An acoustic analysis of the variation in alveolar fricative /s/ production in Hong Kong Cantonese

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Abstract

Cheung (2005) conducted the first systematic perceptual study on the allophonic variation of /s/ production in Hong Kong Cantonese, with the variables age, gender and vowel context found to be contributing to the variation. The current study was an extension of Cheung (2005) aiming to objectively investigate the phenomenon through acoustic analysis and further our understanding on the variation. Five acoustic measurements (spectral peak and the first four spectral moments) were employed. Results indicated that there were two distinct categories of the variation (alveolar [s] and post-alveolar [s]) but no distinctive categories were found among the post-alveolar realizations, which was inconsistent with the observations frequently mentioned in the literature. Besides, spectral mean and kurtosis were found to be the key measurements for discriminating between the different places of articulation of this variation. Possible reasons for these findings as well as the clinical and research implications were discussed.

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Phonology is defined as the study of speech sounds regarding the systematic rules governing the pronunciation that brings about meaning in a language, while phonetics is concerned with the articulatory, perceptual and physical characteristics of sounds of speech (Ball, Rahilly & Trench, 1996). A phoneme is a speech sound that is capable of conveying a change in meaning. Variations in phonemes may occur at the phonemic or phonetic level, with the phonemic level of variations resulting in a change of meaning. When the variation takes place at the phonetic level, no meaning contrast would be shown. The alternative realizations of the sounds that are phonetically similar (i.e. produced with similar place and manner of articulation) are termed allophones (Lowe, 1994).

Apart from studying the organization of speech sounds in a language, phonology is also concerned with sound changes. In sociophonology, variations in pronunciation that are socially significant (i.e. the differences are shared by groups of speakers) are investigated (Honey, 1997). Factors such as age, gender, social group and region may lead to variations in speech. For instance, in American English vocalization of the post-vocalic /r/ have long been studied regarding the effects of gender as well as geographical locations (Labov, 2001; Labov 1966; Kurath & MacDavid, 1961 as reported in Ellis, Groff & Mead [2006]).

The sound changes in Hong Kong Cantonese

In Hong Kong Cantonese (HKC, henceforth), sound changes have also been observed. Matthews and Yip (1994) reported several patterns of observed variations. Firstly, the initial alveolar nasal /n/ is produced as alveolar lateral [l], for example, /nei$_{23}$/ 你 ('you') is produced as [lei$_{23}$] 李 (a Chinese surname). This variation is noticed to be affected by age and social variables. For example, Chan and Li (2001) reported that this variation is common in the young population, while Matthews and Yip stated that in the older population this variation occurs in less formal speech registers.

The second observed pattern is the production of initial labio-velar stop /kw/ as velar stop [k]. For instance, the word /kwɔ$_{33}$/ 過 ('cross') is pronounced as [kɔ$_{33}$] 個 (a classifier) (Zee, 1996). Matthews and Yip (1994) stated that this variation is again more frequently observed in less formal speech and among young speakers.

For the above two variations, ambiguity of meaning arises at single word level. However, at conversational level the meaning is disambiguated with the support of contextual information.

The third variation is the realization of alveolar fricative /s/ as alveolar fricative [s], alveo-palatal fricative [¥] or palatal fricative [ʊ] (Bauer & Benedict, 1997). It is suggested that there is a tendency for the high front vowel /y/ to cause palatalization of /s/ to either [¥] or [ʊ], e.g. /sy$_{55}$/ 書 ('book') may be pronounced as either [¥y$_{55}$] or [ʊy$_{55}$]. Unlike the two

variations mentioned above, since there is no palatal fricative in HKC, no ambiguity of meaning arises at either single word or conversational level.

Apart from initial consonants, variation also takes place among final consonants. One observed pattern is the realization of final velar nasal /-ŋ/ as final alveolar nasal [-n]. For instance, /saŋ$_{55}$/ 生 ('produce') is produced as [san$_{55}$] 山('mountain'). It is suggested that this variation is under a vowel context effect, as it occurs more frequently after the vowel /a/.

There are several other patterns of sound change mentioned in Matthews and Yip (1994). The first one is the realization of initial velar nasal /ŋ/ as glottal stop [ʔ], e.g. /ŋɔ$_{23}$/ 我 ('I') → [ʔɔ$_{23}$]. Secondly, the initial aspirated /k^{h}/ may be pronounced as glottal fricative [h], as in the example /k^{h}ɵy$_{23}$/ 佢 (personal pronoun) → [hɵy$_{23}$]. The third one is the realization of the syllabic nasal /ŋ/ as [m], e.g. /ŋ$_{21}$/ 吳 (a Chinese surname) → [m$_{21}$]. Lastly, the final velar plosive /-k/ may be produced as an alveolar plosive [-t], e.g. /bak$_{3}$/ 百 → [pat$_{3}$].

In spite of these observed changes, very limited systematic studies have been reported so that conclusive generalizations on the nature of the sound changes cannot be reached (Zee, 1996).

A recent systematic study on /s/ variation in HKC

Cheung (2005) carried out a perceptual study on the allophonic variation of /s/ in HKC, which was the first systematic study on this phenonmenon. She recruited a sample consisting of 58 female and 59 male normal speakers which formed three age groups (Teenagers: 14 to

18 years old; Adults: 30 to 40 years old; Older Adults: 55 years old or above). The participants' production of /s/ at both word level and connected-speech level was narrowly transcribed by two trained listeners upon four choices: (1) alveolar fricative [s]; (2) palatalized alveolar fricative [sʲ]; (3) palatal fricative [ʃ], and; (4) 'others'.

The effects of age, gender and vowel context (i.e. rounded versus unrounded vowels) were examined by comparing the mean percentage of alveolar fricative [s] production of the groups. A significant main effect of age was found, as older adults tended to produced more allophonic variations than teenagers. A main effect was also found for gender, with a higher occurrence of allophonic variations in male than female. Moreover, a vowel context effect was found. The variation was more likely to occur when the target /s/ was followed by a rounded vowel.

Acoustic phonetics and the normal variation of /s/

The previous study on the normal variation of fricative /s/ in HKC was only based on perceptual phonetic analysis. However, with the nature of the variation being the change in place of articulation, subjective measures such as perceptual analysis would not be able to capture the variation quantitatively. As a result, the articulatory and physical properties of the change in speech sounds should be investigated.

Fricative consonants are produced with a narrow constriction at any point that articulators approximate along the vocal tract (Ohde & Sharf, 1992;). A turbulence is created

by the rapid flowing of air though the constriction, with the varying speed of the air flow forming the sound source. There have been a number of acoustical studies on fricatives in English, and the acoustic cues that are reliable in distinguishing between the different places of articulation of fricatives have been reported (Jongman et al., 2000; Evers, Reetz & Lahiri, 1998; Hedrick, 1997; Forrest et al., 1988; Behrens & Blumstein, 1988; Heinz & Stevens, 1961). Kent & Read (2000) concluded that there are several acoustic cues to the identification of the alveolar and palatal fricatives in English: (1) spectral peak location; (2) the first four spectral moments (i.e. spectral mean, spectral variance, skewness and kurtosis); (3) observation of energy concentration at particular frequency region, and; (4) measurement of spectral slope at the high-frequency and low-frequency regions.

Comparing the alveolar and palatal fricative, Jongman et al. (2000) found that regarding the above four acoustic cues, when the place of articulation was more posterior, a lower spectral peak and spectral mean, a larger spectral variance, a less negative skewness and a smaller kurtosis value would be shown. Behrens and Blumstein (1988) found that alveolar fricative tended to have a higher energy concentration in the 3500 Hz to 5000 Hz region, while Evers et al. (1998) found that alveolar fricative had a shallower slope below the 2500 Hz region.

Aims of the current study

Cheung's (2005) showed that there exists the effect of age, gender and vowel context on

the allophonic variations of /s/ in HKC based on her perceptual investigation. However, the change in the physical properties of the variations in place of articulation was not captured. It was not known objectively how different the variations of /s/ were. In order to quantify the difference, an acoustic analysis should be carried out.

Secondly, although several acoustic variables were reported to be able to distinguish between different places of articulation of fricatives, it is not known which of the parameters are most powerful in discriminating between the allophones of /s/ in HKC. In order to provide recommendations on the choice of acoustic parameters for future studies on this fricative variation, the contribution of each parameter should be investigated.

In addition, there is no agreement regarding the perceptual realizations of the allophones yet, except the general agreement on the realization alveolar [s]. Rao, Ouyang and Zhou (1996) described the other realization as a palatal [ʊ] while Chao (1947) used the phonetic transcription palato-alveolar [¥]; Bauer and Benedict (1997) suggested that both [¥] and [ʊ] exists, while Cheung (2005) noted that the label palatalized alveolar fricative [s^{j}] was used in anecdotal reports. In order to investigate the possible distinctive categories among the variations, objective measurements obtained from acoustic analysis could be incorporated into a qualitative exploratory data analysis.

Method

Materials

There were two groups of stimuli (i.e. the alveolar [s] and the post-alveolar [s] groups) in the current study. They were extracted from the speech samples of Cheung's study (2005) and the selection procedure is illustrated below.

In Cheung's study (2005) there were a total of 9360 disyllabic word speech samples with the phoneme /s/ at within-word position. Among those samples, 87.82% were rated as alveolar [s], 10.41% were rated as a palatalized [sʲ] or a palatal [ʃ], and the remaining were rated as 'others'. All the samples rated as a palatalized [sʲ] or a palatal [ʃ] were included in the current study, forming the post-alveolar [s] group. One hundred and five samples of those rated as alveolar [s] were included, forming the alveolar [s] group. The alveolar [s] group was consisted of only 105 samples, which was around 10% of the post-alveolar [s] group, because this group aimed at providing normative data regarding the most common realization of normal /s/ variations. The stimuli rated with other places of articulation in Cheung's (2005) study were not included in the current study (e.g. dentalized [s]), as they only accounted for a very small proportion among all the samples.

Nevertheless, 166 of the post-alveolar [s] samples were discarded due to the presence of a low-frequency background noise in part of the post-alveolar [s] samples, which hindered the acoustic measurements. As a result, there were a total of 913 speech samples, with 808 samples belonging to the post-alveolar [s] group and 105 samples belonging to the alveolar [s] group.

Acoustic analysis

Regarding the acoustic cues, measurements of the spectral peak and the first four spectral moments were employed in the current study as they were capable of distinguishing between places of articulation of fricatives. The other two cues mentioned above (i.e. observation of energy concentration and measurement of spectral slope) were not chosen as they are reliable only when the vowel context following the fricative consonants is constant, which is a criterion that the stimuli of the current study did not satisfy.

The Praat software version 4.4.13 (Boersma & Weenink, 2006) was used in the acoustic analysis. All the acoustic signals were digitized at a sampling frequency of 22 kHz. The acoustic measurements were obtained according to the procedures described by Jongman et al. (2000).

For the spectral peak location, a 40-ms full Hamming window was placed in the middle of the frication noise to generate an FFT spectrum. The peak with the highest amplitude in the spectrum was regarded as the spectral peak.

For the first four spectral moments, a 40-ms full Hamming window was used to calculate an FFT spectrum at the onset of the fricative, which is the point defined as “at which high frequency first appeared on the spectrogram” (Jongman et al, 2000). The first 40-ms was chosen since it was shown in Jongman et al. (2000) that this window location was more able to discriminate among fricatives’ places of articulation than others. Defining the

fricative onset was aided by locating the point nearest to zero crossing. The spectral mean, spectral variance, skewness and kurtosis of the selected interval were then computed by the computer program automatically.

Reliability

Pearson Product Moment Correlation was used in assessing the intra- and inter-judge reliability. The correlations were obtained by measuring 10% of the samples again by the investigator again and by another judge. The 10% of samples were selected with a rough proportion of balance among the variations in age, gender and vowel contexts.

Correlations for the acoustic measurements are summarized in Table 1. All of the correlations were significant at $p < .05$, and they were all high.

Table 1

Summary of Intra- and Inter-rater Reliability of the Acoustic Measurements

	Spectral peak	Spectral mean	Spectral Variance	Spectral Skewness	Spectral kurtosis
Intra-rater	0.88	0.90	0.88	0.94	0.84
Inter-rater	0.86	0.91	0.91	0.92	0.82

Data analysis

The means and standard deviations of the each of the five acoustic measurements of the two [s] groups were calculated and general observations on the distributions of the two

groups would be made. A non-parametric inferential statistical procedure, the Kruskal-Wallis one-way ANOVA with place of articulation as the factor, was used in comparing between the alveolar [s] group and the post-alveolar [s] group among the five acoustic variables at the same time since the two groups were of unequal group size.

Canonical discriminate function analysis was performed to investigate the contributions of each of the acoustic measurements in discriminating between the places of articulation of /s/. All observations (a total of 913 stimuli) were included in the analysis. The five acoustic measurements were regarded as the independent variables, while the perceived place of articulation (i.e. alveolar [s] and post-alveolar [s]) was regarded as the dependent variable. Statistically significant canonical function(s) (i.e. $p < .05$) were further investigated by examining the contribution of each of the five independent variables to the discrimination between the two [s] groups. The two variables with the greatest absolute magnitude of their respective standardized canonical discriminant function coefficients were considered as contributing most significantly.

For the exploratory data analysis on the post-alveolar [s] groups, a principal component analysis was performed on the post-alveolar [s] group so as to first reduce the dimensionality of the dataset (Everitt, 1994). The components that were capable of retaining the contribution of the acoustic variables to the variance were chosen based on the magnitude of the eigenvalue (i.e. eigenvalue > 1). After reducing the five variables into a few representative

components, the factor scores were then used in constructing a scatter-plot so as to investigate the presence of possible cluster structure among the post-alveolar [s] group. Possible cluster structures observed in the scatter-plot of the component scores would be indicators of further exploratory technique such as cluster analysis (Everitt, 1994).

Results

Table 2

Group means, Standard Deviations and Range of the Five Acoustic Measurements among the Two [s] Groups

	Alveolar [s] group			Post-alveolar [s] group		
	Mean	Standard deviation	Range	Mean	Standard deviation	Range
Spectral Peak (Hz)	5859.84	1124.17	5857.06	5227.23	1624.63	7063.85
Spectral Mean (Hz)	6104.63	735.30	4370.06	5035.06	1026.90	6382.33
Spectral Variance (MHz)	4.07	1.81	9.09	5.14	2.44	20.91
Spectral Skewness	-0.55	0.81	3.47	-0.12	0.76	6.20
Spectral Kurtosis	3.97	3.12	20.35	1.16	2.80	33.47

Table 2 shows the group means, standard deviations and range of each of the acoustic measurements among the two [s] groups. It was observed that for all the measurements, the range of the post-alveolar [s] group was larger than the alveolar [s] group.

A one-way ANOVA was performed among the five acoustic variables at the same time, with the variation in place of articulation as the factor. The result is summarized as follow:

Spectral peak

The spectral peak of alveolar /s/ group (5859.84 Hz) was significantly higher than the backward-shift /s/ group (5227.23 Hz), $p < .05$.

Spectral Mean

The spectral mean value of the alveolar [s] group (6104.63 Hz) was significantly higher than the post-alveolar /s/ group (5035.06 Hz), $p < .05$.

Spectral variance

The spectral variance of the alveolar [s] group was significantly smaller than the post-alveolar [s] group (alveolar [s] = 4.07 MHz; post-alveolar [s] = 5.14 MHz), $p < .05$.

Spectral skewness

The alveolar /s/ group was found to have a significantly more negative skewness value (-0.55) than the post-alveolar [s] group (-0.12), $p < .05$.

Spectral kurtosis

The alveolar [s] group had a significantly larger kurtosis value than the post-alveolar [s]

group (alveolar [s] = 3.97; post-alveolar [s] = 1.16), $p < .05$.

In conclusion, the two [s] groups differed significantly among all five acoustic measurements. Further analysis was then performed to determine which of the five measurements appeared most important in guiding the listeners' perception of the difference in place of articulation, and whether two or more explanatory clusters could be formed by reducing the dataset.

Discriminant Analysis

Only one canonical function was obtained as there were two groups to be discriminated. The canonical function was statistically significant ($p < .05$). The standardized coefficients of each of the acoustic measurements are summarized in Table 3.

Table 3

Standardized Canonical Discriminant Function Coefficients of the Five Acoustic Measurements

	Standardized coefficient
Spectral Peak	-0.11
Spectral Mean	0.72
Spectral Variance	0.31
Spectral Skewness	-0.07
Spectral Kurtosis	0.79

The standardized coefficients revealed that among the five measurements, spectral kurtosis (0.79) and spectral mean (0.72) contributed most significantly to the discrimination between the two /s/ groups.

Principal Component Analysis

Two principal components were chosen with respect to the eigenvalue (i.e. the eigenvalue was larger than one). After reducing the five acoustic measurements into two principle components, a scatter-plot was made so as to visually examine the patterns of the distribution of the data and notice a possible clustering phenomenon (see Figure 1).

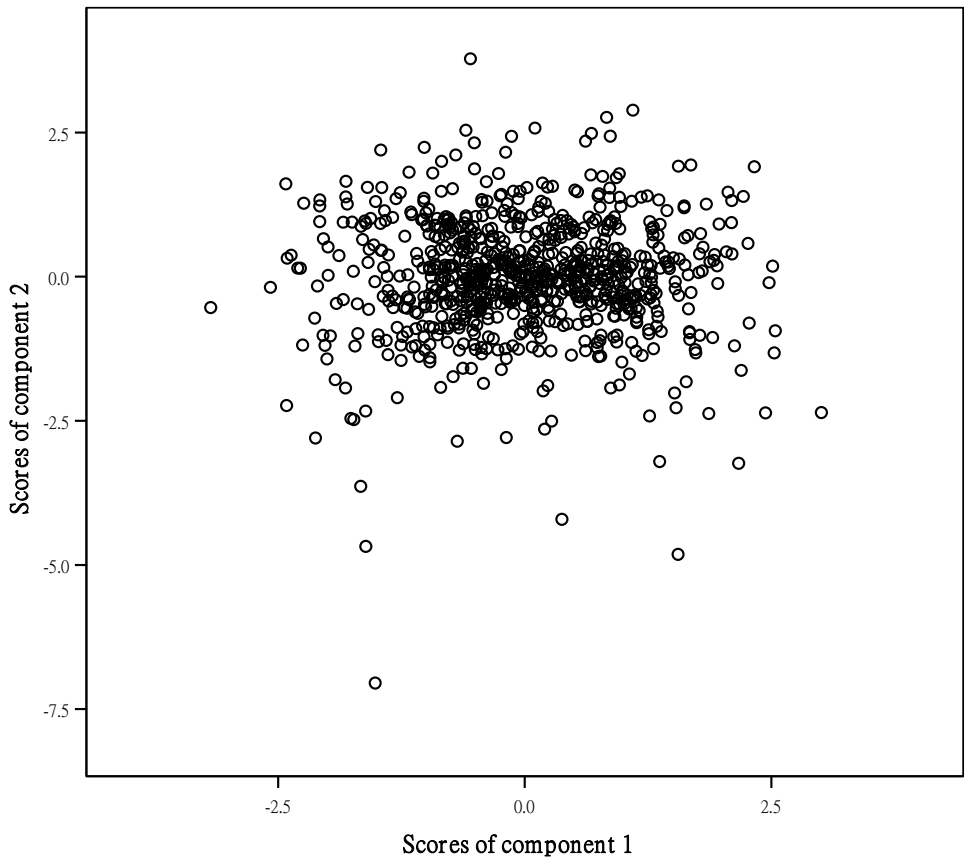

Figure 1. A scatter-plot of the scores of the two principal components of the post-alveolar [s] group.

As shown in Figure 1, no distinctive clusters was present among the post-alveolar /s/ groups, and thus further data mining techniques such as cluster analysis were not implemented (Everitt, 1994).

Discussion

This study aimed at investigating the allophonic variation in fricative /s/ production in HKC using acoustic analysis. The allophonic variation in /s/ production was first systematically examined by Cheung (2005) in a perceptual study, with the variables age, gender and vowel context found to be contributing to the variations. This study was an extension of Cheung (2005) in order to objectively investigate the change in physical properties of this allophonic variation, to provide recommendations on the selection of acoustic cues in future studies of /s/ in HKC, and to study the possible distinctive clusters among the variation of /s/ frequently mentioned (Chao, 1947; Matthews & Yip, 1994; Rao et al., 1996; Bauer & Benedict, 1997).

Through the acoustic analysis, the change in physical properties of the allophonic variation was quantified. It was found that the realization alveolar [s] had a higher spectral peak and spectral mean, a smaller variance, a more negative skewness and a larger kurtosis than post-alveolar [s]. It indicated that the realization post-alveolar [s] had a concentration of energy at the lower-frequency region, and less clearly defined peaks in its spectrum. This finding was in agreement with previous acoustical studies on fricatives with these acoustic

measures employed (Jongman et al., 2000; Forrest et al., 1998). According to Kent & Read (2002), an integrated understanding of speech sounds require the study of perceptual, physiological and acoustical phenomena. The quantification of the change in acoustical properties thus supplements the understanding of the allophonic variation of /s/ in HKC.

As mentioned above, the allophonic variation of /s/ has been mentioned frequently but a lack of systematic reports was noted. In order to investigate it through acoustic measurements, a number of acoustic measurements were included in this study so as to capture as much information as possible. However, in future acoustical studies, in order to be more efficient examination of only a few acoustic parameters that were found to be able to significantly discriminate between the different place of articulation in /s/ production would be more desirable. In the current study, the two [s] groups differed significantly among all five variables, suggesting that all of them could be used in investigating the variation in place of articulation. Nevertheless, spectral mean and spectral kurtosis were the two variables contributing most significantly to the discrimination, which indicated that in future acoustical studies on this variation, these two acoustic cues should be considered.

In addition, Jongman et al. (2000) stated that both local and global spectral information are important in identifying different places of articulation of fricatives. Local spectral information refers to the spectral peak, spectral mean and variance, while global information refers to the spectral shapes, as reflected in the skewness and kurtosis (Forrest et al, 1998;

Jongman et al., 2000). The result of the current study in fact agrees with Jongman et al.'s statement on the selection of acoustic cues to places of articulation of fricatives, as spectral mean and kurtosis are local and global spectral information respectively. This finding provides recommendation for acoustical study on the variation of /s/ in HKC.

In the literature there appears no widely accepted phonetic transcription on the realizations of the variation, except the general agreement on describing the more common realization alveolar [s]. A number of labels, such as alveolar [s], palatal [ʃ], palato-alveolar [ɕ] and palatalized alveolar fricative [s^{j}], have been used by different authors (Chao, 1947; Matthews & Yip, 1994; Rao et al., 1996; Bauer & Benedict, 1997; Cheung 2005). It appeared that there would be distinctive categories among the places of articulation among the realizations. This claim was in fact supported in the current study. The alveolar [s] and post-alveolar [s] were found to be two distinctive categories, with the post-alveolar [s] produced at a more backward place of articulation as shown in the acoustic measurements (Jongman et al., 2000; Kent & Read, 2002).

Among the post-alveolar [s], however, the scatter-plot revealed that there was no distinctive categories such as the above-mentioned palatalized alveolar fricative [s^{j}], palato-alveolar [ɕ], palatal [ʃ]. There are two possible explanations for the lack of distinctive categories observed. Firstly, in Cheung's study (2005) the trained listeners commented that "it was not easy to make a clear distinction between palatalized alveolar fricative [s^{j}] and palatal

fricative [ʊ̟]" (p.11). It may imply that there is in fact no distinctive category among the post-alveolar productions, but only the two distinctive categories alveolar [s] and post-alveolar [s]. Secondly, it might have been due to the limitation of the information captured by the acoustic measurements employed. Borden, Harris and Raphael (2003) suggested that apart from the difference in place of articulation, alveolar /s/ and palatal /ʊ̟ also differs in the size of the midline groove at the tongue and the extent of lip rounding and lip protrusion. Palatal /ʊ/ is produced with a shallower midline groove, and there is a certain extent of lip rounding and protrusion in /ʊ/ production. Regarding the acoustic cues employed in the current study, they were found to be sensitive to change in place of articulation of fricatives only. As a result, the lack of distinctive categories shown in the current study would only imply that there was no distinctive categories among the post-alveolar production with reference to place of articulation. Further studies investigating other dimensions of the change (e.g. size of the midline groove) among the post-alveolar production is suggested.

There were clinical implications of the current study. Alveolar fricative /s/ is a vulnerable sound in disordered speech (Whitehill & Ciocca, 2000). It is also a difficult sound in normally developing speech, as it is a late sound to be acquired by Cantonese-speaking children and the latest sound to be acquired among the fricatives in HKC (Cheung & Abberton, 2000). In the clinical setting it is essential to have a clear idea of what is normal,

especially on this vulnerable sound, in order to give an accurate diagnosis for clients with possible phonetic/phonological delay and/or disorders. With reference to the significant difference between the two realizations of the /s/ variation (i.e. alveolar [s] and post-alveolar [s]) found in the current study as well as the age and gender effect on this variation found in Cheung's study (2005), it can be concluded that the fricative /s/ production in HKC is undergoing change. Since these two distinctive realizations of /s/ do not result in ambiguity of meaning, the acceptability of the variations in clinical setting is an issue raised.

This acoustical study also has research implication on the allophonic variation of fricative /s/ in HKC. The fact that in Cheung's study (2005) the two listeners were able to distinguish between the post-alveolar productions as two distinct categories [sʲ] and [ʊ] contrasts with the findings of the current study that no distinctive clusters was shown among the post-alveolar [s] group. This contrasts indicated two directions of further investigation. Firstly, other instrumental studies such as electropalatographic (EPG) analysis, a technique that allows the collection of temporal and spatial information regarding the tongue-palatal contacts, may be carried out so as to provide further objective data of the variation (Hardcastle & Gibbon, 1997). More dimensions of the change, such as the size and width of the groove at the tongue, would be captured by electropalatography. By further collecting information on the physiological aspect to supplement the acoustical findings of the current study and the perceptual findings from Cheung's study (2005), a comprehensive

understanding of the allophonic variation of /s/ would be reached (Kent & Read, 2002). Secondly, regarding the comments made by the two listeners in Cheung's study on the difficulty in making a clear judgement on the post-alveolar productions and the fact that only two listeners were recruited, the perceptual study may be replicated with more trained listeners or recruiting expert listeners so as to increase the perceptual reliability.

In conclusion, this follow-up study of Cheung (2005) furthered our understanding of the allophonic variation of /s/ in HKC. Two distinctive categories (i.e. alveolar [s] and post-alveolar [s]) were found and the physical properties of the variation were quantified. However, no distinctive categories were found among the post-alveolar realizations, which was inconsistent with the description in the literature (Chao, 1947; Matthews & Yip, 1994; Rao et al., 1996; Bauer & Benedict, 1997). Recommendations for further studies on this phenomenon such as the selection of acoustic cues were also provided.

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