SPECTRAL MEASURES FOR SIBILANT FRICATIVES OF ENGLISH, JAPANESE AND MANDARIN CHINESE

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1.INTRODUCTION

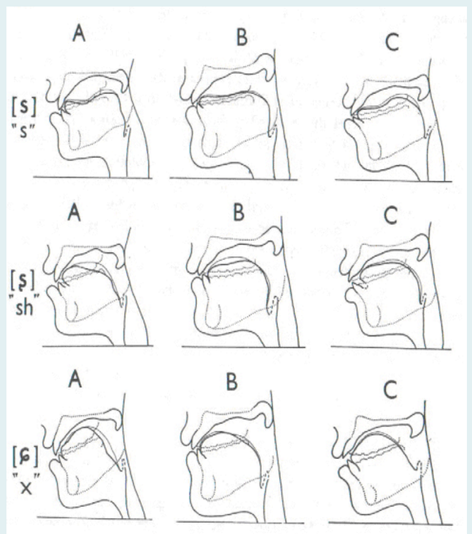
Table 1. The voiceless sibilants of English, Japanese and Mandarin

	Dental/ alveolar	Post-alveolar		
		Alveolo-palatal	Retroflex	Palato-alveolar
English	s			[ʃ]
Japanese	s	[ɕ]		
Mandarin	s	[ɕ]	[ʂ]	

actually involve **two different types of articulatory contrast** …

- **English /[ʃ]/ and /s/:** contrast in **constriction place**. The narrowest lingual constriction for /[ʃ]/ is further back than for /s/.
- **Japanese /[ɕ]/ and /s/:** contrast in **tongue posture** as well as in place. Not only is the constriction in /[ɕ]/ further back than the one in /s/, it also involves bunched predorsum, rather than the tongue tip/blade as in /s/.
- o **Mandarin /[ʂ]/, /[ɕ]/, and /s/:** contrast in **constriction place independently of tongue posture**. The postalveolar /[ʂ]/ and /[ɕ]/ contrast with /s/ in tongue position, and /[ʂ]/ contrasts with /[ɕ]/ and /s/ in tongue posture**.**

Figure 1. X-ray tracings of 3 Mandarin speakers producing /s-[ʂ]-[ɕ]/ (Ladefoged &Wu, 1984)



2. EXISTING ACOUSTIC MEASURES AND WHY THEY ARE NOT COMPLETELY SATISFATORY

2.1. Centroid frequency: A measure of constriction PLACE

- Used by Forrest et al. (1988), Jongman et al. (2000), Shadle & Mair (1996), among others.
- Defined as the first moment (mean frequency) when power spectrum is treated as a probability distribution.
- Interpreted as a measure of place, since it tends to be negatively correlated with the length of the front cavity in English sibilants.
- This interpretation fails for Mandarin /[ʂ]/, which has a slack constriction, allowing energy to leak from the back cavity (Fig. 3).

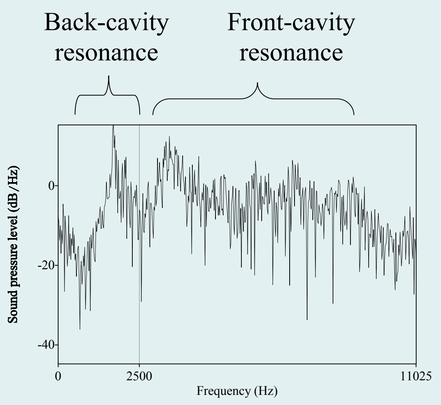


Figure 2. Spectrum of Mandarin /[ʂ]/ in *shí-zǐ* 'stone'. The spectral prominence below 2500 Hz reflects the long back cavity.

2.2 Onset F2 Frequency: A measure of constriction POSTURE

- Used by Funatsu (1995), Halle & Stevens (1997), among others.
- Defined as the F2 frequency taken at the onset of voicing in the vowel following the lingual fricative.
- Tends to be negatively correlated with the length of the back cavity.
- Exact value depends on following vowel, making cross-language comparison difficult when vowel systems differ.
- Value not always available – e.g., Tokyo Japanese vowels are frequently deleted or devoiced after voiceless fricatives.

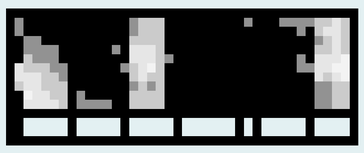


Figure 3. Production of *sakana* 'fish'by a male adult speaker of Tokyo Japanese, with the first [a] devoiced.

3. MATERIALS AND DATA COLLECTION

- **Materials:** Audio recordings of words beginning with target fricative followed by vowels /a/, /i/, /u/, /e/, /o/.
- **Participants:**10 speakers for each language (5 males and 5 females), recorded in Tokyo, Japan, Columbus, US, and Songyuan, China.

4. DEVELOPING NEW ACOUSTIC MEASURES

- Based on separating contribution of front cavity resonance in higher frequencies from contribution of back cavity in the F2 region (see Fig. 4).
- F2 region: Ideally, this is the F2 in the fricative or in [[ʂ]]. Since there is no observable F2 peak in [s] or [[ʂ]], and no true neutral vowel in these three languages, the F2 region was approximated by taking the F3 of /a/ and multiplying by 3/5 for each speaker in each language.

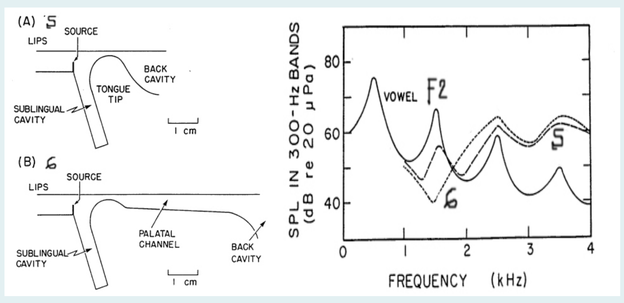
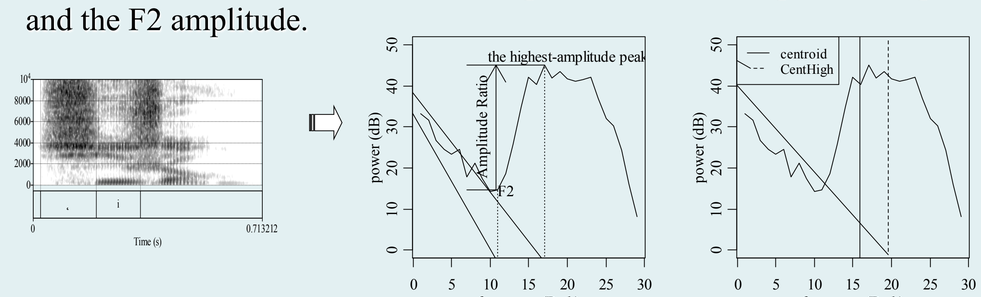


Figure 4. Cavity shapes for /[ʃ]/ and /[ɕ]/ (left panel), with /[ʃ]/ having a short slack constriction, whereas /[ɕ]/ involves a long palatal channel instead. The right panel is the theoretical spectra of /[ʃ]/ and /[ɕ]/ overlaid on the spectrum of a neutral vowel (from Halle & Stevens 1997).

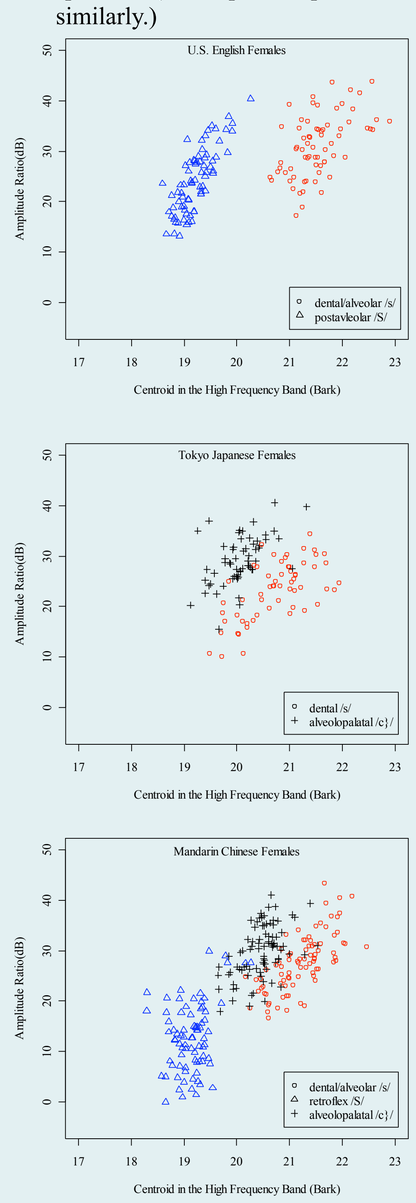
- **Centroid in the Higher Frequency Band (CentHigh):** A measure of constriction **PLACE**. Refinement of the centroid frequency measure so that it is now calculated over a higher frequency band above "F2 region".
- **Amplitude Ratio (ampRatio):** A measure of tongue **POSTURE.** It is the difference in dB between the amplitude of the most prominent peak and the F2 amplitude.



5. RESULTS

- **English:** /s/ and /[ʃ]/ differentiated by centHigh, with /s/ having higher values than /[ʃ]/ (Fig. 5, top).
- **Japanese:** /s/ and /[ɕ]/ differentiated by both centHigh and ampRatio (Fig. 5, middle). Linear discriminant analysis showed both parameter to correctly identify 92% of the tokens.
- **Mandarin:** The place distinction was captured by centHigh, and the posture difference was captured by ampRatio (Fig. 5, bottom). Linear discriminant analysis again correctly identified 92% of the tokens.
- The typically apico-alveolar /s/ of English had higher centHigh and higher ampRatio than the lamino-dental /s/ of Japanese and Mandarin.

Figure 5. AmpRatio plotted against CentHigh for English, Japanese and Mandarin female speakers. (Male speakers pattern similarly.)



6. DISCUSSION

- CentHigh and ampRatio are two parameters that can effectively distinguish two types of articulatory contrasts: contrast in tongue position and contrast in tongue posture.
- The /s/ phonemes in the three languages differ in phonetic detail, in a way that maximizes the contrast with the alveolo-palatal fricative in the inventory.

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