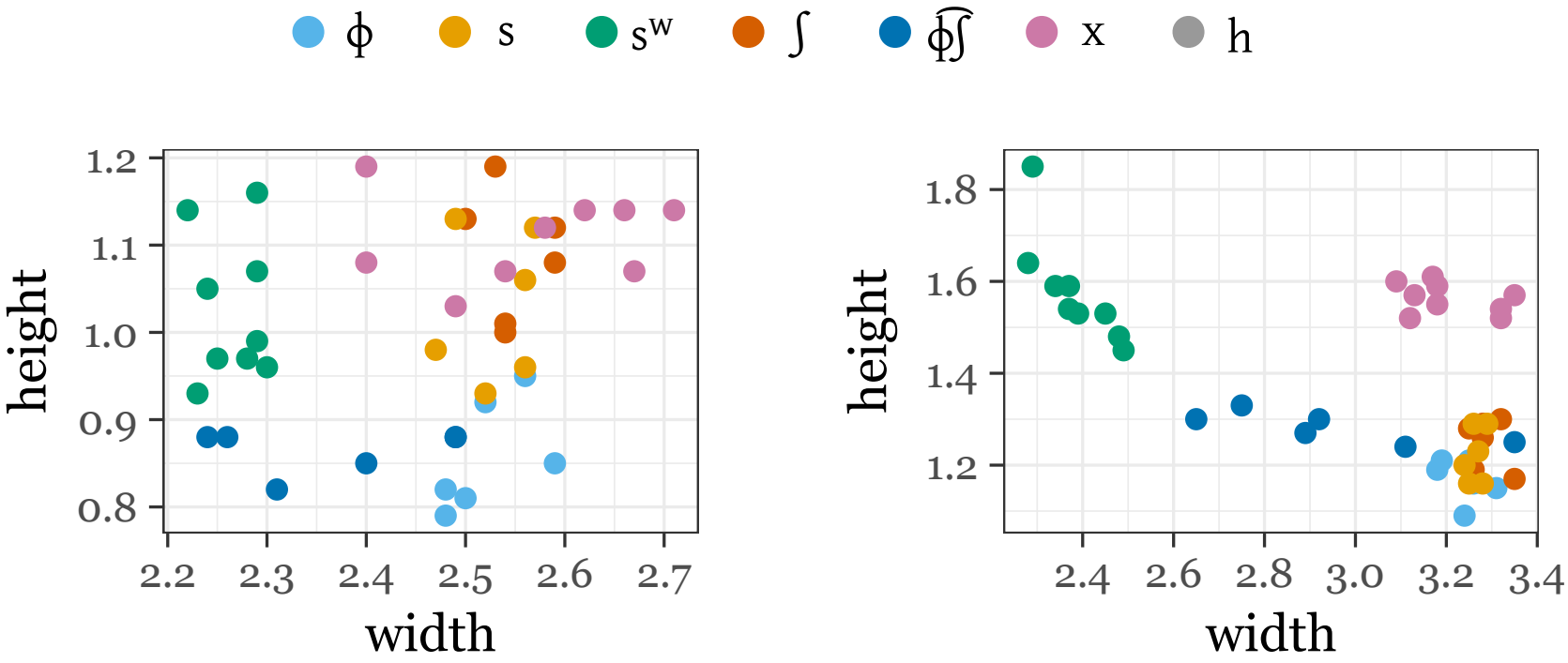


(a) Sengwato Speaker 3

(b) Sengwato Speaker 4

Figure 16: Polar SSANOVA tongue contours for Sengwato speakers

More lip configurations

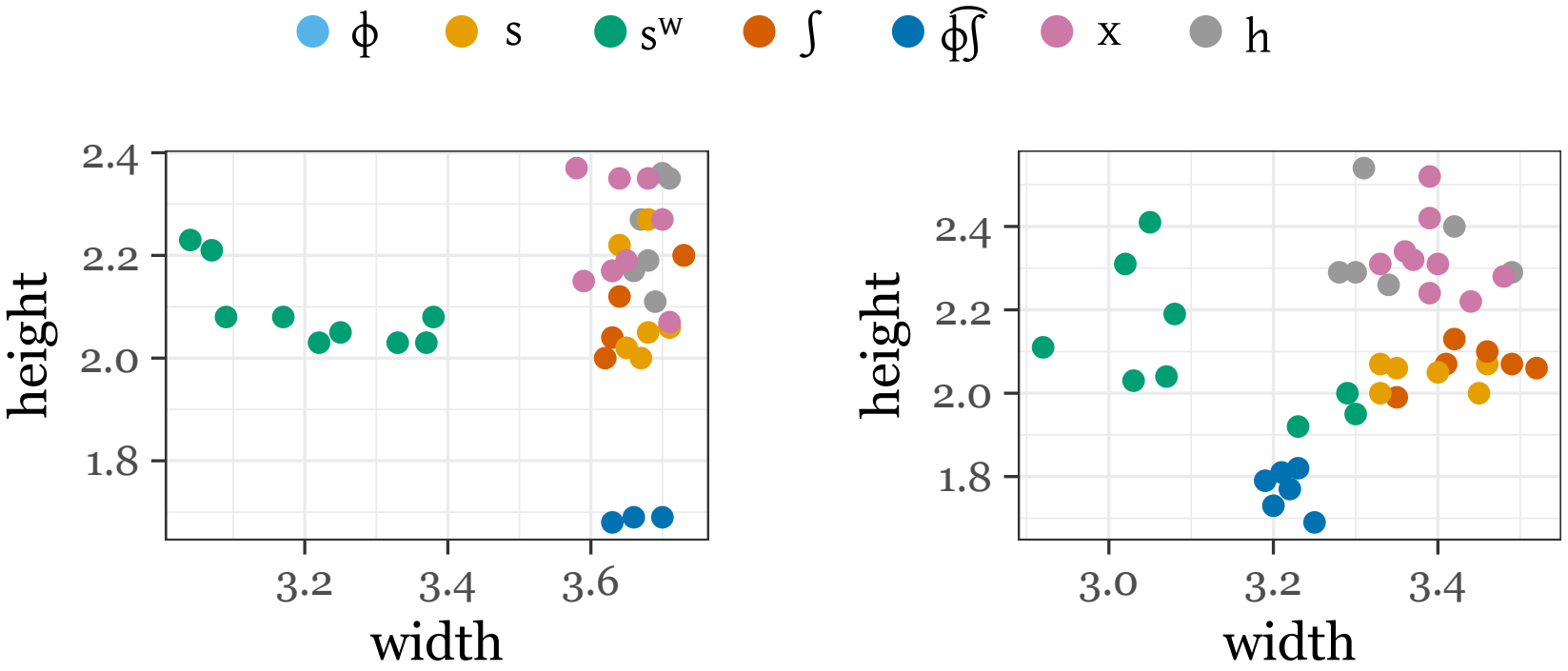


(a) Sekgatla Speaker 3

(b) Sekgatla Speaker 4

Figure 17: Lip video measurements for Sekgatla speakers.

More lip configurations



(a) Sengwato Speaker 3

(b) Sengwato Speaker 5

Figure 18: Lip video measurements for Sengwato speakers.