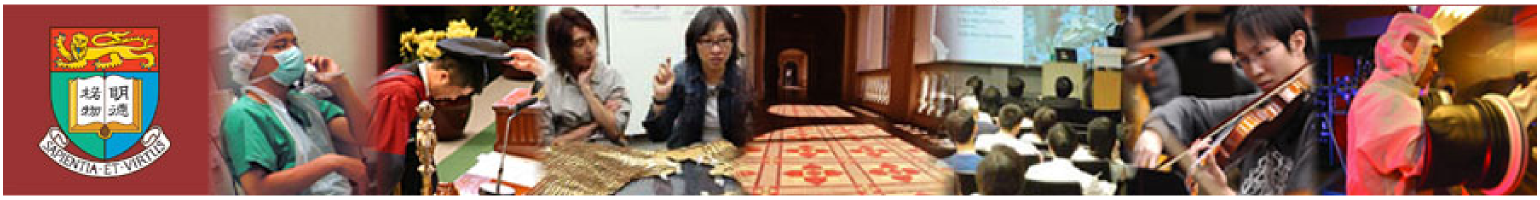


| | |
|---|---|
| Title | Cantonese affricates |
| Author(s) | Yiu, Hoi-yee, Heidy; 姚凱怡 |
| Citation | |
| Issued Date | 2008 |
| URL | http://hdl.handle.net/10722/173657 |
| Rights | Creative Commons: Attribution 3.0 Hong Kong License |

# Cantonese affricates :

# an acoustic analysis

**Yiu Hoi Yee, Heidy**

A dissertation submitted in partial fulfillment of the requirements for the Bachleor of Sciences (Speech and Hearing Schiences), The University of Hong Kong, June 30, 2008

## ABSTRACT

The purpose of this study was to compare the stop and fricative component of Cantonese affricates (/ts/ and /ts$^h$/) with their stop (/t/,/t$^h$/) and fricative (/s/) counterparts. The subjects were 12 Cantonese speaking adults, who had no history of speech, language, hearing or visual problems. The speech stimuli were 60 target words embedded in a carrier phrase. Each target word contained a target phoneme (/ts/, /ts$^h$/, /t/, /t$^h$/, /s/) which was in minimal or close to minimal pairs. The acoustic measures employed were frication period, closure period, and voice onset time (VOT). There were significant differences between the frication period of affricates and fricatives. There were also significant differences between the closure period and the VOT of affricates and stops. The shorter frication period and closure period of affricates were suggested to result from the effects of sequential articulations within the phoneme. The longer VOT in affricates was due to the presence of a frication period in the release phase. This study described temporal features of affricates using acoustic analysis and provided normative data about Cantonese affricates.

# INTRODUCTION

An affricate is defined as a sequence of stop followed by a homorganic fricative (Catford, 1977; MacKay, 1987; Ladefoged, 2001). It is considered as a single phoneme, even though it contains two components. Similar to stops, affricates are produced with a shutting and closure phase. While, similar to fricatives, affricates involve with a period of frication noise which is produced by air escaping through narrow constricting articulators at high velocity (Johnson., 2003). The purpose of this study was to compare the stop and fricative component of Cantonese affricates /ts/, /ts$^h$/ to stops /t/,/t$^h$/ and fricatives /s/ in time aspects. This study was a part of a cross linguistic project, "Cross-Linguistic Phonetic Survey of Affricates", organized by M. Ball and N. Müller.

Cantonese has two affricates, /ts/, /ts$^h$/, which are articulated at alveolar region and contrast in aspiration (Zee, 1991; Cheung & Abberton, 2000; Ng & Cheung, 2002). Affricates are produced with shutting, closure and release phases (Johnson, 2003). When producing the Cantonese affricates /ts, ts$^h$/, lingual alveolar contact is produced for the stop component (/t/) in closure phase. As the vocal tract is completely constricted, intraoral pressure is built behind the place of articulation by using the tongue tip (Johnson, 2003). Then, in the release phase, a central groove is produced (Clark & Yallop, 1995) for the fricative component (/s/). In this delayed release, the air kept under high pressure escapes through the narrow constriction at high velocity. Frication noise is produced as a result.

Studies in English and other languages (e.g. Fletcher, 1989; Kent & Read, 1992; Byrd, 1993;

Szymanski, 2005) have found that the stop and fricatives were different from the affricate they resemble in several aspects. However, the number of studies comparing affricates, especially Cantonese affricates, to their stop and fricative counterparts are limited (Szymanski, 2005). Most previous studies only compared these phonemes briefly, using phonological or palatographical approaches. Although palatography studies provide information about the articulatory movements of phonemes, it is unable to show the relationship between articulation and speech sounds or the characteristics of speech sounds (MacKay, 1987). Also, palatography studies are not commonly available in clinics (Ladefoged, 2001). In contrast, acoustics studies provide information about the physical aspects of speech sounds, such as the frequency, intensity and duration, which are related to the perception of speech (MacKay, 1987). Therefore, in order to have a better understanding about Cantonese affricates, an acoustic study for affricates is needed.

Phonologically, affricates have been classified differently by different authors (Grunwell, 1987). Affricates have been classified as stops (Lisker & Abramson, 1964), as stops with fricatives in delayed release stage (Katamba, 1989; Schane, 1973), and fricatives with abrupt onset (Gibbon & Hardcastle, 1994). Clark and Yallop (1995) classified affricates according to the duration and strength of frication noise. Affricates with short duration and weak strength were suggested to be "affricated stops", while affricates with long and strong frication were classified as affricates. Affricates were classified by Ladefoged as both stops and fricatives (1971), stops (1993) and affricates (2001). The disagreements and problems in classifying affricates could be due to the complexity involved in their articulation.

Palatography has been used to show the complexity involved in articulating affricates and its stop and fricative components. Fletcher (1989) investigated the similarity between the stop and fricative components of English affricates /tʃ/, /dʒ/ and plain stops /t/, /d/ and fricatives /ʃ/, /ʒ/. The fricative component of affricates had similar place of articulation, pattern of lingual-palatal contact and magnitude of contact as the plain fricatives (Fletcher, 1989). The dimension of groove created for frication and the duration of frication were also comparable between the fricative component of affricates and the plain fricatives (Fletcher, 1989). However, the place of articulation was different between the stop components of affricates and the plain stops (Fletcher, 1989). The stop components also had greater lingual-palatal contact area and longer voice onset time than the plain stops.

Acoustic analysis may also assist us in understanding affricates by relating their articulatory gestures to their acoustic features. On oscillogram, an affricate first appears as a stop gap when the speaker produces the stop component in the closure phase. It is then followed by an abrupt aperiodic rise in wave, which represents the burst and frication noise in the release phase (Kent & Read, 2002). Finally, a periodic wave for the voicing of vowel follows (Lieberman & Blumstein, 1988; Kent & Read, 2002). Various authors (Kent and Read, 2002; Johnson, 2003) suggested that the rise time of affricates is longer than that of stops, but shorter than that of fricatives. Rise time is the duration required for a phoneme to release its energy at maximum or near maximum amplitude. In addition, the frication period of affricates has been found to be slightly shorter than that of fricatives (Kent and Read, 2002). These are because, like stops, the place of articulation of affricates is totally obstructed and energy could be built behind the place of articulation. For stops, the articulators are opened, air is released under high pressure at high velocity (Johnson, 2003). However, as affricates involve a fricative component in the release phase, air is released gradually (Kent and Read, 2002). Therefore, affricates have a longer rise time than stops and a frication time shorter than fricatives. Since affricates involve a period of frication, voice onset time (VOT) would also be longer than that of stops. The rise time and frication time of affricates reflect that affricates combine the acoustics features of both stops and fricatives.

The results of acoustic studies concur with Fletcher's (1989) palatographic results, which suggested that affricates had a longer voice onset time than stops. However, Fletcher (1989) only concluded that the frication period of affricates and fricatives were comparable and did not state clearly the relationship between them. There are relatively few studies which focused on comparing affricates, fricatives and stops. The results of these few previous studies need to be verified and further developed. More studies comparing the similarities and differences between affricates, stops and fricatives are needed.

Cross linguistic studies allow us to have a deeper understanding about the nature of affricates. Fletcher (1989) showed that English affricates (/tʃ/, /dʒ/ ) were more comparable to their fricative component (/ ʃ/, ʒ/) than their stop component in terms of place of articulation. The results of Cantonese (Kwok, 1992) and Mandarin (Svantesson, 1983; Ladefoged & Wu, 1984) studies also supported Fletcher's view. The Cantonese EPG study found that affricates /ts, $ts^h$/ and fricatives /s/ were articulated at a similar place of articulation, but were more posterior than that of stops /t, $t^h$/ (Kwok, 1992). A Mandarin palatography study also suggested that affricate /ts/ had similar place of articulation as fricative /s/ (Ladefoged & Wu, 1984). An acoustic Mandarin study again concluded that the fricative component of affricates resembled more of the plain fricatives (Svantesson, 1983).

Affricates are one of the phonemes that pose most difficulty for children to acquire (So & Dodd, 1994; Stokes &Whitehill, 1996; Cheung & Abberton, 2000). Clinically, without a clear understanding about affricates, clinicians are less able to provide effective phonological treatment for the phonemes. Besides, if affricates are acoustically described with normative data, clinicians will be able to compare the disordered speech to that of the norm. Although palatographic studies provided information about the dimensions and articulations of affricates, limited information was provided about the physical aspect of speech sounds. Temporal aspects of speech sounds are critical as they can influence categorical perception in speech recognition (Ryalls, 1996). Time duration could be measured by acoustics analysis, which is better in describing and analyzing features of phonemes (Ladefoged, 2001). Also, the use of acoustic analysis is more accessible and affordable in clinics (Ladefoged, 2001).

The aim of this study was to compare the stop and fricative component of Cantonese affricates (/ts/, /$ts^h$/) to stops (/t/,/$t^h$/) and fricative (/s/). The phonemes were compared acoustically in three time aspects, including (1) frication period, (2) closure period and (3) voice onset time (VOT).

Frication period was compared as affricates contain a fricative component, which was characterized by frication noise and long frication period. Closure period and VOT were compared as affricates also contain a stop component, which includes both closure and release phase of stop.

## METHOD

### Subjects

The subjects were 12 normal speaking adults. In order to get a representative speech sample, subjects of different gender and age group were recruited. The subjects were from two age groups: mature adults (30-53 years old) and young adults (20-30 years old). There were three males and three females in each male age group. The subjects were native Cantonese speakers and had no history of speech, language, hearing and visual problems. All subjects passed a pure tone audiological screening test, except from three subjects. The three subjects who did not receive or pass hearing screening reported no history of hearing problems, or was observed to have no problems in perceiving speech at normal conversation level. The pure tone screening test was conducted at 25 dB HL at 500 Hz, 1000 Hz, 2000 Hz and 4000 Hz in a sound treated room. The subjects had normal speech patterns, as screened from interview. The subjects were recruited from the Department of Speech and Hearing Sciences in the University of Hong Kong and the investigator's personal contacts.

### Stimuli

The speech stimuli were 60 target words embedded in a carrier phrase. The carrier phrase was

"我講___俾你聽" ("I say ___ to you"). Each target word focused on a target phoneme: /ts/, /ts$^h$/, /t/, /t$^h$/ or /s/. The target phoneme was placed in word initial and word medial position in the target word. For word initial position, the target phoneme was placed in a monosyllabic word. For word medial position, the target phoneme was placed in disyllabic syllable initial word final (SIWF) position. Target phoneme in word initial position was placed with different vowel context, /a/, /ɛ/, /i/, /ɔ/, /u/, to form a real word. For target phoneme in word medial position, the coda of its preceding syllable was varied as the different vowels mentioned. The syllable structure of target word was controlled as CV or CVC structure. The tone of the target word was controlled as tone 1 (high level), although four target words had a different tone in order to compose real words. In order to allow phonemes to be compared in pairs (e.g. /t/compared to /**t**s/, /t$^h$/compared to /**t**s$^h$/), two sets of stimuli for /s/ were prepared. This was referred as /s/ and /s'/. This allowed two separate sets of /s/ words to be compared to /t**s**/ and /t**s**$^h$/ words. Each target phoneme with different combination of vowel context and word position appeared once in the stimuli list, except from the two identical sets of /s/ stimuli in word initial position. The stimuli were randomized and presented as a word list (appendix A) for the speakers to read aloud.

**Procedures**

The experiment took place in a sound treated room in the Department of Speech and Hearing Sciences. Data were collected from each subject individually. A word list with all stimuli randomized was presented to the subjects. The subjects were asked to read the list before reading the stimuli aloud. This allowed subjects to be familiar with the stimuli and avoided errors to be made during production of the carrier phrase. Each stimulus was produced repeatedly for five times. Verbal instructions and demonstrations were provided by the investigator. The subjects were asked to produce stimuli at a steady rate, with a controlled volume, intonation and stress. This aimed to avoid other variables that might affect results (Lisker & Abramson, 1964). The whole procedure lasted about 45 minutes. The data were collected by the investigator and two trained research assistants, who collected data of 6 subjects. The investigator and research assistants were all native Cantonese speakers and trained speech therapy students.

Speech samples were recorded by sound recording software MDVP in CSL (model 5105, version 2.4), Cool Edit 2000 and Audacity 1.2.6. A low noise unidirectional microphone AKG C525S was held at a mouth-to-microphone distance of 10 cm. A pre-amplifier, Aardvark Direct Mix USB3, was connected to a computer for recording.

**Acoustic analysis**

Although each stimulus “我講___俾你聽” (“I say __ to you”) was produced consecutively five times, only the middle 3 target phonemes were used. The middle three target phonemes of each stimulus were analyzed using the PRAAT version 5.0.02 software, and extracted to two decimal places. Data obtained from the three phonemes of a stimulus were then averaged. Three acoustic variables were measured: (1) frication period, (2) closure period, and (3) VOT. The fricative components of the affricates (i.e. the /s/ in /ts/, /$ts^h$/) were compared with plain fricatives for frication period. Whereas, the stop components of the affricates (i.e. the /t/, /$t^h$/ in /**t̠**s/, /**t̠**$s^h$/) were compared to plain stops for closure period and VOT. As this study was part of a large cross linguistic project (M. Ball), the methodology had to be consistent with other members of the project to allow comparisons to be made across languages.

Fricatives are characterized by the gradual release of frication noise (Kent & Read, 2002). Frication noise is produced by turbulent airflow (Johnson, 2003). Fricatives have a lower energy level than vowels, which contain vocal energy. Therefore, frication period was defined and extracted as the period between (1) the sudden drop of intensity (release of fricative), and (2) the sudden increase and transition of intensity (Stokes & Ciocca, 1999; M. Jones, personal communication, 26th April, 2007) (appendix B). As suggested by M. Ball (personal communication, 26th April, 2007), the intensity curve on spectrogram was used to identify the frication period, which appeared as a deepened, plateau period of curve. The corresponding waveform of frication should be aperiodic in the oscillogram.

For identification of VOT, in order to make the measurement objective and consistent across and within languages, the intensity curve was used (M. Jones, personal communication, 26th April, 2007). VOT was defined and extracted as the period between (1) the beginning of the periodic wave (voicing of vocal folds) in the oscillogram (Ladefoged, 2001), and (2) the lowest point of intensity curve in spectrogram (release of closure phase) (appendix C).When the beginning of periodic wave was less distinguishable on the oscillogram, the first wave indicated by the first vertical pulse (which represented glottal pulsing) was used (Lisker & Abramson, 1964).

Closure period is the period when articulators move towards each other and obstruct the vocal tract (Ladefoged, 2001). There is minimal intensity during closure period. Hence, closure period was defined and extracted as the period between (1) the end of the periodic wave of the preceding vowel in the oscillogram, and (2) the lowest point of the intensity curve in the spectrogram (total obstruction of vocal tract) (appendix D). For cases when the end of periodic wave was less distinguishable on the oscillogram, the last period wave indicated by the last vertical pulse (indicating glottal pulsing) was used (Lisker & Abramson, 1964).

The zero crossing method was used for identification of periodic wave. Intra rater and inter rater reliability of acoustic analysis were determined by re-analysising 5% of all data. For intra-rater reliability, 87% of data was within 11 msec difference for frication period, 100% of data was within 9 msec difference for closure period and 91% of data was within 10 msec difference for VOT. For inter-rater reliability, 87% of data was within 11 msec difference for frication period, 78% of data was within 15 msec difference for closure period and 96% of data was within 15 msec difference for VOT. The research assistant, who participated in data collection and was trained in acoustic analysis, was involved in the inter rater reliability test.

## RESULTS

The purpose of this study was to compare the stop and fricative components of Cantonese affricates (/ts/, /ts$^h$/) to plain stops (/t/,/t$^h$/) and fricative (/s/). Affricates were compared to plain fricatives in terms of frication period, and compared to plain stops on closure period and VOT.

The average, range and S.D. of frication period, closure period and VOT are summarised in *Table 1.* The values presented in *Table 1* were obtained from phonemes with different vowel context and word position. Therefore, the range of values was large.

***Table 1:*** *Mean, range and S.D. of frication period, closure period and VOT.*

| Time measurement | Phoneme | Mean duration (msec) | Range of duration (msec) | Standard deviation |
|---|---|---|---|---|
| Frication period | /s/ | 97.11 | 29.00-166.00 | 28.85 |
| | /s'/ | 89.58 | 10.33-168.00 | 27.85 |
| | /ts/ | 50.37 | 15.33-114.33 | 18.42 |
| | /ts$^h$/ | 68.58 | 15.00- 152.00 | 21.96 |
| Closure period | /t/ | 32.80 | 9.00- 66.00 | 9.25 |
| | /t$^h$/ | 25.78 | 10.33- 55.33 | 8.27 |
| | /ts/ | 27.55 | 9.33- 48.33 | 7.19 |
| | /ts$^h$/ | 19.79 | 5.00- 41.00 | 6.53 |
| VOT | /t/ | 46.06 | 13.00- 141.67 | 14.78 |
| | /t$^h$/ | 59.23 | 12.33- 138.33 | 26.43 |
| | /ts | 76.73 | 26.33- 141.00 | 19.25 |
| | /ts$^h$/ | 94.54 | 31.67- 170.33 | 23.85 |

**Effect of age and gender**

The effects of gender and age group were investigated first. A 2x2 Analysis of variance (ANOVA) for repeated measures was performed using all the data. The factors involved were gender (male, female) and age (mature 30-53 years old, young 20-30 years old). The results showed that either the effect of gender ($F = 2.75$, $p > 0.005$) nor the effect of age ($F = 0.204$, $p > 0.005$) were statistically significant. Therefore, the data collected from all subjects was entered and analyzed together in three separate AVOVAs, for frication period, closure period and VOT.

**Frication period**

As shown on *Table 1*, the average frication period of /s/ (97.11 msec) and /s'/ (89.58 msec) appeared to be longer than that of /tsʰ/ (68.58 msec) and /ts/ (50.37 msec). Frication period obtained from fricatives and affricates with different vowel contexts and word positions were averaged and presented in Table2.

***Table 2:*** *Mean frication period (msec) for phoneme /s/, /s'/, /ts/, /tsʰ/, with different vowels and word positions.*

| Phoneme for frication period | Initial position Vowel context | | | | | Medial position Vowel context | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | /a/ | /ɛ/ | /i/ | /ɔ/ | /u/ | /a/ | /ɛ/ | /i/ | /ɔ/ | /u/ |
| /s/ | 86.83 | 92.50 | 120.16 | 106.36 | 120.56 | 92.58 | 59.81 | 100.22 | 97.19 | 94.94 |
| /s'/ | 86.83 | 92.50 | 120.16 | 106.36 | 120.56 | 63.97 | 105.08 | 55.42 | 74.14 | 68.06 |
| /ts/ | 40.81 | 45.83 | 65.47 | 47.53 | 55.81 | 55.44 | 35.31 | 52.25 | 56.81 | 48.42 |
| /tsʰ/ | 69.69 | 67.50 | 108.69 | 62.48 | 80.78 | 57.03 | 83.39 | 49.81 | 52.69 | 53.78 |

The average frication period was calculated. At word initial position, the frication period of /s/ and /s'/ were 105 msec, for /ts/ was 51 msec, and for /tsʰ/ was 78 msec. At word medial position, the average frication period of /s/ was 89 msec, for /s'/ was 73 msec, for /ts/ was 50 msec, and for /tsʰ/ was 59 msec. As shown in *table 2*, in word initial position, the frication period for all phonemes (with some exceptions for /tsʰ/) appeared to be the longest when accompanied by vowel /i/, followed by /u/, /ɔ/, /ɛ/, and /a/. The frication period for /tsʰ/ followed a similar pattern, but its third longest frication period was obtained when accompanied by /a/ (69.69 msec), /ɛ/ (67.50 msec) and then /ɔ/ (62.48 msec). Although phonemes with /i/ had the longest frication period for word initial position, /s/ and /ts/ with /i/ had the shortest frication period in word medial position (*Table 2*). For word medial position, no pattern was immediately observed for all vowel contexts.

The measurement of frication period obtained from /s/, /s'/, /ts/, /$ts^h$/ were entered into a 4x2x5 ANOVA for repeated measures. The factors involved were phoneme (/s/, /s'/, /ts/, /$ts^h$/), word position (word initial, word medial) and vowel (/a/, /ɛ/, /i/, /ɔ/, /u/). The results showed that there was a significant main effect for phoneme ($F$ (3, 27) = 43.19, $p < 0.001$), for positions ($F$ (1, 9) = 66.03, $p < 0.001$) and for vowels ($F$ (4, 36) = 8.53, $p < 0.001$). There were also statistically significant interactions between phoneme and position ($F$ (3, 27) = 13.33, $p < 0.001$); between phoneme and vowel ($F$ (12, 108) = 11.67, $p < 0.001$); between position and vowel ($F$ (4, 36) = 31.55, $p < 0.001$); and between phonemes, positions and vowels ($F$ (12, 108) = 11.26, $p < 0.001$).

Post-hoc analysis, using Tukey's HSD test, was performed to further investigate the differences between phonemes. Results indicated that frication period of fricative /s/ (97.11 msec) and /s'/ (89.58 msec) was not significantly different from each other (Tukey, HSD, $p > 0.05$). Besides, the frication period of fricative /s/ and /s'/ were significantly longer than that of /ts/ (50.37 msec) (Tukey, HSD, $p < 0.05$) and from that of /$ts^h$/ (68.58 msec) (Tukey, HSD, $p < 0.05$). Also, the frication periods of /$ts^h$/ were significantly longer than that of /ts/ (Tukey, HSD, $p < 0.05$). In summary, fricatives had a significantly longer frication period than affricates, while aspirated affricates (/$ts^h$/) had a significantly longer frication period than unaspirated affricates (/ts/). Post-hoc analysis of vowels and word positions would not be carried out as they were not the main focus of this study.

Post hoc results showed that for the two way interaction between phonemes and vowels, the frication period of /s/ and /s'/ were significantly longer when accompanied by /u/, followed by /ɔ/, /ɛ/, and /a/ (Tukey, HSD, $p < 0.05$). The effect of all vowels on affricates /ts/ and /tsʰ/ were insignificant (Tukey, HSD, $p > 0.05$), except that the frication period of /tsʰɛ/ was longer than that of /tsʰɔ / (Tukey, HSD, $p < 0.05$). For the interaction between phonemes and positions, the average frication period of /s/, /s'/ and /tsʰ/ at word initial position were significantly longer than that of word medial position (Tukey, HSD, $p < 0.05$).

Post-hoc analysis was also performed to investigate the interaction between phonemes, positions and vowels. For /ts/ and /s/, results showed that the frication period of /s/ was significantly longer than that of /ts/ (Tukey, HSD, $p < 0.05$) when they were in all vowel contexts (/a/, /ɛ/, /i/, /ɔ/, /u/) in both word positions (initial and medial). For /tsʰ/ and /s'/, results showed that the frication period of /s'/ was significantly longer than that of /tsʰ/ (Tukey, HSD, $p < 0.05$) when they were with vowel /ɔ/, /u/ in word initial position, and vowels /ɛ/ in word medial position.

**Closure period**

As shown in *Table 1*, the average closure period of /t/ (32.80 msec) appeared to be longer than /ts/ (27.55 msec). The closure period of /tʰ/ (25.78 msec) also appeared to be longer than that of /tsʰ/ (19.79 msec). While, the unaspirated phonemes /t/, /ts/ were shown to have longer closure period than their aspirated contrastive pairs (/tʰ/, /tsʰ/). The mean closure periods obtained from stops and affricates in different vowel contexts and word positions were presented in *Table 3*.

***Table 3:*** *Mean closure period (msec) for phoneme* /t/, /t$^h$/, /ts/ and /ts$^h$/, *with different vowels and word positions.*

| **Phoneme for closure period** | **Initial position** *Vowel context* | | | | | **Medial position** *Vowel context* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | /a/ | /ɛ/ | /i/ | /ɔ/ | /u/ | /a/ | /ɛ/ | /i/ | /ɔ/ | /u/ |
| /t/ | 31.36 | 38.28 | 40.76 | 39. 89 | 36. 89 | 31.08 | 27.53 | 24.00 | 29.19 | 29.06 |
| / t$^h$ / | 25.64 | 23.18 | 31.05 | 25.44 | 31.94 | 24.92 | 24.81 | 21.78 | 29.25 | 19.76 |
| /ts/ | 27.28 | 28. 67 | 32.00 | 27.08 | 30.78 | 27.78 | 22.64 | 28.00 | 28.39 | 22. 89 |
| /ts$^h$/ | 20.61 | 20.39 | 19. 89 | 19.94 | 22.31 | 18.77 | 21.53 | 17.53 | 17.28 | 19.67 |

The average closure period was calculated. At word initial position, the closure period of /t/, /t$^h$/, /ts/ and /ts$^h$/ were 36.80 msec, 27.45 msec, 29.29 msec and 20.81 msec, respectively. Meanwhile, at word medial position, the average closure period of /t/, /t$^h$/, /ts/ and /ts$^h$/ were 28.17 msec, 24.10 msec, 26.70 msec and 18.96 msec, respectively.

The stop components of affricates (i.e. /**t**s/, /**t**s$^h$/) were compared to the plain stops /t/, /t$^h$/ for closure period. The closure period data was entered into a 3-way ANOVA for repeated measures. The factors involved were phoneme (/t/, /t$^h$/, /ts/, /ts$^h$/), word position (word initial, word medial) and vowel (/a/, /ɛ/, /i/, /ɔ/, /u/). The results showed that there was a significant main effect for phoneme ($F$ (3, 27) = 22.05, $p < 0.001$) and for positions ($F$ (1, 9) = 6.48, $p < 0.05$). There was also a significant interaction between phoneme and position ($F$ (3, 27) = 4.33, $p < 0.05$), between position and vowel ($F$ (4, 36) = 3.69, $p < 0.005$), and between phoneme, position and vowel ($F$ (12, 108) = 3.26, $p < 0.001$). There was no significant main effect for vowel ($F$ (4, 36) = 0.64, $p > 0.05$), and no significant interaction between phoneme and vowel ($F = 1.70$, $p > 0.05$).

Post-hoc results showed that the closure period of /t/ (32.80 msec) was significantly longer than that of /ts/ (27.55 msec). The closure period of /t$^h$/ (25.78 msec) was also significantly longer than that of /ts$^h$/ (19.79 msec) (Tukey, HSD, $p < 0.05$). Besides, the closure period of unaspirated phoneme (/t/, /ts/) were longer than that of their aspirated minimal pair (/t$^h$/, /ts$^h$/) (Tukey, HSD, $p < 0.05$). Post hoc analysis of word positions were not investigated as it was not the main focus of this study. Post hoc results showed that the interaction between phonemes and position was only significant for /t/ (Tukey, HSD, $p < 0.05$), when the closure period of /t/ at word initial position was significantly longer than that of word medial position.

Post-hoc analysis was also performed to investigate the interaction between phonemes, positions and vowels. The closure period of /t/ was significantly longer than that of /ts/ in vowel context /ɔ/ in word initial position (Tukey, HSD, $p < 0.05$). For /t$^h$/ and /ts$^h$/, the closure period of /t$^h$/ was significantly longer than that of /ts$^h$/ in vowel context /i/ in word initial position (Tukey, HSD, $p < 0.05$), and vowel context /ɔ/ in word medial position (Tukey, HSD, $p < 0.05$).

**VOT**

From *Table 1*, the average VOT of affricates /ts/ (76.73 msec) and /ts$^h$/ (94.54 msec) appeared longer than that of their stop counterparts /t/ (46.06 msec) and /t$^h$/ (59.23 msec). Besides, the aspirated phonemes /t$^h$/, /ts$^h$/ appeared to have longer VOT than their unaspirated contrastive pairs (/t/, /ts/). VOT obtained from stops and affricates in different vowel context and word position were averaged and presented in *Table 4.* The average VOT was calculated. At word initial position, the VOT of /t/ were 52.91 msec, for /t$^h$/ was 69.11 msec, for /ts/ was 79.80 msec, and for /ts$^h$/ was 106.01 msec. At word medial position, the average VOT of /t/ were 39.21 msec, for /t$^h$/ was 49.36

msec, for /ts/ was 43.65 msec, and for /ts$^h$/ was 83.02 msec.

***Table 4:*** *Mean VOT (msec) for phoneme* /t/, /t$^h$/, /ts/ and /ts$^h$/, *with different vowels and word positions.*

| **Phoneme for VOT** | **Initial position** *Vowel context* | | | | | **Medial position** *Vowel context* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | /a/ | /ɛ/ | /i/ | /ɔ/ | /u/ | /a/ | /ɛ/ | /i/ | /ɔ/ | /u/ |
| /t/ | 44.28 | 61.44 | 54.70 | 53.11 | 51.00 | 40.25 | 37.64 | 42.47 | 38.42 | 37.28 |
| / t$^h$ / | 64.47 | 65.15 | 72.72 | 64.53 | 78.67 | 40.67 | 52.28 | 48.64 | 55.23 | 49.97 |
| /ts/ | 63.75 | 71.50 | 101.03 | 69.97 | 92.75 | 83.50 | 57.25 | 76.36 | 79.72 | 71.44 |
| /ts$^h$/ | 94.58 | 89.83 | 132.69 | 101.91 | 111.31 | 78.86 | 107.83 | 71.95 | 77.78 | 78.67 |

According to *Table 4,* in word initial position, the visually largest VOT was mostly obtained when the phonemes were accompanied by vowel context /i/, followed by /u/, /ɛ/, /ɔ/, and /a/. For word medial position, no pattern was immediately observed. VOT obtained from aspirated phonemes appeared longer than that of their unaspirated contrastive pairs.

The VOT of the stop components of affricates were also compared to VOT of the plain stops. VOT data were entered into a 3-way ANOVA for repeated measures. Again, the factors involved were phoneme, word position and vowel. The results showed that there was a significant main effect for phoneme ($F$ (3, 27) = 40.21, $p < 0.001$), position ($F$ (1, 9) = 59.71, $p < 0.001$) and vowel ($F$ (4,36) = 5.88, $p \leq 0.001$). There were also statistically significant interactions between phoneme and position ($F$ (3, 27) = 6.51, $p < 0.005$); phoneme and vowel ($F$ (12, 108) = 2.68, $p < 0.005$); position and vowel ($F$ (4, 36) = 8.97, $p < 0.005$), and phoneme, position and vowel ($F$ (12, 108) = 9.07, $p <$ 0.001).

Post-hoc analysis was performed to further investigate the phoneme effect. The VOT of affricates /ts/ (76.73 msec) and /ts$^h$/ (94.54 msec) were significantly longer than that of their stop counterparts /t/ (46.06 msec) and /$t^h$/ (59.23 msec) (Tukey, HSD, $p < 0.05$). The VOT of aspirated phonemes /$t^h$/, /$ts^h$/ were also significantly longer than their unaspirated contrastive pairs (Tukey, HSD, $p < 0.05$). Post hoc analysis of word positions and vowels were not investigated as they were not the main focus of this study.

For the interaction between phonemes and positions, the average VOT of /t/, /$t^h$/ and /$ts^h$/ at word initial position were significantly longer than that of word medial position (Tukey, HSD, $p < 0.05$). For the interaction between phoneme and vowel, VOT of /ts/ with vowel /u/ was significantly longer than that of /ɛ/ (Tukey, HSD, $p < 0.05$).

Post-hoc analysis was also performed to investigate the interaction between phonemes, positions and vowels. For /ts/ and /t/, the VOT of /ts/ was significantly longer than that of /t/ when it was accompanied by /i/, /u/ at word initial position, and /a/, /i/, /ɔ/, /u/ in word medial position (Tukey, HSD, $p < 0.05$). For /$ts^h$/ and /$t^h$/, results showed that the VOT of /$ts^h$/ was significantly longer than /$t^h$/ when it was with vowel /a/, /i/, /ɔ/, /u/ in word initial position, and /a/, /ɛ/, /u/ in word medial position (Tukey, HSD, $p <0.05$).

## DISCUSSION

The purpose of this study was to compare the stop and fricative components of Cantonese affricates (/ts/, /$ts^h$/) with plain stops (/t/, /$t^h$/) and fricative (/s/), on several acoustic temporal measures. The results showed that affricates had a shorter frication period than plain fricatives, a shorter closure period than plain stops, and a longer VOT than plain stops. The unaspirated phonemes (/t/, /ts/) were also found to have significantly longer closure period but a shorter VOT than their aspirated contrastive pairs (/$t^h$/, /$ts^h$/).

**Frication period**

The frication period obtained in this study concur with those found in other studies. In this study, the average frication periods of /s/, /$ts^h$/ and /ts/ were 93.21 msec, 68.58 msec, and 50.37 msec, respectively. Klatt (1974, 1976) suggested that frication period could range from 50- 200 msec. Stokes & Ciocca (1999) found that the frication noise of Cantonese fricative /s/ was about 100-135 msec. Also, a study investigating affricate /ts/ in Vlach, a language spoken in Romania, reported a 139.46 msec frication period of /s/ (Szymanski, 2005).

Results of this study supported the findings of Szymanski (2005), who found that the frication period was reduced in affricates when compared to fricatives. The frication period of affricates /ts/ was only 70% that of fricatives. Kent and Read (1992) also noted that the frication duration of affricates appeared to be shorter than fricatives.

As mentioned in the introduction, although affricate contains two components, it is considered a single phoneme. In order to allow affricate to be perceived as a single unit, its duration must not exceed that of its singleton component excessively (MacKay, 1987). Therefore, the articulation of the stop component in affricate has to be transited to its fricative component rapidly. In this blended productions of stop and fricative component, the durations of components are reduced (Kent & Read, 1992). This phenomenon, the effect of sequential articulations within a phoneme, may also occur in consonant cluster production and coarticulation (Kent & Read, 1992). The explanation could be supported by results of this study and those of Szymanski (2005). Szymanski (2005) found that the frication duration and closure duration of components in affricates /ts/, /tʃ/ were shorter than that of plain stops and fricatives. Yet, the total duration of affricate was nearly equal to the duration of a plain fricative or stop. Hence, affricate had duration comparable to a single unit, but not the sum of duration of two phonemes.

When the productions of components are blended, different features of the components would be altered (Kent & Read, 1992). Duration of components is one of the features. Other features of phoneme, as reported by different instrumental studies, could also be altered. Fletcher's (1989) palatographic studies found that the place of articulation of the stop components of affricates and the plain stops was different. Fletcher (1989) suggested that that in order to improve the speed and precision in articulating affricates, speakers may change the place of articulation. A Cantonese EPG study also found that affricates /ts/, /ts$^h$/ were articulated at a more posterior position than stops /t, t$^h$/, even though there were all alveolar phonemes (Kwok, 1992).

In this study, frication period of /s/ and /s'/ were significantly longer with /u/, followed by /ɔ/, /ɛ/, and /a/. From this ranking, it was observed that the length of frication period decreased as the highness of vowels lowered. The result was consistent with the findings of Hall, Hamann & Zygis (2006), who concluded that high front vowels were better than low vowels in facilitating production of assibilations. Moreover, the production of assibilations could be better maintained when phonemes were accompanied by closed vowels, such as /u/, than open vowels, such as /a/. Hall and colleges (2006) concluded that as the vocal tract of high front vowel was narrowly constricted, it facilitated production of turbulence noise in frication. This stabilized production of frication noise and prolonged the frication period.

Besides, this study found that frication period of /s/, /s'/, /ts$^h$/ at word initial position were longer than those in word medial position. Consonants at word medial position were used to terminate the preceding syllable and initiate the next syllable (Bernthal & Bankson, 1998). Hence, the word medial position created complexity for speech production (Bernthal & Bankson, 1998) and was less facilitating for producing phonemes. A shorter frication period of phoneme was resulted.

**Closure period**

In this study, it was found that the closure period of stop /t/ was significantly longer than that of affricate /ts/. The closure period of /t$^h$/ was also significantly longer than that of /ts$^h$/.

Results of this study supported the findings of Byrd (1993) and Szymanski (2005). Byrd (1993) found that the closure period of affricates /tʃ/ (43 mec) and /dʒ/ (43 mec) were shorter than that of plain stops /t/ (53 msec) and /d/ (52 msec). Szymanski (2005) also concluded with the same results. Szymanski (2005) reported that the closure period of affricates was reduced by nearly 50% from stops. A significant reduction in closure period could be observed by comparing the closure duration of affricate /ts/ (46 msec) to stop /t/ (97 msec).

Affricates' short closure period compared to stops was suggested to be a result of the effects of sequential articulations within phoneme, which was mentioned earlier. In order to allow affricates to be perceived as a single unit, rather than two units (a separate stop and fricative), the total duration of affricate must not exceed that of its singleton component excessively (MacKay, 1987). Therefore, articulations of components in affricates were transited rapidly, reducing the duration of each components (Kent & Read, 1992).

This study also found that the unaspirated phonemes /t/, /ts/ had longer closure period than their aspirated contrastive pairs (/$t^h$/, /$ts^h$/). Aspiration is produced in the release phase, after the release burst (Kent & Read, 1992). To create a contrast in aspiration, aspirated phonemes had longer VOT for aspiration noise to be produced (Ladefoged, 2001). In order to include a longer release phase in phonemes without extending the overall duration of phoneme excessively, the duration of another phase (e.g. closure phase) would be reduced.

**VOT**

This study found that affricates /ts/, /$ts^h$/ had significantly longer average VOT than their stop counterparts /t/, /$t^h$/. The average VOT of /t/, /$t^h$/, /ts/ and /$ts^h$/ was 46.06 msec, 59.23 msec, 76.73 msec and 94.54 msec respectively.

The VOT of stop /$t^h$/ found in this study was comparable to that of Lisker and Abramson (1964), and Clumeck, Barton, Macken and Huntington (1981). The range of VOT for /$t^h$/ was reported as 45-95 msec by Lisker and Abramson (1964), and 43-160 msec by Clumeck et al. (1981). However, the VOT of /t/ obtained in this study contrasted with that of Lisker and Abramson (1964).

This is suggested to be due to the different method used in extracting VOT. The beginning of VOT was extracted as the first abrupt burst of aperiodic wave by Lisker and Abramson (1964), while it was extracted as the lowest point of intensity curve (M. Jones, personal communication, 26th April, 2007) in this study.

In this study, it was found that affricates had longer average VOT than stops. This result supported previous findings by Fletcher (1989) and Byrd (1993). In Fletcher (1989)'s palatographic studies about English affricates /tʃ/, /dʒ/, the duration between burst and vowel onset was measured. Fletcher (1989) found that the VOT of plain stops was less that that of stop component in affricates. In Byrd (1993), VOT was measured as the release phase. Byrd (1993) also reported that the release phrase of affricates /tʃ/ (86 msec), /dʒ/ (62 msec) was longer than that of stops /t/ (49 msec), /d/ (24 msec).

The longer VOT of affricates could be explained by its articulatory phrase. Affricates are produced in three stages: shutting, closure and release phase (Johnson, 2003). The frication of the fricative component in affricate is produced after the release burse in release phrase. Therefore, the frication period is included in the VOT. As frication noise is produced by a gradual release of air flow, the presence of frication period would lengthen VOT. As a result, VOT of affricates are longer than that of stops. Similarly, while producing aspirated phonemes, aspiration is produced after the release burst in the release phrase (Johnson, 2003). The presence of aspiration noise would also lengthen VOT. Hence, VOT of aspirated phonemes are found to be longer than that of unaspirated phonemes.

Besides, this study also found that the VOT of /t/, /t$^h$/ and /ts$^h$/ at word initial position were significantly longer than those in word medial position. This finding coordinated with results observed in frication period, which further suggested that phoneme at word medial position were used to terminate the preceding syllable and initiating the next syllable (Bernthal & Bankson, 1998). Hence, the complexity involved in articulation had not facilitated the production of phonemes at word medial position.

## Conclusion

Affricates are composed of a stop and a fricative component. However, this study showed that the stop and fricative components of Cantonese affricates /ts/, /ts$^h$/ were not identical to the plain stops /t/, /t$^h$/ and fricative /s/ in frication period, closure period and VOT. In summary, affricates had a shorter frication period than plain fricative. Affricates also had a shorter closure period and a longer VOT than plain stops. These results were similar to results of previous studies done across languages.

The shorter frication period and closure period of affricates were suggested to result from the effects of sequential articulations within phoneme. In order to allow affricates to be perceived as a single unit, rather than two units, the total duration of the affricate must not exceed that of its singleton component excessively (MacKay, 1987). Therefore, articulations of component in affricates were transited rapidly, reducing the duration of components (Kent & Read, 1992). On the contrary, VOT of affricates were longer than that of stops. As frication noise of the fricative component of affricate is produced in release phase and included in VOT, the presence of frication period would lengthen VOT of affricates.

This study provides a better understanding about Cantonese affricates, which were difficult phonemes for children to acquire (So & Dodd, 1994) and often problematic in speech disorders (Cheung & Abberton, 2000). As affricates are acoustically described in frication period, closure period and VOT, normative data about affricates components are provided. The normative data may allow comparisons to be made between normal speech and abnormal speech produced by children with speech disorder. However, this study had focused in Cantonese, which only contains a contrastive pair of affricates. In order to achieve a better understanding about affricates, acoustics studies should be performed on languages with more contrastive pairs of affricates, such as Mandarin.

**ACKNOWLEDGEMENTS**

The author would like to express her sincere gratitude to her supervisor, Professor Tara Whitehill, for her guidance, advice and support given through the course of study. Special thanks are given to Dr Karen Chan and Dr Lawrence Ng for their comments and suggestions. Thanks are also given to the research assistants and subjects who participated in the study.

## REFERENCE


Bernthal, J. E., & Bankson, N. W. (1998). *Articulation and phonological disorders*. Boston: Allyn and Bacon

Byrd, D. (1993). American stops. *Phonetics*, ***83***, 97-116.

Catford, J. C. (1977). *Fundamental problems in phonetics*. Edinburgh: Edinburgh University Press.

Cheung, P., & Abberton, E. (2000). Patterns of phonological disability in Cantonese-speaking children in Hong Kong. *International Journal of Language and Communication Disorders,* ***35,*** 451-473.

Clark, J., & Yallop, C. (1995). *An introduction to phonetics and phonology* (2nd ed). Oxford: Blackwell Publishing. Inc.

Clumeck, H., Barton, D., Macken, M.A., and Huntington, D.A. (1981). The aspiration contrast in Cantonese word-initial stops: Data from children and adults. *Journal of Chinese Linguistics*, **9**, 210-224.

Fletcher, S. (1989). Palatometric specification of stop, affricate and sibilant sounds. *Journal of Speech and Hearing Research*, ***32***, 736- 748.

Gibbon, F., & Hardcastle, W. (1994). Articulatory description of affricate production in speech disordered children using electropalatography (EPG). *Proceedings of the International Conference on Spoken Language Processing*, Japan, 3, 1191-1194

Grunwell, P. (1987). *Clinical phonology* (2nd ed). London: Croom Helm.

Hall, T., Hamann, S. & Zygis, M. (2006) The phonetic motivation for phonological stop assibilation.

*Journal of the International Phonetic Association*, 36 (***1),*** 59-81.

Johnson, K. (2003) *Auditory & acoustic phonetics*. Malden, MA: Blackwell Publishing.

Katamba, F. (1989). *An introduction to phonology*. London: Longman Publishing.

Kent, R. D., & Read, C. (1992). *Acoustic analysis of speech*. California: Singular Publishing Group

Kent, R. D. & Read., C. (2002). *Acoustic analysis of speech* (2nd ed). California: Singular Publishing Group.

Klatt, D. H. (1974). Duration of [s] in English words. *Journal of Speech and Hearing Research* ***17***, 41-40.

Klatt, D. H. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. *Journal of the Acoustical Society of America*, ***59***, 1208-1221.

Kwok, I. C. L. (1992). *Electropalatography investigation of normal Cantonese speech: a qualitative and quantitative analysis.* Hong Kong: University of Hong Kong

Ladefoged, P. (1971). *Elements of acoustic phonetics*. Chicago: University of Chicago Press.

Ladefoged, P. (1993). *A course in phonetics* (3rd ed). Fort Worth: Harcourt College Publishers.

Ladefoged, P. & Wu, Z. (1984). Places of articulation: an investigation of Pekingese fricatives and affricates. *Journal of Phonetics*, ***12***, 167-178.

Ladefoged, P. (2001). *A course in phonetics* (4th ed). Fort Worth: Harcourt College Publishers.

Lisker, L., & Abramson, A. S. (1964). A cross-language study of voicing in initial stops: Acoustical measurements. *Word*, ***20***, 384-422.

MacKay, I. (1987). *Phonetics: The science of speech production* (2nd ed). Boston: Little, Brown and Company, Inc.

Ng, A., & Cheung, P. (2002). *Hong Kong Articulation Test (HKCAT) Manual*. Hong Kong: Child Assessment Service.

Ryalls, J. (1996) *A basic introduction to speech perception*. San Diego, CA: Singular Publishing Group.

Schane, S. A. (1973). *Generative phonology.* Englewood Cliffs, NJ: Prentice-Hall.

So, L. K. H., & Dodd, B. J. (1994). Phonologically disordered Cantonese-speaking children. *Clinical Linguistics & Phonetics*, ***8***, 235-255.

Stokes, S. F., & Ciocca, V. (1999). The substitution of [s] for aspirated targets: Perceptual and acoustic evidence from Cantonese. *Clinical Linguistics and Phonetics.,* ***13***, 183-197.

Stokes, S. F., Whitehill, T. L., Yuen, K. C. P., & Tsui, A. M. Y. (1996). EPG treatment of sibilants in two Cantonese-speaking children with cleft palate. *Clinical Linguistics & Phonetics*, 10, 265-280.

Svantesson, J. (1986). Acoustic analysis of Chinese fricatives and affricates. *Journal of Chinese Linguistics*, ***14***, 53-70.

Szymanski, T. (2005). Project 3: Valch affricates, stops and fricatives. *Phonetics*, ***512***, 17-28.

Zee., E. (1991). Chinese (Hong Kong Cantonese). *Journal of the International Phonetic Association.* ***21***, 46-8.

## APPENDIX

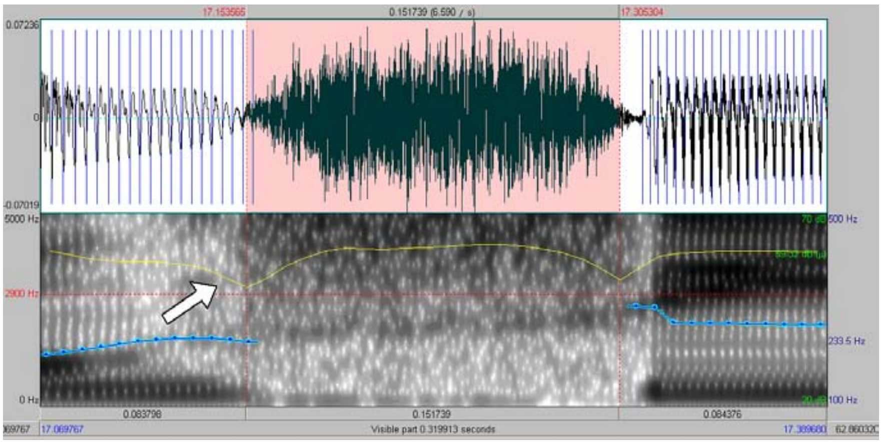
***Appendix A: A word list, with target words embedded in a carrier phrase, was presented to the subjects.*** The target words were transcribed by International Phonetic Association (IPA) transcription for readers as a reference. Transcription of the carrier phrase “我講__俾你聽” (I say ___ to you) were /ŋɔ1 ŋɔŋ2 ___ pei2 nei5 t$^{h}$ɛŋ1/.

| Stimuli | IPA transcription | Stimuli | IPA transcription |
|---|---|---|---|
| 我講渣俾你聽 | /tsa1/ | 我講差俾你聽 | /ts$^{h}$a1/ |
| 我講沙俾你聽 | /sa1/ | 我講沙俾你聽 | /sa1/ |
| 我講打俾你聽 | /ta1/ | 我講他俾你聽 | /t$^{h}$a1/ |
| 我講遮俾你聽 | /tsɛ1/ | 我講車俾你聽 | /ts$^{h}$ɛ1/ |
| 我講些俾你聽 | /sɛ1/ | 我講些俾你聽 | /sɛ1/ |
| 我講爹俾你聽 | /tɛ1/ | 我講聽俾你聽 | /t$^{h}$ɛŋ1/ |
| 我講助俾你聽 | /tsɔ6/ | 我講初俾你聽 | /ts$^{h}$ɔ6/ |
| 我講蔬俾你聽 | /sɔ1/ | 我講蔬俾你聽 | /sɔ1/ |
| 我講多俾你聽 | /tɔ1/ | 我講拖俾你聽 | /t$^{h}$ɔ1/ |
| 我講知俾你聽 | /tsi1/ | 我講痴俾你聽 | /t$^{h}$si1/ |
| 我講詩俾你聽 | /si1/ | 我講詩俾你聽 | /si1/ |
| 我講啲俾你聽 | /ti1/ | 我講天俾你聽 | /t$^{h}$in1/ |
| 我講豬俾你聽 | /tsy1/ | 我講村俾你聽 | /ts$^{h}$yn1/ |
| 我講書俾你聽 | /sy1/ | 我講書俾你聽 | /sy1/ |
| 我講端俾你聽 | /tyn1/ | 我講脫俾你聽 | /t$^{h}$yt7/ |

| | | | |
|---|---|---|---|
| 我講花枝俾你聽 | /fa1 tsi1/ | 我講丫叉俾你聽 | / ŋa1 tsʰa1/ |
| 我講傢俬俾你聽 | /ka1 si1/ | 我講莎莎俾你聽 | /sa1 sa1/ |
| 我講加啲俾你聽 | /ka1 ti1/ | 我講沙攤俾你聽 | /sa1 tʰan1/ |
| 我講姐姐俾你聽 | /tsε1 tsε1/ | 我講車痴俾你聽 | /tsʰε1 tsʰi1/ |
| 我講車聲俾你聽 | /tsʰε1 sεŋ1/ | 我講謝師俾你聽 | /tsε6 si1/ |
| 我講爹爹俾你聽 | /tε1 tε1/ | 我講遮天俾你聽 | /tsε1 tʰin1/ |
| 我講多枝俾你聽 | /tɔ1 tsi1/ | 我講初初俾你聽 | /tsʰɔ1 tsʰɔ1/ |
| 我講波斯俾你聽 | /pɔ1 si1/ | 我講囉嗦俾你聽 | /lɔ1 sɔ1/ |
| 我講多啲俾你聽 | /tɔ1 ti1/ | 我講多胎俾你聽 | /tɔ1 tʰɔi1/ |
| 我講呢枝俾你聽 | /li1 tsi1/ | 我講思親俾你聽 | /si1 tsʰɐn1/ |
| 我講醫師俾你聽 | /ji1 si1/ | 我講醫生俾你聽 | /ji1 sɐŋ1/ |
| 我講啲啲俾你聽 | /ti1 ti1/ | 我講私吞俾你聽 | /si1 tʰɐn1/ |
| 我講豬豬俾你聽 | /tsy1 tsy1/ | 我講呼出俾你聽 | /fu1 tsʰɵt7/ |
| 我講書書俾你聽 | /sy1 sy1/ | 我講書商俾你聽 | /sy1 sœŋ1/ |
| 我講書店俾你聽 | /sy1 tim3/ | 我講豬腿俾你聽 | /tsy1 tsʰɵy2/ |

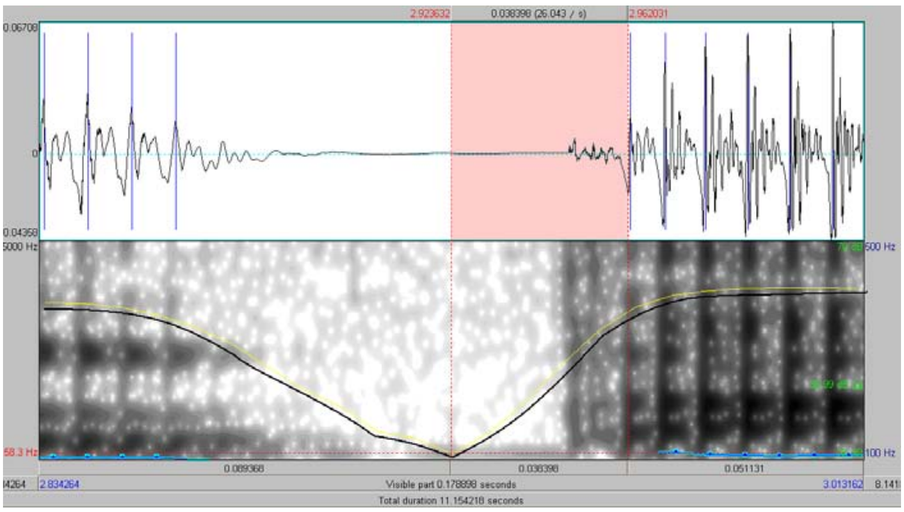
***Appendix B: Frication period of W.Y.H.'s production of /s/ in /si/.***

*Frication period was identified by the intensity curve (see white arrow) and was marked by the shaded area.*




***Appendix C: VOT of C.S.H.'s production of /t/ in /ta/.***

*VOT was marked by the shaded area. Its* ***starting*** *point was identified by the intensity curve. A black curve has been placed under the intensity curve to assist readers in tracing the intensity curve.*



***Appendix D: Closure period of C.S.H.'s production of /t/ in /ta/.***

*Closure period was marked by the shaded area. Its* ***ending*** *point was identified by the intensity curve. A black curve has been placed under the intensity curve to assist readers in tracing the intensity curve.*