The effects of Cantonese tones on vocal attack time (VAT)

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Abstract

There were much research papers concerning the acoustic-physiological parameters of voice onset and phonation such as the voice onset time (VOT). Recently, a new acoustic-physiological parameter called the vocal attack time (VAT) was being studied. However, few literatures were available on investigation of this pre-phonatory parameter. The aim of the present study was to establish normative data of VAT in Cantonese and to investigate the effects of tones on VAT. In this study, sound pressure and electroglottographic signals were collected simultaneously form 62 participants (33 females and 29 males). All data collected were subjected to a Matlab-based analysis program for calculating the VAT values. Results revealed that gender-related differences exist. Males generally have higher VAT values while females have lower VAT values. Effects of tone on VAT values were more prominent in the female group than in the male group.

Key words: vocal attack time (VAT), Cantonese tones, gender-related differences, tone level and contour, vocal fold physiology

Introduction

Vocal attack time (VAT) is a physiological index related to vocal fold physiology in the pre-phonatory phase (Orlikoff, Deliyski, Baken & Watson, 2007). There are two distinct phases concerning the onset of phonation. The former phase is termed the pre-phonatory phase, which is followed by the attack phase (Orlikoff et al., 2007). The pre-phonatory phase involves various physiological settings of the phonatory mechanisms including the setting of the tension of vocal folds, the gesture of the different phonatory components such as the vertical larynx position (Shipp, 1975), the activity of extrinsic and intrinsic muscles for phonation (Hirano, Ohala & Vennard, 1969), and the setting of aerodynamic forces for phonation (Titze, 1988). All these settings are prepared for the later attack phase.

Two physiological concepts are important for measurement of the VAT, which are the sound pressure signal and the eletroglottographic (EGG) signal. Sound pressure signal is correlated to the amplitude of vocal fold oscillations and vibrations. The greater the vibration of the vocal folds, the higher the sound pressure level (Colton, Casper & Leonard, 2006). It is suggested that prior to vocal fold adduction, sound pressure signal already occurs (Titze, 1988). Later contact of vocal folds is detected by presence of EGG signals.

Electroglottography is a technique for measurement of the vocal fold contact area (Colton et al., 2006). It is based on the principle of the conductivity of current in human tissues. Electroglottography is conducted by passing low current signals between the vocal folds through electrodes attaching on the neck skin at the thyroid lamina locations (Colton et al., 2006; Ma & Love, in press). The larger the contact between the two vocal folds, the larger the amplitude of the EGG waveform signals.

Titze (1988) suggested that before the vocal folds adducted to the midline, there is small-amplitude oscillations already existed in the vocal folds, generating small sound pressure levels. Once the vocal folds adduct to the midline and periodic adduction-abduction cycle starts, the sound pressure level becomes stable. As proposed by Orlikoff et al. (2007), VAT refers to the time lag between the start of presence of sound pressure signal and the real contact between the vocal folds (Orlikoff et al., 2007).

Orlikoff et al. (2007) suggest that different types of voice onset are associated with different VAT values. In their study, a validation procedure of VAT was carried out. The procedure involved instructing five subjects to produce the three types of voice onset, namely hard glottal attack, comfortable onset and breathy onset. Results revealed that VAT values indeed vary distinctively across the three types of voice onsets. The VAT value was the greatest for breathy onset and decreases from breathy onset to comfortable onset and finally to hard glottal attack onset (Orlikoff et al., 2007).

Results of their study showed voice onset with hard glottal attack results in a negative VAT value; breathy onset results in a relatively large positive VAT value while the VAT values of comfortable onset fell between that of hard glottal attack onset and breathy onset. VAT is calculated by subtracting the time of occurrence of the sound pressure signal by the occurrence of the EGG signals (Orlikoff et al., 2007). In normal phonation physiology, when vocal folds oscillate, sound pressure will be generated and draw the vocal folds attaching together immediately (Colton et al., 2006; Ladefoged, 1988). Thus, the abovementioned results indicate that the EGG signals appeared prior to the sound pressure signals in hard glottal attack (Orlikoff et al., 2007). It is because in voice onset with hard glottal attack, the vocal folds touch each other first, and then small-amplitude oscillation of vocal folds begins (Colton et al., 2006). On another hand, in breathy onset, after sound pressure is generated, the adduction of vocal folds is abnormally delayed. Thus, phonation started when the vocal folds are not completely adducted. This results in an intraglottal gap between the vocal folds during voice onset and resulting a breathy onset. Thus, a comparatively positive and large VAT value is correlated to a breathy onset (Colton et al., 2006).

Most languages in East Asia, including Cantonese, are tonal languages. A tonal language refers to a language that the pitch (tone) of individual syllables helps to assign different meanings for it. In other words, tonal language employs tones to represent their words (Gussenhoven, 2004; Matthews & Yip, 1994). Thus, production of different tones in tonal language is important to distinguish different meanings of words.

Cantonese is a tonal language having six contrastive lexical tones (Matthews & Yip, 1994; Yip, 2002). Table 1 shows an example of the syllable /Na/ across six lexical tones in Cantonese and the associated tone levels and tone contours (Matthews & Yip, 1994):

Table 1: Examples of the syllable /Na/ across the six Cantonese lexical tones and the associated tone characteristics (tone level and tone contour)

Tone**	Pitch**	Contours**	Chinese characters(/Na/)	Meanings
1	high	level	鴉	crow, raven
2	high	rising	啞	A mute
3	mid	level	亞	second
4	low	falling	牙	teeth
5	low	rising	雅	graceful
6	low	level	掗	take; hold; give forcefully

** The tone notation (tone 1 to 6) and features (tone pitch and contour)of the six Cantonese tones shown in this table is adopted from the Cantonese Romanization Scheme proposed by The Linguistic Society of Hong Kong in 1993 (Matthews & Yip, 1994).

Different studies showed that the six Cantonese tones are associated with different Fo (Ciocca & Khouw, 2007; Li, 1997; Li, 2006). Results from these studies consistently showed that production of syllables or words with Cantonese tone 1 involves the highest mean Fo while production with tone 4 involves the lowest Fo. Tone 2 and tone 3 have similar Fo while tone 5 and tone 6 have similar ones. Tone 2 and tone 3 have generally high Fo level than tone 5 and tone 6. The mean and standard deviation (in parenthesis) of the results from Ciocca and Khouw (2007)'s study were as the follows:

Table 2: Mean fundamental frequency in Hertz of the six Cantonese tones (standard deviation in parenthesis)

	Tone					
	1	2	3	4	5	6
Mean Fo	245.7 (8.3)	210.8 (7.6)	215.2 (6.5)	190.6 (6.6)	205.0 (6.6)	202.9 (6.7)

** Adapted from "Ciocca & Khouw (2007). Perceptual correlates of Cantonese tones. *Journal of Phonetics, 35* (1), 104-117"

It is generally proposed that phonation with different Fo involves different laryngeal physiology and pre-phonatory laryngeal settings (Colton et al., 2006; Hirano et al., 1969; Ohala, 1973; Shipp, 1975). Hirano and colleagues (1969) suggested that increased Fo is associated with increased cricothyroid (CT) and thyroarytenoid (TA) muscle contractions, which assist in tensing the vocal folds for high-frequency vibration afterwards. Lateral cricoarytenoid muscle, a paired muscle assisting in vocal fold adduction, is also shown to be activated for increasing Fo (Erickson, 1993; Ohala, 1973). Apart from the association shown between these muscles and Fo increasing, several studies explicitly showed that prior to Fo increases, CT muscles were activated and prior to Fo decreases, the infrahyoid strap muscles were activated, although the contribution of the infrahyoid strap muscles was not yet absolutely been proved (Erickson, 1993; Ohala, 1973; Yip, 2002). Thus, it is possible that different laryngeal and vocal fold settings such as the vertical laryngeal positions, vocal fold length and tensions are appropriately-set before phonation at different Fo (Hirano et al., 1969; Shipp, 1975).

Moreover, it is suggested that increased activity levels of different adductor muscles at higher Fo phonation situations will result in a narrower opening of the glottis before phonation (Hirano et al., 1969). In other words, a narrower glottal opening is set at the pre-phonatory stage to prepare for higher Fo phonation. As suggested by Orlikoff and colleagues (2007), VAT is calculated as the time lag between the first notice of sound pressure signals and the presence of EGG signal, while the notice of sound pressure signals is usually prior to presence of EGG signals in most normal phonations (Colton et al., 2006). It is possible that a narrower glottis will reduce the time that the glottis to fully adducted due to the reduced distance between the two vocal folds. In order words, a narrower glottis in the pre-phonatory stage will result in a shorter VAT. Thus, phonation with higher frequencies will result in a shorter VAT.

Cantonese tones were divided into level tones and contour tones according to their tone contour (Bauer & Benedict, 1997; Matthews & Yip, 1994; Rose, 1996; Yip, 2002). Level tones are tones which have consistent pitch level (or Fo) throughout the production of the entire tone. Contour tones, including rising and falling tones, are tones that changes in pitch level were noted within the production of the tone (Bauer & Benedict, 1997; Matthews & Yip, 1994; Rose, 1996; Yip, 2002).

Since different muscles are activated and coordinated for production of different Fo, it is possible that when producing a rising or falling tone, the physiology of production will be more complex than production of a level tone since different muscles will be activated and needed to be coordinated for the changes in Fo within the production of the tone.

Combining findings on the relationship between Fo and vocal fold physiology, and in view of that different Cantonese tones are associated with different Fo (Ciocca & Khouw, 2007, Li, 1997; Li, 2006), it is possible that production of different Cantonese tones is associated with different vocal fold physiological mechanisms, and VAT will differ among production of different tones in a tonal language.

The aim of this study is to investigate the effects of different Cantonese tones on VAT, as well as to set up a normative database for VAT in Cantonese. Theoretically, this leads to a better understanding of the basic physiologic mechanisms in producing different tones in a tonal language.

More importantly, it helps to establish normative data of VAT in producing different tones in a tonal language, which may contribute to further study in this field.

Method

Participants

Sixty-two participants, 29 males (aged from19 to 23 years old; mean age = 20.7 years old; SD= 1.2) and 33 females (aged from 19 to 24 years old; mean age=21.2 years old; SD= 1.4) were participated in this study. All participants were native Cantonese speakers. Each participant was judged as having correct Cantonese tone production and normal voice by the investigator, who is a final-year speech pathology student studying in The University of Hong Kong, and an experienced speech therapist. The two judges had 100% agreement with each other in judging the tone production of the participants. Participants were excluded if they have had previous or current voice, speech and language and hearing problems. All participants were in good health on the day of data collection.

Instrumentation

Sound pressure (SP) signals were collected using an M-Audio Fast Track recording interface device (Fast Track USB) with a Radio Shack 33-3012 headset microphone. Electroglottograph (EGG) signals were collected using a digital Fourcin Laryngograph Processor (Laryngograph Ltd, London). SP and EGG signals were collected simultaneously with a software program Audacity (version. 1.2.6). Recordings were done on stereo track, at a sampling rate of 44,100 Hz. A mouth-to-recorder distance of 5 cm was set and maintained throughout the recording.

Procedures

All recordings were carried out in sound booth unit at the Division of Speech and Hearing Sciences, The University of Hong Kong. Background noise was set as 30dB.

Preparation works described below were done before actual recording to ensure sufficient effectiveness of the electrode-to-skin contact in the neck area. The investigator cleaned each participant's neck area using alcohol swab to enhance the electrode-to-skin contact effectiveness. Then, the investigator identified each participant's thyroid lamina position by hands. Two eletrolaryngographic surface electrodes were then placed on the participant's neck on each side at the identified position. In order to find out the most effective electrode-contact position, each participant was asked to phonate a vowel /a/ several times with his or her most comfortable pitch and loudness. The EGG waveform was shown on an oscilloscope. The electrodes were moved slightly upwards and downwards around the neck region until a regular waveform with the largest amplitude was noted. This was to ensure that the contact position was the most appropriate position with the highest electrode-to-skin contact (Ma & Love, in press). After the appropriate position was identified, the electrodes were attached on the back of the neck. The neckband was adjusted sufficiently tightly in order to maximize the effectiveness of the contact.

Each participant was briefed once about the recording stimuli. The participants were instructed to read through all the stimuli once with his or her most comfortable pitch and loudness in order to ensure that the participants can get a general picture about the stimuli he or she would read in the following recording and to make sure that the participants were able to read all the stimuli correctly.

Stimuli

Disyllabic words with the target syllable /Na/ at word initial position were presented to the participants as stimuli. The stimuli words were constructed across the six Cantonese tones. Two homophones, which are words having the same pronunciation but with different meanings (Matthews & Yip, 1994), were prepared for each tone resulting in a total of 12 disyllabic words. The 12 disyllabic words with the corresponding pictures were randomized and presented for reading in each trial. The task was repeated for five times, with the order of the words being randomized and was different in each trial. The participants were instructed to read the words with his or her most comfortable pitch and loudness.

Data analysis

The sound pressure (Sp) signals and the electroglottographic (EGG) signals acquired were subjected to VAT analysis software created by the Matlab for automatic computation of the VAT. VAT values of production of the middle three trials (i.e. the second, third and froth trial) of each homophone were calculated for each participant. 36 Sp and 36 EGG signals will be subjected to analysis for each participant (6 tones x 2 homophones x 3 trials). The VAT values obtained from these three trials were averaged as the mean VAT value for each homophone. The mean VAT values of the two homophones of each tone were further averaged as the mean VAT value of each tone for each participant. Furthermore, VAT values for all participants at a particular tone will be averaged for all six tones in order to estimate the correlation between tones and VAT. This contributes to the normalization procedure of VAT across the six tones in Cantonese.

Statistical analysis

This study involves one independent variable, the Cantonese tones (6 levels) while the dependent variable is the VAT value. A one-way repeated measures analysis of variance

(ANOVA) will be performed to investigate the presence of significant differences between tones on the VAT values.

Reliability

One of the aims of the current study is to establish normative data on VAT in Cantonese. Therefore, reliability of the participants' voice and their recordings are important factor to be concern in this normalization process. Both the inter-rater reliability and the test-retest reliability were investigated. Six participants (10% of the 62 participants) were randomly selected for re-test one month after their first data collection. The test-retest reliability was done by estimating the correlation of the VAT values of the production of the second, third and forth trials for each homophone produced by these six participants in the first and the second recording. Inter-rater reliability test was done by estimating the correlation of the VAT values measured by the investigator and another examiner, who is a final-year speech pathology student. Both intra-rater reliability and inter-rater reliability showed 100% agreement (i.e. a correlation coefficient of 1.00). Test-retest reliability showed a moderate strength correlation between the first and second recording for each individual datum (i.e. a correlation coefficient of 0.419, $p < 0.05$).

Results

Each participant produced 12 disyllabic word stimuli (two homophones for each of the six Cantonese tones), each for five times. Mean VAT values of the second, third and forth production of each homophone for each participant was subjected to statistical analysis.

Data were excluded in the following situations: 1) outliers identified by statistical measurement: the VAT values of the second, third and forth trails of each homophone of all participants were subjected to plotting of the boxplot graph, independently for each trial. Comparisons were done among all the participants. Outlier data shown in the boxplot graph were excluded; 2) abnormal displays of results found during the automatic VAT analysis program: during the computed automatic analysis program, a parameter called the SP-to-EGG delay was normally shown as a normal distribution graph (i.e. a bell-shaped graph) and the delay value calculated refers to the VAT value. Data were excluded when the SP-to-EGG delay graph shown was deviated. Deviated graphs include:

(a). multiple peaks (including double or triple peaks) shown on the delay graph

(b). the delay graph was not a normal distribution curve, i.e. not a bell-shape graph

(c). no delay in SP and EGG signals could be detected

Method of analysis

Independent sample t-test: Gender-related differences

Independent-sample t-test revealed that significant differences existed between the two gender groups for tone 1($p< 0.01$), tone 3($p<0.05$) and tone 6($p< 0.01$). Table 3 and 6 show the mean VAT values and standard deviations of the six Cantonese tones for the female and male group respectively. Figure 1 and 2 show the mean VAT values of both the male and female groups across the six tones and the 12 homophones respectively. Therefore, further statistical analyses were done separately for male and female participants.

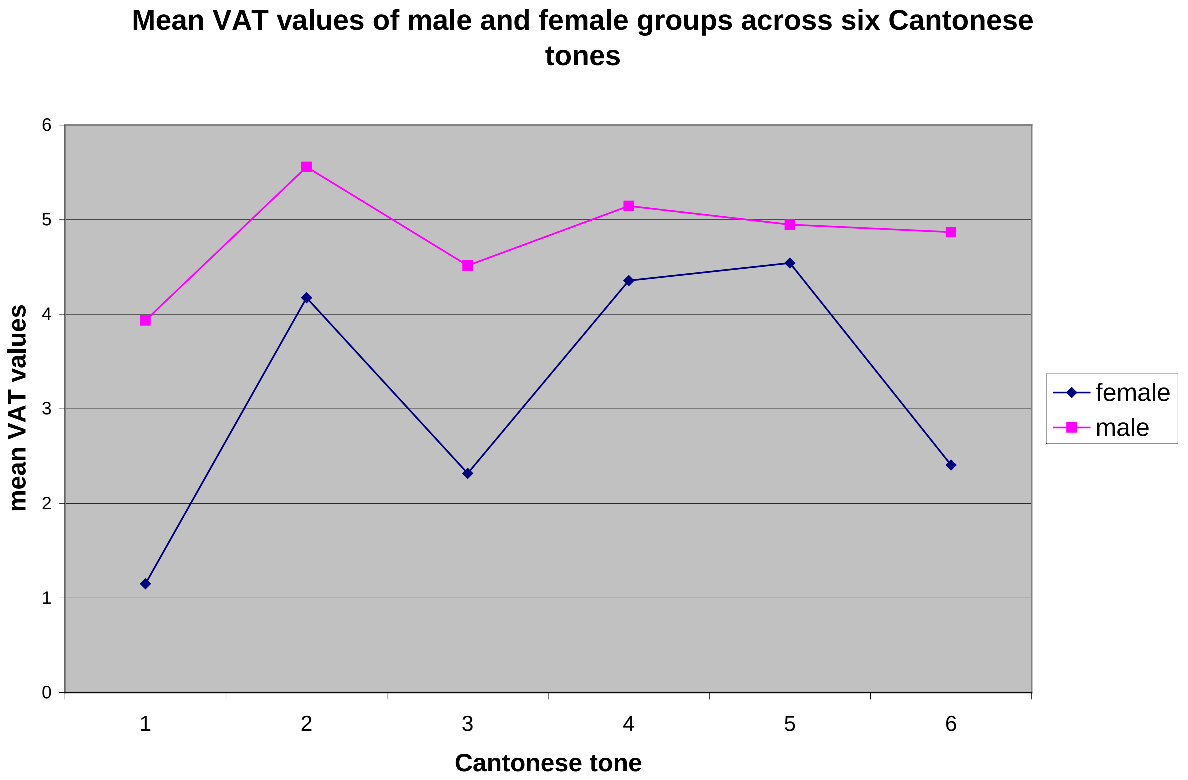

Figure 1: Mean VAT values of male and female groups across six Cantonese tones.

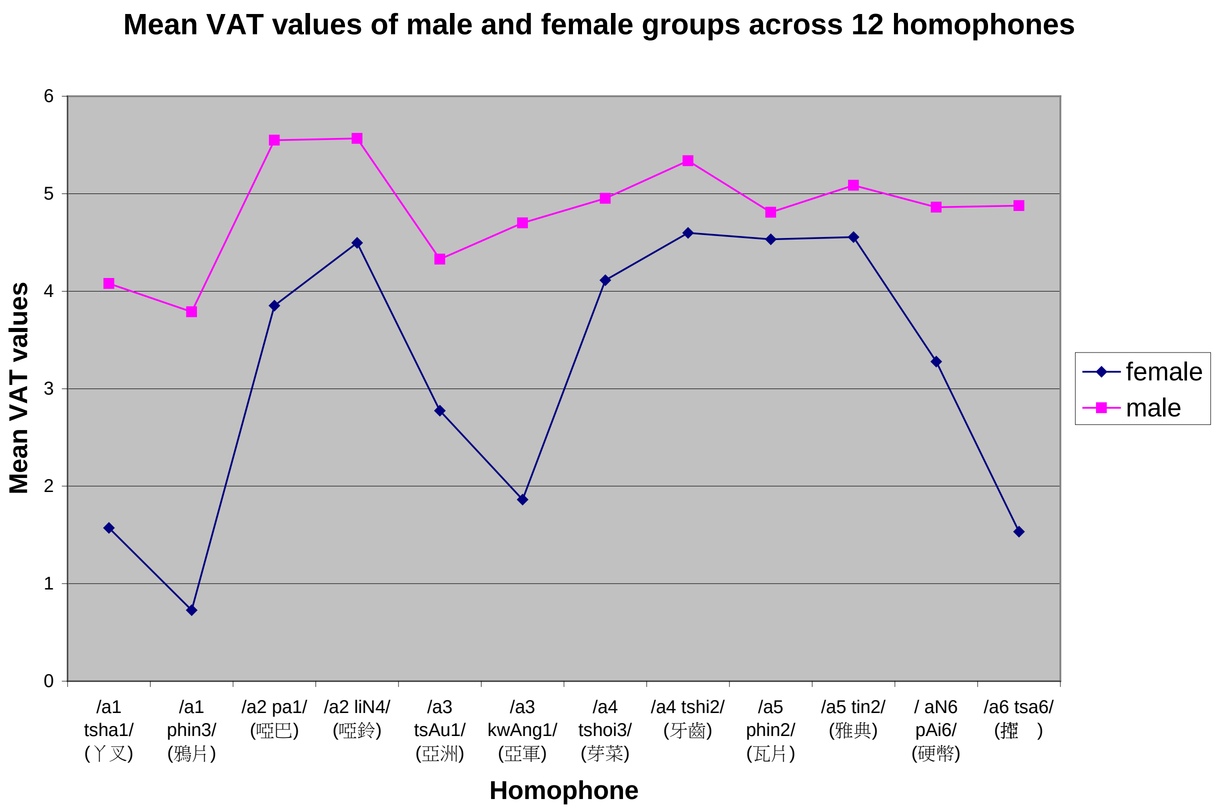

Figure 2: Mean VAT values of male and female groups across 12 homophones.

Repeated measure analysis of variance (ANOVA)

There was one independent factor in this study, the Cantonese tone. Two levels of statistical analysis were done: for level 1 analysis, mean VAT values for production of the six tones for each participant were subjected to repeated measures analysis of variance (ANOVA). For level 2 analysis, the mean VAT values for production of the twelve homophones for each participant were also subjected to repeated measures ANOVA. These were done for male and female groups separately.

Results of the female group

Table 3 shows the mean VAT values and the standard deviation (in parenthesis) of the six Cantonese tones and the 12 homophones in the female group.

Table 3: Mean VAT values in milliseconds and standard deviation (in parenthesis) of the six Cantonese tones and the 12 homophones of the female group

Tone	Homophones	Mean VAT	Averaged mean VAT
1	/a_1 ts^ha_1/ 丫叉	1.57 (4.01)	1.15 (3.88)
	/a_1 p^hin_3/ 鴉片	0.73 (4.58)	
2	/a_2 pa_1/ 啞巴	3.85 (3.67)	4.17 (3.50)
	/a_2 liN_4/ 啞鈴	4.50 (3.91)	
3	/a_3 $tsAu_1$/ 亞洲	2.77 (4.61)	2.32 (3.95)
	/a_3 k^wAN_1/ 亞軍	1.86 (4.05)	
4	/a_4 ts^hoi_3/ 芽菜	4.11 (4.20)	4.36 (3.80)
	/a_4 ts^hi_2/ 牙齒	4.60 (3.68)	
5	/a_5 p^hin_2/ 瓦片	4.53 (3.32)	4.54 (3.19)
	/a_5 tin_2/ 雅典	4.55 (3.72)	
6	/ aN_6 pAi_6/ 硬幣	3.28 (4.10)	2.41 (4.05)
	/a_6 tsa_6/ 揸炸	1.53 (4.67)	

For the female group, statistical results showed that the mean VAT differed significantly as a function of tone. Post Hoc, pairwise comparison (Bonferroni test) showed that significant differences existed between the three level tones, i.e. tone 1, and tone 3 and tone 6, and the three contour tones, i.e. tone 2, tone 4 and tone 5. In other words, for each level tone, significant differences were shown between the level tone and the other three contour tones. All significantly different tone pairs involve a significance level of $p < 0.05$. Details of the significance levels of the involved tone pairs are summarized in table 4.

Table 4: Mean differences in milliseconds and the significance level of tone pairs of the three level tones in female group

Level tones (X)	Contour tones (Y)	mean difference (X-Y)	Significance level**
1	2	-3.02	.0001
	4	-3.21	.0001
	5	-3.39	.0001
3	2	-1.86	.03
	4	-2.04	.006
	5	-2.23	.002
6	2	-1.77	.002
	4	-1.95	.04
	5	-2.14	.004

Table 5: Mean differences in milliseconds and significance level of tone pairs of the three contour tones in female group

Contour tones (Y)	Level tones (X)	mean difference (Y-X)	Significance level**
2	1	3.023	.0001
	3	1.855	.03
	6	1.767	.002
4	1	3.205	.0001
	3	2.037	.006
	6	1.949	.04
5	1	3.393	.0001
	3	2.225	.002
	6	2.136	.004

** All differences were statistically significant at $p < 0.05$ level.

To view more in deep on the analysis results of the differences between the 12 homophones (level 2 analysis) for the female group, results of the level 2 analysis were consistent with that of the level 1 analysis. The statistically significance level of the homophone pairs were summarized in table 6 and 7. In significantly different tone pairs, such as tone pair 1 and 5, the mean VAT values of the two homophones of tone 1, /a1 ts^{h}a1/ 丫叉 and /a$_1$ p^{h}in$_3$/ 鴉片 differ significantly with the two homophones of tone 5, /a$_5$ p^{h}in$_2$/ 瓦片 and /a$_5$ tin$_2$/ 雅典. For several significantly different tone pairs such as tone 1 and tone 4, the homophones /a$_1$ ts^{h}a$_1$/ 丫叉 of tone 1 showed significantly differences with the homophones /a$_4$ ts^{h}i$_2$/ 牙齒 and /a$_4$ ts^{h}oi$_3$/ 芽菜 of tone 4 while the homophone /a$_1$ p^{h}in$_3$/ 鴉片, was only significantly different from the homophone /a$_4$ ts^{h}i$_2$/ 牙齒 of tone 4 but not /a$_4$ ts^{h}oi$_3$/ 芽菜 of tone 4. Results shown that for a tone pair which showed statistically significant difference existed between them, at least one homophone of one tone will show significant difference with at least one homophone of the other tone. Details are displayed in table 6 and 7.

Table 6: Mean differences and significance level of homophone pairs of the three level tones in female group

Level tone (X)	Homophone of level tone (X)	Contour tone (Y)	Homophone of contour tone (Y)	Significance level**
Tone 1	/a$_1$ ts^{h}a$_1$/ 丫叉	Tone 2	/a$_2$ liN$_4$/ 啞鈴	.003
	/a$_1$ p^{h}in$_3$/ 鴉片		/a$_2$ pa$_1$/ 啞巴	.04
			/a$_2$ liN$_4$/ 啞鈴	.003
	/a$_1$ ts^{h}a$_1$/ 丫叉	Tone 4	/a$_4$ ts^{h}oi$_3$/ 芽菜	.02
			/a$_4$ ts^{h}i$_2$/ 牙齒	.0001
	/a$_1$ p^{h}in$_3$/ 鴉片		/a$_4$ ts^{h}i$_2$/ 牙齒	.003
	/a$_1$ ts^{h}a$_1$/ 丫叉	Tone 5	/a$_5$ p^{h}in$_2$/ 瓦片	.0001
			/a$_5$ tin$_2$/ 雅典	.002
	/a$_1$ p^{h}in$_3$/ 鴉片		/a$_5$ p^{h}in$_2$/ 瓦片	.001
			/a$_5$ tin$_2$/ 雅典	.006
Tone 3	/a$_3$ k^{w}AN$_1$/ 亞軍	Tone 2	/a$_2$ liN$_4$/ 啞鈴	.001
	/a$_3$ k^{w}AN$_1$/ 亞軍	Tone 4	/a$_4$ ts^{h}oi$_3$/ 芽菜	.02
			/a$_4$ ts^{h}i$_2$/ 牙齒	.0001
	/a$_3$ k^{w}AN$_1$/ 亞軍	Tone 5	/a$_5$ p^{h}in$_2$/ 瓦片	.001
			/a$_5$ tin$_2$/ 雅典	.01
Tone 6	/a$_6$ tsa$_6$/ 揠拃	Tone 2	/a$_2$ liN$_4$/ 啞鈴	.0001
	/a$_6$ tsa$_6$/ 揠拃	Tone 4	/a$_4$ ts^{h}oi$_3$/ 芽菜	.001
	/a$_6$ tsa$_6$/ 揠拃	Tone 5	/a$_5$ p^{h}in$_2$/ 瓦片	.001
			/a$_5$ tin$_2$/ 雅典	.03

** All differences were statistically significant at $p< 0.05$ level.

Table 7: Mean differences and significance level of homophone pairs of the three contour tones in female group

Contour tone (Y)	Homophone of tone (Y)	Level tone (X)	Homophone of tone (X)	Significance level**
Tone 2	/a_2 pa_1/ 啞巴	Tone 1	/a_1 p^hin_3/ 鴉片	.04
	/a_2 liN_4/ 啞鈴		/a_1 ts^ha_1/ 丫叉	.003
			/a_1 p^hin_3/ 鴉片	.003
	/a_2 liN_4/ 啞鈴	Tone 3	/a_3 k^wAN_1/ 亞軍	.001
	/a_2 liN_4/ 啞鈴	Tone 6	/a_6 tsa_6/ 揸拃	.0001
Tone 4	/a_4 ts^hoi_3/ 芽菜	Tone 1	/a_1 ts^ha_1/ 丫叉	.02
	/a_4 ts^hi_2/ 牙齒		/a_1 ts^ha_1/ 丫叉	.0001
			/a_1 p^hin_3/ 鴉片	.003
	/a_4 ts^hoi_3/ 芽菜	Tone 3	/a_3 k^wAN_1/ 亞軍	.02
	/a_4 ts^hi_2/ 牙齒		/a_3 k^wAN_1/ 亞軍	.0001
	/a_4 ts^hoi_3/ 芽菜	Tone 6	/a_6 tsa_6/ 揸拃	.001
Tone 5	/a_5 p^hin_2/ 瓦片	Tone 1	/a_1 ts^ha_1/ 丫叉	.0001
			/a_1 p^hin_3/ 鴉片	.001
	/a_5 tin_2/ 雅典		/a_1 ts^ha_1/ 丫叉	.002
			/a_1 p^hin_3/ 鴉片	.006
	/a_5 p^hin_2/ 瓦片	Tone 3	/a_3 k^wAN_1/ 亞軍	.001
	/a_5 tin_2/ 雅典		/a_3 $k^wAN\ _1$/ 亞軍	.01
	/a_5 p^hin_2/ 瓦片	Tone 6	/a_6 tsa_6/ 揸拃	.001
	/a_5 tin_2/ 雅典		/a_6 tsa_6/ 揸拃	.03

** All differences were statistically significant at $p < 0.05$ level.

Results of the male group

Generally, the mean VAT value of each tone is higher in male than in female. Table 8 shows the mean VAT values and standard deviation (in parenthesis) of the six Cantonese tones and the 12 homophones in the male group.

Table 8: Mean VAT values in milliseconds and standard deviation (in parenthesis) of the six Cantonese tones and the 12 homophones of the male group

Tone	Homophones	Mean VAT	Averaged mean VAT
1	/a_1 ts^ha_1/ 丫叉	4.08 (3.08)	3.93 (2.90)
	/a_1 p^hin_3/ 鴉片	3.79 (3.31)	
2	/a_2 pa_1/ 啞巴	5.55 (2.43)	5.56 (2.49)
	/a_2 liN_4/ 啞鈴	5.57 (3.04)	
3	/a_3 $tsAu_1$/ 亞洲	4.33 (3.14)	4.52 (2.93)
	/a_3 k^wAN_1/ 亞軍	4.70 (3.38)	
4	/a_4 ts^hoi_3/ 芽菜	4.95 (3.09)	5.15 (2.84)
	/a_4 ts^hi_2/ 牙齒	5.34 (3.39)	
5	/a_5 p^hin_2/ 瓦片	4.81 (3.28)	4.95 (2.94)
	/a_5 tin_2/ 雅典	5.09 (3.00)	
6	/ aN_6 pAi_6/ 硬幣	4.86 (2.73)	4.87 (2.73)
	/a_6 tsa_6/ 掗拃	4.88 (3.57)	

Statistical analysis of the mean VAT values of the six tones produced by each male participants show that VAT differed significantly as a function of tone. Post Hoc, pairwise comparison (Bonferroni test) showed that significant differences existed only between tone pair 1 and 2 ($p < 0.05$). No significant differences exist between other tone pairs ($p > 0.05$). Results of analysis of the mean VAT values of the 12 homophones in the male group reveals that no significant differences exist for all homophone pairs ($p > 0.05$).

Discussion

The aims of the present study is to investigate the effects of different Cantonese tones on the recently-proposed acoustic-temporal parameter at the pre-phonatory stage, the vocal attack time (VAT) and to set up a normalized database of VAT in Cantonese speakers. This investigation will contribute to a better understanding of the laryngeal physiology in producing different tones in a tonal language in the pre-phonatory phase.

Gender-related differences

As proposed by Chan and Titze (1999), in their study investigating the elasticity and viscosity of human vocal folds mucosa, i.e. the superficial layer of the lamina propria of the vocal folds, gender-related differences existed (Chan & Titze, 1999). It is proposed in the paper that male vocal folds are more elastic (i.e. stiffer) and more viscous than the female ones. Since viscosity is directly related to the resistance of a material being displaced (Poole, 2007), based on this evidence, it is possible that the speed of displacement of the vocal folds from it’s abducted position towards the adduction to the mid-line will be slower in male participants than female participants. This is because male’s vocal folds are more resistant to movement due to its high viscosity.

Moreover, pre-phonatory laryngeal configurations, including the tension of the vocal folds, shape of glottis, distance between the two vocal folds, are different for production of different Fo. Due to the more elastic and vicious properties of the male vocal folds, deformation of the vocal folds is more difficult to be achieved (Chan & Titze, 1999). Thus, it is possible that the degree of adjustments for the pre-phonatory laryngeal configurations in male speakers is smaller and consequently, no significant differences in the mean VAT values across the six lexical tones in the male group results.

VAT differences and tone level and contour

From the results of the female group, production of tone 1, which has the highest pitch level, resulted the smallest VAT value. Tone 2, 4 and 5 have similar VAT values as shown in the results. Tone 3 and 6 also have similar VAT values, which are slightly larger than tone 1 but smaller than tone 2, 4 and 5.

Based on the results, it is possible that the smallest VAT value associating with tone 1 production was due to its high frequency nature in production (Ciocca & Khouw, 2007; Li, 1997). It is suggested that prior to a high Fo phonation, a narrowing of glottal opening results by the contribution of different muscular activities (Hirano et al., 1969). Narrowing of the glottal opening leads to a decrease in the distance between the two vocal folds. As a consequence, this result in a decrease in time for vocal adduction, i.e. for the vocal folds to adducted to the midline from the abducted condition (Colton et al., 2006).

Level tones versus contour tones

Results shown that the three contour tones (i.e. rising or falling tones) tone 2, tone 4 and tone 5 have mean VAT values statistically larger than the three level tones, i.e. tone 1, tone 3 and tone 6 (mean VAT values of tone 2 = 4.17ms, tone 4 = 4.36 ms, tone 5 = 4.54 ms; tone 1= 1.15 ms, tone 3= 2.32 ms, tone 6= 2.41 ms). As mentioned by Rose (1996), in his study of variation in Fo of Cantonese tones, Fo of the contour rising tone, tone 2, has a higher variability than the level tone, tone 1, in which the two tones have similar mean Fo level. He suggested that this might reflect a physiological difference in producing a level tone versus a contour tone, with production of a contour tone involves greater complexity (Rose, 1996). It is generally realized that production of a contour tone involves rapid changes in the Fo within the syllable or word (Fujisaki, Ohno & Gu, 2004).

VAT and the anatomy and physiology of phonation

Changes in Fo are primarily associated with the cricothyroid (CT) and infrahyoid strap muscles, with the CT muscles are shown to be the major contributor in Fo regulation in phonation. The relationship between the CT activity and Fo is linear: when CT muscular levels increases, Fo increases; when CT muscular levels decreases, Fo decreases. The control of Fo by the infrahyoid muscles is not yet clearly depicted. However, it was generally accepted that these muscles are associated with Fo lowering (Erickson, 1993; Hirano & Ohala, 1969; Ohala, 1973; Rose, 1996; Yip, 2002). Since changes in Fo level is involved in contour tones, activation and coordination of different muscles will be involved according to the changes in Fo levels within the syllable/ word.

For example, as mentioned by Erickson (1993) in his study of the laryngeal muscle activities for production of Thai tones, in production of a rising tone, CT muscle is deactivated at the beginning while activated from the mid-point towards the end; while the strap muscles make contribution at the beginning of production of a falling tone and is deactivated when the fall of a falling tone started (Erickson, 1993).

As a result, it is possible that the VATs were lengthened in production contour tones due to the complex mechanism involved in production of these tones, which involves activations and coordination between different muscles and the continuous adjustments of the vocal fold length and tensions for the changes in Fo level.

Among the three Cantonese level tones, mean VAT of tone 1 production is obviously shorter while the mean VAT of tone 3 and 6 are similar. It is stated by Rose (1996), in his study of the variation of Fo in Cantonese tones, that no significant differences were found between the variability of the Fo of the mid level tone 3 and the low-mid level tone6, while significant differences existed between the high level tone 1 and the mid level tone 3 (Rose, 1996). Provided that the variability of Fo is related to the production mechanism (Rose, 1996), it is possible that the production mechanism for tone 3 and 6 are more similar among the three level tones. This can be shown in the results of this study, in which the mean VAT values for tone 3 and 6 are more similar among the three level tones both in male and female groups, while the mean VAT value for tone 1 are exceptionally smaller. This may indicates that the pre-phonatory laryngeal settings, which are directly related to the VAT values, are consistent with the phonation mechanisms in the Cantonese level tones.

The results of the Post Hoc pairwise comparison (Bonferroni test) showed that no significant differences existed between mean VAT values of the 12 homophones produced by the male participants. Comparing with the results of the female group, in which significant differences exist between tones or homophones, it is possible that the contrasts between the two gender groups were due to the differences in the anatomy and physiology of the laryngeal structures and vocal fold functioning between males and females.

According to Sulter, Schutte & Miller (1996), male and female speakers have different laryngeal anatomy and physiology of phonation. For male speakers, it was shown that they have thicker, longer and tenser vocal folds. As mentioned above, the cricothyroid (CT) muscle is the major extrinsic laryngeal muscle for regulating the vocal fold configurations such as vocal fold thickness, length and tension, in order to regulate and control the production of different fundamental frequencies. (Erickson, 1993; Hirano & Ohala, 1969; Ohala, 1973; Rose, 1996; Yip, 2002). Under normal situation, when speakers produce a higher fundamental frequency, the CT muscles will be activated and contracted, thus tensing the vocalis muscles of the vocal folds and resulting in a vibration of higher fundamental frequency.

As the vocal folds of male speakers tend to be tenser and thicker, it is possible that changes in the thickness, length and tension of the vocal folds will be more difficult to be adjusted by the extrinsic muscles (i.e. the CT muscles, lateral and inter-cricoarytenoid muscles and the vocalis muscles) since more muscular forces are needed to change the configuration of a thicker, higher-mass and tenser vocal folds (Newton’s Second Law) (Stronge, 2004).

Relationship between VAT and Cantonese homophones

Cantonese is a Chinese dialect in which a syllable or a word with a particular tone may convey different meanings. Syllables or words with the same tone but with different meanings are referred to as homophones (Matthews & Yip, 1994). In this study, each participant was instructed to produce two homophones for each tone in analyzing the effects Cantonese tones on VAT. Results showed that in some tone pairs such as tone 1 and tone 5, both homophones of tone 1 are significantly different to both homophones of tone 5. However, in some tone pair such as tone 1 and tone 2, the homophone /a_1 ts^ha_1/ 丫叉 of tone 1 showed significant differences only with the homophone /a_2 liN_4/ 啞鈴 of tone 2 but not /a_2 pa_1/ 啞巴 of tone 2.

This phenomenon is explained here by using the results of the statistical differences between the homophones of the tone 1(which is a level tone) and the homophones of the three contour tones.

As shown from the results above, the homophone /a_1 ts^ha_1/ 丫叉 of tone 1 did not show significantly difference with the homophone /a_2 pa_1/ 啞巴 of tone 2. Similarly, the homophone /a_1 p^hin_3/ 鴉片 did not show significant difference with /a_4 ts^hoi_3/ 芽菜 of tone 4. This can be explained by the nature of the second syllable in the disyllabic word stimuli. The second syllable in the word /a_1 ts^ha_1/ 丫叉 and /a_2 pa_1/ 啞巴, i.e. /ts^ha_1/ 叉 and /pa_1/ 巴 respectively, are both tone 1 syllable. Likewise, the second syllable in the word /a_1 p^hin_3/ 鴉片 and /a_4 ts^hoi_3/ 芽菜, i.e. /p^hin_3/ 片 and /ts^hoi_3/菜 respectively, are both tone 3 syllables. Apart from the abovementioned example, there were also no significant differences between the homophone /a_3 $tsAu_1$/ 亞洲 of tone 3 and the homophone /a_2 pa_1/ 啞巴 of tone 2; /a_4 ts^hoi_3/ 芽菜 and /a1 p^hin_3/ 鴉片 etc. Details were displayed in table 6 and 7.

Phonation of syllables of the same tone (i.e. with same pitch level and same tone contour) involves more or less the same laryngeal settings and vocal fold physiology (Erickson, 1993; Ohala, 1973; Yip, 2002). For examples, phonation of tone 1, a high level tone, involves activation of the CT muscles and tense vocal folds (Hirano et al., 1969; Shipp, 1975). It is possible that the same laryngeal physiology in phonation of the second syllables with the same tone leads to more similar phonation mechanism (e.g. activation of different laryngeal muscles and setting of the tension of vocal folds) affects the phonation physiology of the first disyllable in the disyllabic word stimuli. This may result in a lack of significant differences exist between the homophones of the significantly different tone pairs. However, this should be subjected to further investigation.

Theoretical implication

Since gender-related differences existed between the VAT values across the six Cantonese tones and the homophones of each tone, it is possible that the vocal fold adduction mechanisms for production of different tones with different Fo in a tonal language was different between male and female speakers. Within the female group, it is shown that the adduction mechanism differs according to the contour of the tones, i.e. whether it is a level or a contour tone. Within the male group, it is shown that no differences existed in the physiology of vocal fold adduction across different tones. This provides direction to further studies on the phonation mechanism of different tones in Cantonese and other tonal language. Female speaker’s phonation mechanisms for different tones may deserve further studies in deep since more prominent results are shown in this study.

Clinical implication

Apart from the proposed theoretical insight, since measurement of VAT has been proved to be a reliable parameter in diagnosing voice disorders such as vocal nodules and pathological voice onset due to it’s close correlation with different voice onset types such as hard glottal attack and breathy onset during vocal fold adduction, it is possible that when investigating such voice disorders in Cantonese speakers using the VAT parameter, the diagnostic stimuli such as the syllables or words and sentences being read by the speakers can be constructed irrespective to the different Cantonese lexical tones in male speakers; while constructing according to the contour of the tones in female speakers. This ensures a more reliable diagnosis being made in Cantonese speakers

Limitation of this study

Since only one independent variable was investigated in this study, further investigations are needed to specifically assess the effect of tones and confirm the results found in this study. This can be done by including a larger sample pool of Cantonese speakers and conducting the experiment in other tonal languages such as Thai and Vietnamese (Yip, 2002).

Moreover, effect of gender and age on VAT should be studied further since laryngeal configurations and phonation physiologies were shown to be affected by aging and different genders in numerous previous literatures. (Benjamin, 1997; Ma & Love, in press, Muller, 1997; Brown, Morris, Hollien & Howell, 1991 etc). Experiments can be conducted across different age groups, for example the young, middle-aged, and older adult groups, each having a sufficient sample number with equal numbers of participants in each gender. Similarly, when exploring the effect of gender on VAT, experiment can be conducted in the two gender groups, with participants matched for their age and even speaking rate since it was shown that speaking rate may also affect the pre-phonatory laryngeal physiology (Swartz, 1992).

Conclusion

This study was the first study investigating the effects of tones on the pre-phonatory vocal fold physiology. It is the first study carried out in tonal language and Cantonese was chosen as the language for the investigation. Results of this study showed that tone features, including tone level and tone contour, has statistically significant effects on the pre-phonatory vocal fold mechanism in females while such effects were absent in male.

It is shown that the mean VAT values for males are generally larger than that of female across the six Cantonese tones. Significant differences existed between the level tones and contour tones in the female group while no statistically significant differences existed between the mean VAT values across the six Cantonese tones in the male group.

Acknowledgement

I would like to express my sincere gratitude to my dissertation supervisor, Dr. Estella Ma, for her valuable guidance and endless support throughout the study in this period. Special thanks are given to Miss. Irene Fong for her help in the analysis process. Also many thanks to my fellow classmates and all the subjects for their keen participations in this study. Lastly, I would like to express my deepest gratitude to my family and friends for their warmest support.

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Appendix 1- consent form and personal information
(a. for participants)

香港大學
言語及聽覺科學系
四年級畢業論文
[廣東話聲調與發聲原理的關係]

<u>參與同意書</u>

這是一項關於廣東話聲調與發聲原理之關係的學術研究。旨在更深入了解發聲原理，以幫助發展日後聲線學用途。

此項研究中， 參與者須根據研究員的指示讀出不同聲調的詞語。本項研究, 是利用電腦儀器分析不同的廣東話聲調與發聲原理的關係。在過程中, 研究員會將兩塊鐵片貼於你的頸部兩旁的位置，以用作錄音用途，整個過程將不會有任何不適的感覺。你將會嘗試發聲及讀出一些詞語，研究員將會錄音以用作研究用途，整個過程將會姐維持約二十分鐘。

是次研究並不為閣下提供個人利益，但所搜集數據將對研究聲線問題提供寶貴的資料。是次研究並不涉及任何風險及不會對參與者的身心理造成任何危險的後果。閣下可隨時提出終止，有關決定將不會引致任何不良後果。參與純屬自願性質，個人資料將絕對保密。如你對是項研究有任何問題，請現在提出。

如日後你對是項研究有任何查詢，請與研究員李佩雯小姐聯絡(電話: 96081393/電郵: puiman11@hkusua.hku.hk)。是項研究由香港大學言語及聽覺科學系助理教授馬珮雯博士負責監督。如你對是項研究有任何查詢，亦可與馬珮雯博士聯絡 (電話: 28590594/ 電郵: estella.ma@hku.hk)。

如你想知道更多有關研究參與者的權益，請聯絡香港大學非臨床研究操守委員會 (2241-5267)。

如你明白以上內容，並願意參與是項研究，請在下方簽署。

參與者姓名: ____________________ 參與者簽署:____________________

研究員姓名: ____________________ 研究員簽署:____________________

參與研究日期: ____________________

(b. for caregivers)

父母/監護人同意

敬啓者：

本人是香港大學言語及聽覺科學學系學士生，將會在香港大學進行一項關於發聲原理的學術研究，對象為十五至七十五歲之人士。研究旨在更深入了解發聲原理, 以幫助發展日後聲線學用途。

由於貴子弟尚未年滿十八歲，此參與同意書必須由父母/監護人簽署作實。在研究過程中，參與者須根據研究員的指示讀出不同聲調的單字。本項研究， 是利用電腦儀器分析不同的廣東話聲調與發聲原理的關係。在過程中, 研究員會將兩塊鐵片貼於你的頸部兩旁的位置，以用作錄音用途，整個過程將不會有任何不適的感覺。你將會嘗試發聲及讀出一些詞語，研究員將會錄音以用作研究用途，整個過程將會姐維持約二十分鐘。

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如日後你對是項研究有任何查詢，請與研究員李佩雯小姐聯絡(電話: 96081393 /電郵: puiman11@hkusua.hku.hk)。是項研究由香港大學言語及聽覺科學系助理教授馬珮雯博士負責監督。如你對是項研究有任何查詢，請可與馬珮雯博士聯絡 (電話: 28590594/電郵: estella.ma@hku.hk)。

如你想知道更多有關研究參與者的權益，請聯絡香港大學非臨床研究操守委員會 (2241-5267)。

如你明白以上內容，並願意參與是項研究，請在下方簽署。

參與者姓名: ____________________　　參與者簽署:____________________

研究員姓名: ____________________　　研究員簽署:____________________

參與研究日期: ______________________

Appendix 3- health questionnaire

香港大學
言語及聽覺科學
四年級畢業論文-[聲線學術研究]
健康問卷調查

請回答以下有關你的健康狀況的問題:

1. 請問你現在/ 曾經有沒有患過聲線上的問題?
   ☐ 有　如有, 請詳細列明情況:____________________________
   ☐ 沒有

2. 你現在/ 曾經有否患過言語及/或 咬字不清的問題?
   ☐ 有　如有, 請詳細列明情況:____________________________
   ☐ 沒有

3. 請問你有沒有任何聽覺問題?
   ☐ 有　☐ 沒有

4. 請問你在過去兩星期曾否有過以下病症? (可選擇多於一項)

☐ 喉嚨發炎　☐ 傷風　☐流行性感冒
☐ 竇炎　☐ 鼻炎　☐過敏性鼻炎(鼻敏感)
☐ 氣喘(病),哮喘　☐甲狀腺機能亢進　☐甲狀腺機能減退
☐ 扁桃腺炎
☐ 不適用, 我沒有任何以上病症

5. 請問一個月前到現在, 你有否服食任何藥物?
   ☐ 有　如有, 請詳細列明情況:____________________________
   ☐ 沒有

6. 你從前或現在有沒有患過哮喘或其他相關的呼吸系統疾病?
   ☐ 有　☐ 沒有

7. 請問你的喉嚨或附近位置曾否受過任何損傷?
   ☐ 有　☐ 沒有

8. 請問你有沒有胃酸倒流的情況?
   ☐ 有　☐ 沒有

9. 請問你今天/近幾天有沒有上呼吸道受感染的情況?
   ☐ 有　☐ 沒有

10. 請問你有否吸煙?

☐ 有 ☐ 沒有

如有, 吸煙的次數及數量是:____

11. 你是否在嘈雜的環境下工作?

☐是 ☐不是

12. 平日工作或消閒時, 你是否須要大聲說話?

☐是 ☐不是

13. 廣東話是否你的母語? ☐是 ☐不是

個人資料:

姓名: ____________________ 性別:_________________________

聯絡電話:___________________

出生日期:___________________ 年齡:___________________________

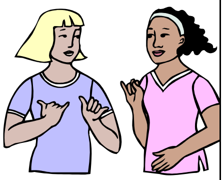
Appendix 4- word stimuli and presentation of stimuli

Word stimuli

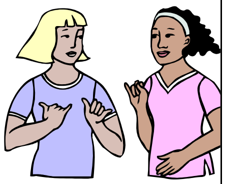
Tone					
1	2	3	4	5	6
丫(丫叉)	啞(啞巴)	亞(亞洲)	芽(芽菜)	瓦(瓦片)	硬 (硬幣)
鴉 (鴉片)	啞(啞鈴)	亞(亞軍)	牙(牙齒)	雅(雅典)	揠(揠拃)

Presentation of stimuli- Stimulus: /Na/

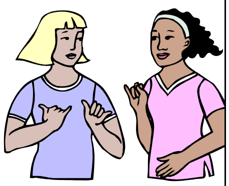
Trial 1

					
丫叉	亞洲	亞軍	瓦片	揠拃	芽菜
					
牙齒	啞鈴	啞巴	鴉片	硬幣	雅典

Trial 2

					
亞軍	雅典	亞洲	瓦片	牙齒	芽菜
					
掗拃	啞鈴	丫叉	鴉片	啞巴	硬幣

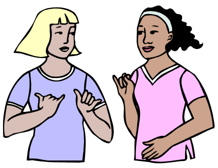
Trial 3

					
硬幣	亞洲	掗拃	丫叉	牙齒	鴉片
					
啞鈴	芽菜	雅典	亞軍	啞巴	瓦片

Trial 4

					
啞鈴	芽菜	亞洲	丫叉	硬幣	瓦片
					
牙齒	啞巴	雅典	亞軍	鴉片	揠拃

Trial 5

					
亞洲	丫叉	啞鈴	瓦片	硬幣	芽菜
					
啞巴	鴉片	揠拃	亞軍	雅典	牙齒