Cross-linguistic interference in the perception of L2 English fricatives by speakers of Chinese, Japanese, and Vietnamese

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Abstract

This study reports an experiment in which native speakers of Chinese, Japanese, and Vietnamese performed an identification task with English voiceless obstruents. Although these three languages resemble English in distinguishing alveolar from post-alveolar fricatives, they all differ in their phonetic implementation of the post-alveolar. We investigate the impact the different realizations have on categorical perception, as well as the ramifications of phonological neutralization, allophonic alternation, and invariant contrast in each of these languages. Results indicate differences in identification performance based on native language that reflect the mapping between phonological categories and phonetic realizations in addition to the phonological behavior of these segments in different vowel environments in each language.

Index Terms: speech perception, L1 interference, fricatives

1. Introduction

A fundamental obstacle to the acquisition of second language speech sounds is the interference imposed by a learner's native language phonetics and phonology.[1][2][3][4][5] Listeners with different native languages genuinely perceive the same speech in another language differently from one another. Acoustic features of the speech signal that constitute robust cues for segment categories in one language may be irrelevant in another or even an impediment to categorization in a third. With extended exposure to target-language input, such as can occur in immersion environments for example, learners often overcome these interference effects;[6][7] without it, however, they typically experience persistent difficulties that undermine their efforts to develop target-like speech.

We examine the perception of English fricatives by native speakers of Chinese, Japanese, and Vietnamese. Although each of these languages distinguishes alveolar from post-alveolar sibilant fricatives, none of them includes the same palato-alveolar [ʃ] articulation that appears in English. Moreover, they differ from one another in how their phonologies treat post-alveolar sibilants.

1.1. Phonetics of sibilants

Table 1 presents the sibilant fricatives of Chinese, Japanese, and Vietnamese as well as English and the precise post-alveolar place of articulation in each one of them. While these languages all share an alveolar fricative effectively identical to one another [s], they all differ in the precise realization of their post-alveolar sibilant.

Table 1: *Articulatory differences in post-alveolars.*

	Post-alveolars		
Ch, En, Ja, Vi	Ch, Ja	En	Ch, Vi
Alveolar	Alveolo-palatal	Palato-alveolar	Retroflex
[s]	[ɕ]	[ʃ]	[ʂ]

Ch = Chinese, En = English, Ja = Japanese, Vi = Vietnamese

The palato-alveolar fricative [ʃ] of English is typically pronounced with a domed tongue shape approaching the area between the alveolar ridge and the palate.[8] Japanese and Chinese both include a laminal alveolo-palatal pronunciation [ɕ] for which the blade of the tongue narrows the airflow path in the area just behind the alveolar ridge, slightly forward of the place for English [ʃ]. Retroflex articulations in Chinese and Vietnamese involve the apical or sub-apical surface of the tongue retracted in the area just ahead of the palate, somewhat behind English [ʃ].[8]

Acoustically, there are (at least) two dimensions along which sibilants differ from one another, [9] as shown in Figure 1, based on Flemming (2018). [10]

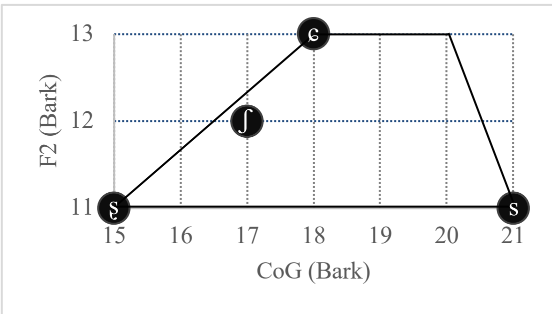

Figure 1: *Acoustic distinctions — F2 and CoG.*

All four of them generate a spectral mass centered in distinct frequency ranges, represented as Center of Gravity (CoG) on the x-axis. The retroflex [ʂ] and alveolar [s] produce F2 transitions into a following vowel roughly equal to one another, [11] as represented on the y-axis, but clearly lower in frequency than the palato-alveolar [ʃ], which is in turn lower than the alveolo-palatal [ɕ]. Whether each of these acoustic dimensions serves as a robust cue for categorization during speech perception may well vary based on a listener's native language and any phonological constraints it may impose. Ultimately, it is an empirical question, which we address below.

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1.2. Phonological distributions of sibilants

While Chinese, Japanese, and Vietnamese all include a post-alveolar sibilant, each one imposes different phonological conditions on it. Chinese, for example, includes the alveolo-palatal [ɕ], but only as an allophone that appears uniquely before [i]. It replaces fricatives in this context generally but has no independent status. In other phonetic contexts, alveolar and post-alveolar sibilants are contrastive, with the latter phoneme realized as a retroflex [ʂ].[12]

In Japanese, the alveolo-palatal fricative constitutes an independent phoneme that contrasts with the alveolar fricative in most vowel environments (e.g., [s]*akai* ‘border’ ~ [ɕ]*akai* ‘society’). The one exception is before the vowel [i], where the contrast is neutralized in favor of [ɕ].[13] The effect of this neutralization is not limited to distributional regularities but induces alternations under morphological inflection as well (e.g., *da*[s]-*u* ‘to take/put out, *pres*.’, but *da*[ɕ]-*ite* ‘take/put out, *prog*.’).

In Vietnamese, a contrast between alveolar [s] and retroflex [ʂ] remains distinctive in all environments with neither neutralization nor allophonic variation.[14] The matrix of contrastive features for voiceless fricatives in these languages appears in Table 2. Corresponding voiced fricatives occur in some but not all of these languages and are therefore set aside for the study reported here.

Table 2: *Distinctive features for voiceless fricatives*.

[coronal]	–	+	+	+		–
[anterior]	+	+	+	–		–
[strident]	+	–	+	+		–
English	f	θ	s	ʃ		
Chinese	f		s	(ɕ)	ʂ	x
Japanese	(ɸ)		s	ɕ		(ç)
Vietnamese	f		s		ʂ	x

Sibilants are characterized by a plus-value (+) for both [coronal] and [strident], with post-alveolars (highlighted in gray in Table 2) additionally specified with a minus-value (–) for [anterior]. The mapping of the post-alveolar sibilant feature matrix to different segmental realizations in each of these languages makes exposure to an alternative variant in another language vulnerable to equivalence classification.[2],[15] Learners of English, for example, must acquire a new mapping of this cluster of feature values in order to achieve a target-like palato-alveolar fricative [ʃ]. The question examined below is whether the phonetic implementation of Chinese, Japanese, and Vietnamese sibilants exposes native-speakers of these languages to perceptual interference that will undermine the process of acquiring that new mapping. Moreover, we examine whether the different phonological behavior of these segments in each language may further impede accurate perception.

2. Method

We presented native speakers of Chinese, Japanese, and Vietnamese with an identification task with the objective of assessing their categorization of English fricatives, with particular interest in their perception of sibilants.

2.1. Participants

Fifty-five participants performed the identification task, including 13 native speakers of Chinese (mean age = 26.2), 29 Japanese (mean age = 20.1), and 13 Vietnamese (mean age = 24.8). None had experience living or studying in an English-speaking country. All the Japanese-speaking participants and most of the Chinese- and Vietnamese-speaking participants were tested in Japan. The remainder were tested remotely in their home country.

2.2. Materials

Stimulus materials were comprised of simple CV-syllables containing a fricative followed by either the vowel [ɑ] or [i] presented in the final position in a carrier phrase. Recordings were made in a sound attenuated room by a male native speaker of American English at a sampling rate of 44.1 kHz and bit depth of 16-bps. The audio was then passed through an 11 kHz low-pass band filter and normalized to a signal intensity of 70 dB.[16] Finally, audio materials were presented under three noise conditions using a babble mask at each of the following signal-to-noise ratios in order to compel the use of categorical representations when rendering identification judgments.

Signal-to-Noise ratio conditions

- No noise mask
- Moderate noise mask: 15 dB
- Full noise mask: 0 dB

Test items contained the following set of CV-syllables:

- [fɑ], [θɑ], [sɑ], [ʃɑ], [tɑ]
  [fi], [θi], [si], [ʃi], [ti]

In addition, the list below contains the consonant-initial English words prepared for participants to use when labeling their identification judgments:

- [ɑ] fan, thank, sand, tank, shine, child
  [i] fin, think, sing, till, ship, chip

The experiment was coded using *Inquisit* (version 5.0.14.0) by Millisecond Software for presentation via an internet browser.[17] This allowed for flexibility in the use of multiple platform operating systems in addition to collection of some additional data performed remotely.

2.3. Procedure

After receiving a brief explanation of the experiment and supplying their informed consent, participants performed a segment identification task. At the start of each trial, an array of 6 English words (see above) appeared on the computer screen. After 100 msec an audio stimulus was presented, and participants then selected the word on the screen whose initial pronunciation matched the initial segment they heard in the final syllable of the carrier phrase. Responses were entered by clicking on the selected word with the computer mouse. After demonstrating their understanding of the task procedure on a set of four practice items, participants advanced to a set of 30 test trials in three blocks, one at each of the three signal-to-noise conditions listed above. The order of blocks was fixed from no mask to full mask, with items within each block randomized for each participants. The entire procedure was typically completed in less than fifteen minutes.

3. Results

Results are reported in a series of confusion matrices,[18] with comprehensive tabulations of identification accuracy and misperceptions for each group in each vowel environment provided separately in the appendix. In those matrices and the one that follows below, audio stimuli appear down the left side with response options presented across the top. Response rate is displayed as the proportion of each audio to receive a given word label identification, with shading used to highlight the strength of response rate. Darker cells indicate higher rates for selecting the indicated label.

Before proceeding to our primary analysis examining the perception of sibilants by native speakers of Chinese, Japanese, and Vietnamese, the exhaustive matrices in the appendix include additional observations that deserve comment. Among Japanese-speaking listeners for example, all of the fricatives are identified less accurately than stops before [i] (Table A1), with non-sibilants [f] and [θ] especially affected. Confusion of these two segments before [ɑ] is roughly symmetrical (Table A2), but before [i] there is strong bias in favor of interdental [θ].

Chinese-speaking listeners, in contrast, do not exhibit any significant difficulty with the labiovelar [f], but they do show perceptual confusion with the interdental [θ]. However, their confusion differs based on the following vowel, with greater difficulty distinguishing it from [f] before [i] (Table A3) but from [s] before [ɑ] (Table A4). Misperceptions of [s] as [θ] occur as well, in both vowel contexts.

Vietnamese-speaking listeners demonstrate excellent identification accuracy for the interdental fricative [θ] before [i] (Table A5) but they are less accurate before [ɑ] (Table A6). Conversely, they appear to misperceive [f] as [θ] before [i] but demontrate fairly accurate identification of [f] before [ɑ]. Unlike either of the other two groups, Vietnamese-speaking listeners misperceive fricatives as a stop [t] before [ɑ].

We now turn to our main interest in this study, the perception of English alveolar and post-alveolar sibilants. These are the segments that exhibit different phonological patterns in each of the three langauges of our participants, both in their phonetic implementation and in their distributions. Table 3 extracts from the comprehensive tables in the appendix the identification rates for sibilants [s] and [ʃ] in both vowel contexts by all three language groups.

Table 3: *Sibilants in each vowel context by Group.*

	Chinese			*Japanese*			*Vietnamese*	
	sing	*ship*		*sing*	*ship*		*sing*	*ship*
[si]	76.7	3.3		46.0	36.8		60.0	20.0
[ʃi]	0.0	100.0		17.2	77.0		0.0	100.0
	sand	*shine*		*sand*	*shine*		*sand*	*shine*
[sɑ]	86.7	0.0		87.4	0.0		100.0	0.0
[ʃɑ]	0.0	96.7		0.0	100.0		26.7	73.3

Chinese-speaking listeners demonstrate generally quite high levels of accuracy identifying the coronal sibilants, with slightly depressed accuracy for alveolar [s] before [i], though this results from confusion not with the post-alveolar sibilant but rather with the non-sibilant interdental fricative [θ], as noted above. This is in stark contrast to the Japanese-speaking listeners who exhibit substantial confusion between alveolar and post-alveolar sibilants, exclusively before the vowel [i]. The confusion is bidirectional but asymmetric; that is, alveolar [s] is twice as likely to be misperceived as [ʃ] as the reverse. Before [ɑ] however, there is no confusion between these segments whatsoever.

Vietnamese-speaking listeners exhibit an intriguing pattern of misperception. They demonstrate perfect identification accuracy for alveolar [s] before [ɑ], and for post-alveolar [ʃ] before [i]. Conversely, they confuse the sibilants when presented with [s] before [i], misperceiving it as [ʃ], and likewise when presented with [ʃ] before [ɑ], misperceiving it as [s].

4. Discussion

The observation of different perceptual patterns among three groups of listeners with different native languages demonstrates that the perceptual processing mechanisms optimized for the phonetics and phonology of an individual's native language alters his or her perception of non-native speech in a unique way. In Japanese, for example, we have seen that an underlying [+/– anterior] contrast between alveolar [s] and post-alveolar [ɕ] is neutralized before [i], both distributionally and productively. This is precisely the vowel environment in which Japanese-speaking listeners confuse the alveolar and post-alveolar sibilants of English. Moreover, the perceptual confusion is asymmetric, favoring misperception of [s] as [ʃ] over the reverse because it is the appearance of [s] before [i] that is prohibited by Japanese phonology. Phonetically, the Japanese category boundary separating alveolar [s] from post-alveolar [ɕ] falls at a considerably higher frequency along the CoG scale than a palato-alveolar [ʃ] of English will have (see Figure 1), making it even less likely that a Japanese-speaking listener might misperceive the [ʃ] as alveolar [s].

In Chinese, retroflex [ʂ] has as an allophone [ɕ] with which it is in complementary distribution. Both realizations, however, are post-alveolar with no abrogation of the [+/–anterior] contrast and thus distinct from [s] in terms of their place of articulation. Phonetically, then, the range of CoG values that map to the corresponding phoneme category varies rather broadly from roughly 15 to 18 Bark, with typical CoG values for the English palato-alveolar [ʃ] falling squarely within that range (see Figure 1). Hence, Chinese-speaking listeners do not exhibit perceptual confusion of the English sibilants. As mentioned above, the diminished identification accuracy for alveolar [s] reflects some degree of confusion with the interdental [θ] (see Tables A3 and A4 in the appendix). This perceptual difficulty likely stems from the absence of contrastive [+/–strident] in Chinese.

Finally, Vietnamese-speaking listeners exhibit the greatest degree of perceptual confusion of English sibilants among our three language groups. Unlike the Japanese group, their misperceptions are not limited to one vowel context, although the directionality of confusion does appear to be sensitive to the identity of the following vowel. Identification accuracy of alveolar [s] is perfect before the vowel [ɑ] but diminished before [i]; conversely, accuracy is perfect for palato-alveolar [ʃ] before the vowel [ɑ] but diminished before [i]. Phonologically, Vietnamese has neither the neutralization nor the allophony affecting sibilants seen in the other languages, with [+/–anterior] preserved in all environments. Phonetically, the coronal sibilant specified for [–anterior] is mapped to retroflex [ʂ] exclusively, and [+anterior] gets mapped to alveolar [s]. Acoustically, these two sibilants are indistinguishible from one another in terms of the F2 transition, setting them apart from the other two sibilants (see Figure 1), thus leaving CoG to be an essential acoustic cue on which Vietnamese speakers rely for discriminating between them. The CoG cue is also fairly robust as these two segments are dispersed rather broadly along that dimension.

The English palato-alveolar [ʃ] falls somewhere between the two Vietnamese sibilants in CoG, which may account for some of the perceptual difficulty. Drawing on the values from Flemming (2018) in Figure 1,[10] a percept with a CoG of 17 Bark such as an English palato-alveolar sibilant may lie beyond the categorial boundary Vietnamese speakers typically associate with their post-alveolar [ʂ] yet not high enough in frequency to fall within the range typically associated with the alveolar [s]. Performance on the identification task may thus be affected by their judging this CoG "dead zone" variably as 'not alveolar' in some instances or 'not post-alveolar' in others rather than mapping directly to one category or the other.

With the typically robust and reliable cue of CoG rendered vague and inconsistent for categorizing English palato-alveolar [ʃ], identification behavior may become subject to influence of other acoustic cues. Notably, the English sibilant contrast is distinguished by the F2 transition out of the fricative in addition to CoG (Figure 1). While distinctive in the acoustic signal however, this is not a cue Vietnamese speakers typically process for categorizing fricatives. They would nevertheless be familiar with processing F2 cues in the speech signal, of course, when distinguishing between front and back vowels. We might speculate that this fact could underlie the interesting asymmetry in identification accuracy Vietnamese-speaking listeners exhibit. When relatively higher F2 palato-alveolar [ʃ] occurs alongside the higher F2 front vowel [i], they demonstrate perfect identification accuracy and likewise for relatively lower F2 alveolar [s] alongside lower F2 back vowel [ɑ]. While capable of detecting the F2 distinction encoded in the fricative contrast, they are unable to use it for mapping to fricative categories. Instead they attempt to map the cue to the unfolding vowel that follows. When the higher F2 of palato-alveolar [ʃ] conflicts with the lower F2 of a following back vowel [ɑ], perceptual confusion arises; likewise for the lower F2 of alveolar [s] followed by the higher F2 front vowel [i]. When the F2 of fricative and vowel are congruent, identification judgments are reinforced which results in greater accuracy.

Whether such cue misassignment represents an additional impediment to perception of non-native speech sounds will need to be addressed in future research. It is clear though that the phonetic environment of novel segments must be taken into consideration as both the mapping of acoustic cues in phonetic implementation and the constraints on segment sequences imposed by phonological operations (e.g., neutralization, allophonic substitution, among others) interfere with the perception, categorization, and identification of non-native speech sounds.

5. Conclusion

Native language interference in the perception of non-native speech is nothing new. In his 1939 opus *Grundzüge der Phonologie*, Trubetzkoy observed that "[o]nce a speaker has learned to attend to certain features only, he supposedly approaches all other languages through his own 'grid' of distinctive versus non-distinctive features" (p.54).[1] While that account continues to provide an insightful explanation for some perceptual difficulties non-native listeners experience, we have examined perception among speakers of three different languages with a common set of distinctive features. Chinese, Japanese, and Vietnamese contain sibilants specified [+strident] and [+coronal] that contrast for [+/–anterior], as does English, the non-native language our participants share. How the languages differ is in their phonetic implementation of these feature bundles and how feature values are changed in phonological operations in the grammar of each language.

None of these three languages includes a post-alveolar sibilant that matches exactly the palato-alveolar [ʃ] of English. Chinese and Vietnamese map their voiceless coronal sibilant with [–anterior] to a retroflex [ʂ]. In Chinese it is in complementary distribution with an allophone, an alveolo-palatal [ɕ], but in Vietnamese it is not. In Japanese, the alveolo-palatal [ɕ] is the only implementation of this bundle of features. Unlike the other languages, however, Japanese phonology neutralizes the phonemic [+/–anterior] contrast before [i], leading underlying alveolars to surface as alveolo-palatal [ɕ], too. These differences in the phonetics and phonology of sibilants in each language underlie the different perceptual confusions experienced by our three groups of participants.

The study does suffer a few limitations that must be acknowledged. Although we did check our materials with a couple native speakers of English, we did not run the experiment on a proper control group. The near perfect identification accuracy for sibilants among the Chinese-speaking listeners does afford us some reassurance that our materials provide faithful renditions of the English fricatives; nevertheless, a control group would allow for direct comparison between groups as part of the analysis.

Another factor we did not consider was whether there might be relevant acoustic differences across these languages in the phonetic realization of the alveolar sibilant [s]. Having relied on linguistic descriptions of the segmental inventories of these languages, we may have missed small but important differences, such as the possibility that speakers of one or more of the languages might produce their anterior sibilant with more dental articulation, [s̪], affecting the corresponding acoustic cues accordingly.

We conclude that listeners not only perceive non-native speech sounds through a prism of native language features [1],[4] but also rely on the mapping of those features to language-particular phonetic categories. Having been attuned to the acoustic cues corresponding to those categories, including variants generated by the phonology, speech processing mechanisms interfere with the categorization and identification of novel speech sounds in a second language. In some cases, acoustic cues detected in the speech stream but inconsistent with the phonetic implementation of categories in the native language appear to lead listeners to misassign those cues to an adjacent segment, further interfering with the perceptual processing of second language speech.

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7. References

[1] Trubetskoy N. S., *Principles of Phonology*, [trans. by Christiane A.M. Baltaxe, Berkeley Linguistic Circle. Originally distributed as *Travaux du Cercle Linguistique de Prague* 7, Prague, 1939.

[2] Flege, J. E. (1995). "Second language speech learning: Theory, findings, and problems." In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research*, Timonium, MD: York Press, pp. 233-277, 1995.

[3] Best, C. T., "A direct realist view of cross-language speech perception." In W. Strange (Ed.), *Speech perception and linguistic experience: Issues in cross-language research*, Timonium, MD: York Press, pp. 171-204, 1995.

[4] Brown, C. A., "The role of the L1 grammar in the L2 acquisition of segmental structure. *Second Language Research*, vol. 14, no. 2, pp. 136–193, 1998.

[5] Strange, W., "Automatic selective perception (ASP) of first and second language speech: A working model." *Journal of Phonetics*, vol. 39, pp. 456-466, 2011.

[6] Kawasaki, T., Tanaka, K., Takeuchi, M., & J. Matthews "Reconstruction of the Perceptual Map for Fricatives in L2 Acquisition." Presentation at the 36th Annual Meeting of the Japan Cognitive Science Society. Hamamatsu (Shizuoka), Japan. September 5-7, 2019.

[7] Matthews, J., T. Kawasaki, K. Tanaka, and M. Takeuchi, "Phonetic drift in fricatives and the effects of L2 experience on L1 phonetic categories," Eigo-Eibei-Bungaku: English Language and Literature, vol. 61, pp. 123–137, 2021.

[8] Ladefoged, P. & Maddieson, I., *The Sounds of the World's Languages*. Oxford: Blackwell, 1996.

[9] Jongman, A., Wayland, R., & S. Wong, "Acoustic characteristics of English fricatives." *Journal of the Acoustical Society of America*, vol. 108, no. 3, pp. 1252-1263, 2000.

[10] Flemming, E., "Systemic markedness in sibilant inventories." Poster presented at Annual Meeting on Phonology (AMP2018). University of California at San Diego, October 6, 2018.

[11] Wilde, L., "Inferring articulatory movements from acoustic properties at fricative-vowel boundaries," *Journal of the Acoustical Society of America*, vol. 94, p. 1881, 1993.

[12] Duanmu, S., *The phonology of Standard Chinese*. Oxford: Oxford University Press, 2000.

[13] Labrune, L., *The phonology of Japanese*. Oxford: Oxford University Press, 2012.

[14] Phạm, A.H., "The non-Issue of dialect in teaching Vietnamese." *Journal of Southeast Asian Language Teaching* (JSEALT), Vol 14, pp 1-17, 2008.

[15] Flege, J. E., "The production of "new" and "similar" phones in a foreign language: Evidence for the effect of equivalence classification. *Journal of Phonetics*, vol. 15, no. 1, pp. 47-65, 1987.

[16] Boersma, P. & D. Weenink, "Praat: Doing phonetics by computer [Computer program]." Version 6.1.01, retrieved 14 August 2019.

[17] Inquisit 5 [Computer software]. Retrieved from online site at https://www.millisecond.com, 2016.

[18] Miller, G. A., and P. E. Nicely (1955). "An analysis of perceptual confusions among some English consonants." *Journal of the Acoustical Society of America*, vol. 27, pp. 338–352.

Appendix

Table A1: *Japanese Group, fricatives before* [i]

	fin	*think*	*sing*	*ship*	*till*	*chip*
[fi]	27.6	46.0	11.5	12.6	2.3	0.0
[θi]	12.6	69.0	5.8	10.3	1.2	1.2
[si]	0.0	16.1	46.0	36.8	0.0	1.2
[ʃi]	0.0	2.3	17.2	77.0	0.0	3.5
[ti]	0.0	0.0	0.0	0.0	97.7	2.3

Table A2: *Japanese Group, fricatives before* [ɑ]

	fan	*thank*	*sand*	*shine*	*tank*	*child*
[fɑ]	73.6	21.8	4.6	0.0	0.0	0.0
[θɑ]	20.7	65.5	12.6	0.0	1.2	0.0
[sɑ]	0.0	12.6	87.4	0.0	0.0	0.0
[ʃɑ]	0.0	0.0	0.0	100.0	0.0	0.0
[tɑ]	0.0	0.0	0.0	0.0	100.0	0.0

Table A3: *Chinese Group, fricatives before* [i]

	fin	*think*	*sing*	*ship*	*till*	*chip*
[fi]	66.7	30.0	3.3	0.0	0.0	0.0
[θi]	36.7	56.7	6.7	0.0	0.0	0.0
[si]	0.0	20.0	76.7	3.3	0.0	0.0
[ʃi]	0.0	0.0	0.0	100.0	0.0	0.0
[ti]	3.3	0.0	0.0	0.0	96.7	0.0

Table A4: *Chinese Group, fricatives before* [ɑ]

	fan	*thank*	*sand*	*shine*	*tank*	*child*
[fɑ]	86.7	6.7	6.7	0.0	0.0	0.0
[θɑ]	16.7	56.7	20.0	0.0	6.7	0.0
[sɑ]	0.0	13.3	86.7	0.0	0.0	0.0
[ʃɑ]	0.0	0.0	0.0	96.7	0.0	3.3
[tɑ]	0.0	0.0	0.0	0.0	100.0	0.0

Table A5: *Vietnamese Group, fricatives before* [i]

	fin	*think*	*sing*	*ship*	*till*	*chip*
[fi]	40.0	60.0	0.0	0.0	0.0	0.0
[θi]	0.0	98.3	0.0	0.0	6.7	0.0
[si]	0.0	20.0	60.0	20.0	0.0	0.0
[ʃi]	0.0	0.0	0.0	100.0	0.0	0.0
[ti]	0.0	0.0	0.0	0.0	100.0	0.0

Table A6: *Vietnamese Group, fricatives before* [ɑ]

	fan	*thank*	*sand*	*shine*	*tank*	*child*
[fɑ]	80.0	0.0	0.0	0.0	20.0	0.0
[θɑ]	6.7	73.8	0.0	0.0	20.0	0.0
[sɑ]	0.0	0.0	100.0	0.0	0.0	0.0
[ʃɑ]	0.0	0.0	26.7	73.3	0.0	0.0
[tɑ]	0.0	20.0	0.0	0.0	80.0	0.0