Title	Effects of class III malocclusion on young adults' vocal tract development
Author(s)	Lam, Wai-ling, Connie; 林慧聆
Citation	
Issued Date	2009
URL	http://hdl.handle.net/10722/173670
Rights	Creative Commons: Attribution 3.0 Hong Kong License

Effects of Class III Malocclusion on Young Adults' Vocal Tract Development: A Pilot Study

Lam Wai Ling, Connie

A dissertation submitted in partial fulfilment of the requirements for the Bachelor of Science (Speech and Hearing Sciences), The University of Hong Kong, June 30, 2009.

ABSTRACT

This study aimed at comparing the vocal tract configuration between speakers with Class III malocclusion and normal counterparts, and investigating the concomitant acoustic changes due to the alterations in vocal tract configuration. Eleven young adults with Class III malocclusion and eleven normal counterparts participated in this study. Acoustic reflection (AR) technology was used to measure vocal tract dimensions between the two groups. Continuous speech and 4 sustained vowels of each participant were recorded to obtain the fundamental frequency and the first 3 formant frequencies. Results showed significantly greater oral length and oral volume for males with Class III malocclusion than their cohorts. The F1 of vowel /u/ was found to be significantly higher in males with Class III malocclusion than their cohorts. The vowel space of the 4 recorded vowels was reduced and the F1-F2 formant map for /u/ was more relatively scattered in males with Class III malocclusion. This study has provided preliminary information on the effects of Class III malocclusion on vocal tract configuration and their concomitant acoustic changes in young adults.

INTRODUCTION

Introduction of Class III malocclusion

Malocclusion refers to the "abnormal occlusion characterized by an incorrect relationship between the arches in any spatial plane or by abnormal anomalies in tooth position" (Henry, 1994, p. 146). Angle's classification is a commonly used classification of malocclusion (Daskalogiannakis, 2000). It is based on the anteroposterior relationship of the upper and lower first molars. In class III malocclusion, "the lower arch is at least one-half cusp width too far forward in relation to the upper arch, judged by the first permanent molar relationship" (Jones & Oliver, 1994, p. 45). It is often diagnosed by cephalometric radiograph and clinical characteristics (Baccetti, Reyes & McNamara Jr, 2007). For aesthetic and/or functional reasons, people with Class III malocclusion, based on the severity and skeletal pattern, have different treatment options, such as extractions, use of appliances or orthognathic surgery, to establish a true occlusal position.

The prevalence of Class III malocclusion varies with different geographical areas. It could be as high as 13% incidence in Asia (Williams, Sarver, Sadowsky & Bradley, 1997). Lew, Foong and Loh (1993) examined the occlusal parameters of 1050 Chinese school children aged 12-14 years. They found an incidence of 12.6% for Class III malocclusion, which showed a lower incidence than Class I (58.8%) and Class II (21.5%) malocclusion. Samman, Tong, Cheung and Tideman (1992) also investigated 300 Hong Kong Chinese patients who had known to have dentofacial deformities and were referred by dental practitioners to a joint orthognathic clinic. They reported that among the 222 patients without cleft lip and palate, 47% had Class III malocclusion. Since the sample represented a selected group, the percentage could not suggest the true incidence of Class III malocclusion in the population.

Past studies on speakers with Class III malocclusion

The effects of Class III malocclusion on the speakers' articulation have been investigated (Hu, Zhou & Fu, 1997; Vallino & Tompson, 1993; Wang et al., 2006; Witzel, Ross & Munro, 1980). It was suggested that distortion of sibilants /s, z/ was a common error pattern for speakers with Class III malocclusion, as they often contact the tongue tip with the upper incisors during production of sibilants and dentalization is resulted. Labiodental consonants are also vulnerable to be distorted, as the upper lip generally contacts with the lower incisors, in a reversed labiodental posture (O' Gara & Wilson, 2007). Vallino and Tompson (1993) found that compensations by tongue and mandibular postures in producing sibilants /s, z/ were shown in patients with Class II malocclusion but not in those with Class III malocclusion. They thus concluded that the sound error nature was specifically affected by the malocclusion type. Other researchers, however, seemed to have different conclusions. Whitehill, Samman, Wong and Ormiston's (2001) study demonstrated that there are no significant differences in speech performance by different types of malocclusion, such as the vulnerability of sibilants production and distortion pattern. Voice and resonance characteristics (Xue, 1999), mastication (English, Buschang & Throckmorton, 2001) and quality of life (Zhang, Mcgrath & Hagg, 2006) in people with Class III malocclusion have also been studied. Many studies also focused on the effects of orthognathic surgery on speech (Hassan, Naini & Gill, 2007; Niemi, Peltomaki & Aaltonen, 2006; O'Gara & Wilson, 2007). It has been expected that people with Class III malocclusion will exhibit a different vocal tract configuration. Xue (1999) has found that higher, but not significantly higher, F1, F2 and F3 were shown in children with Class III malocclusion than those with normal occlusion. He made a tentative hypothetical explanation that in Class III malocclusion, the forwardly-protruding lower jaw would result in a relatively more elevated larynx, which makes the total vocal tract length shortened. However, no objective evidence has been provided on the effects of Class III malocclusion on the vocal tract characteristics of the speakers.

The anatomical and physiological functions of the speech systems will have direct effects on the acoustic qualities of speech. Xue, Hao and Mayo (2006) have found that morphological differences, particularly vocal tract volumes, are important contributing factors to the acoustic differences in speakers. Any alterations in vocal tract dimensions in speakers with Class III malocclusion will be expected to bring concomitant acoustic changes. Therefore, the alterations in vocal tract hypothesized by Xue (1999) could contribute to increased vowel formant frequencies, according to the inverse relationship between vocal tract length and formant frequencies demonstrated in the tube resonator model (Titze, 1994). However, no literature has been available on the possible correlation between changes in vocal tract configuration and the concomitant acoustic changes in people with Class III malocclusion.

Introduction of acoustic reflection technology

In the device of acoustic reflection (AR) technology, a wave tube is connected with participant’s mouth via a mouthpiece. Sound energies are transmitted into the airway through the wave tube and reflected at points of discontinuity along the upper airway. Cross sectional area-distance graphs (pharyngogram) delineating the vocal tract is obtained according to the amplitude and arrival times of the reflected signals, which are recorded by a microphone at the mouthpiece (Xue & Hao, 2003).

It is suggested that AR technology is a beneficial alternative to magnetic resonance imaging (MRI), X-ray or ultrasound for assessing vocal tract configurations in human, without the infliction of radiation exposure in X-ray, the requirement of 3-D structure reconstructions of the airway shapes in MRI (Xue & Hao, 2006), and their high costs for routine use. AR is safe, non-invasive and rapid, and accurately characterizes changes in area and volume in the vocal tract (Xue et al., 2006). Its accuracy has been well validated with computerized tomography (CT) (D’Urzo et al., 1987; Min & Jang, 1995) and MRI (Corey, Gungor, Nelson, Fredberg & Lai, 1997; Hilberg, Jensen, & Pederson, 1993), and its reproducibility has been also demonstrated (Brooks et al., 1984). AR has shown wide applications in assessing the dimensions of nasal airway (Corey et al., 1998), glottic area (D'urzo et al., 1988), upper airway (Fredberg, Wohl, Glass & Dorkin, 1980; Hoffstein & Fredberg, 1991), pharyngeal structures (Brown, Zamel & Hoffstein, 1986; Hatzakis, Karsan, Cook, Schloss & Davis, 2003), and vocal tract (Xue et al., 2006; Xue & Hao, 2003; Xue & Hao, 2006; Xue, Jiang, Lin, Glassenberg & Mueller, 1999). It has been used as an objective diagnostic system for assessing the upper airway obstruction, especially obstructive sleep apnea (OSA) (Kamal, 2001). Aging effects in vocal tract dimensions (Xue et al., 1999) and racial differences in nasal cross-sectional areas (Corey et al., 1998) have also been documented using AR.

Purposes of this study

This study acts as a pilot study to (i) compare the vocal tract configurations of a small group of young adults with Class III malocclusion, with a control group with normal occlusion, (ii) compare the acoustic measurements of vowel formant frequency between the two groups, and (iii) find out the possible correlations between the alterations in vocal tract configuration and concomitant acoustic changes in speakers with Class III malocclusion. These information are required before all the possible impacts of Class III malocclusion on the speaker's speech could be delineated.

Based on the tentative explanation made by Xue (1999), i.e. the protruding lower jaw in Class III malocclusion contributes to a shorter total vocal tract length, it was hypothesized in this study that (i) partcipants with Class III malocclusion would have a significantly different vocal tract configurations from the controls, with shorter and smaller oral cavity and pharyngeal area, shorter total vocal tract length and smaller total vocal tract volume; (ii) there would be significant differences in vowel formant frequencies in partcipants with Class III malocclusion; and (iii) the alterations in vocal tract configurations would bring about acoustic changes in vowel formant frequencies in partcipants with Class III malocclusion.

METHOD

Participants

Eleven young adults (with 8 males and 3 females, from aged 16 to 25) with Class III malocclusion and eleven counterparts (with 8 males and 3 females, from aged 17 to 24) with normal occlusion were voluntarily involved in this study. Seven participants with Class III malocclusion were recruited from the Department of Oral and Maxillofacial Surgery, Prince Philip Dental Hospital, the University of Hong Kong, while another four were referred from friends. All participants were Cantonese speakers and had been diagnosed to have Class III malocclusion by professional dentists. Each participant was invited to fill in a consent form and a brief background questionnaire before the testing (See Appendices).

Past studies found that vocal tract length is closely related to a speaker's height and weight (Titze, 1994), and aging also has significant impact on vocal tract configuration and acoustic measurement of voice (Xue & Deliyski, 2001). Age, gender, height and weight were thus matched for both groups in this study. All participants passed a pure-tone hearing screening bilaterally at 20 dB HL at 0.5, 1, 2 and 4 kHz. They reported no history of neurological, respiratory and speech disorders, cleft palate or other craniofacial structural abnormalities, and oro-maxillo-facial surgeries or orthodontic treatment. They were all in good health, with no cold or upper respiratory infections at the time of testing. The demographic information of all participants was summarized in Table 1.

The mean age of the males in malocclusion group was 19.80 years (*SD* = 2.30; range = 16-22) and the mean age of the males in the control group was 19.75 years (*SD* = 1.67; range = 17-22). There were no significant differences in the age between males in malocclusion group and control group ($F(1, 14) = .00$, $p = 1.00$). The mean height and weight of the males in malocclusion group were 175.35 cm (*SD* = 5.89; range = 165.3-185.0) and 61.34 kg (*SD* = 6.08; range = 54.3-65.7). The mean height and weight of the males in the control group were 176.50 cm (*SD* = 6.61; range = 164.0-185.0) and 62.19 kg (*SD* = 3.85; range = 56.8-67.1). A one-way analysis of variance (ANOVA) showed no significant differences in the height ($F(1, 14) = .13$, $p = .72$) and weight ($F(1, 14) = .11$, $p = .74$) between the males in malocclusion group and control group.

The mean age of the females in malocclusion group was 22.30 years (*SD* = 3.06; range = 19-25) and the mean age of the females in the control group was 22.00 years (*SD* = 2.65; range = 19-24). There were no significant differences in the age between females in malocclusion group and control group ($F(1, 4) = .02$, $p = .89$). The mean height and mean weight of the females in malocclusion group were 161.83 cm (*SD* = 2.02; range = 160-164) and 53.63 kg (*SD* = 8.19; range = 47.8-63.0). The mean height and mean weight of the females in the control group were 161.00 cm (*SD* = 1.00; range = 160-162) and 53.57 kg (*SD* = 6.17; range = 47.7-60.0). A one-way ANOVA showed that there were no significant differences in the height ($F(1, 4) = .41$, $p = .56$) and weight ($F(1, 4) = .00$, $p = .99$) between the females in malocclusion group and control group.

Table 1. Demographic information for participants in Class III malocclusion group and control group.

	Male		Female	
	Class III malocclusion (n =8)	Control (n = 8)	Class III malocclusion (n =3)	Control (n = 3)
Mean age (yrs)	19.80	19.75	22.30	22.00
SD	2.30	1.67	3.06	2.65
Range	16 - 22	17 - 22	19 - 25	19 - 24
Mean height (cm)	175.35	176.50	161.83	161.00
SD	5.89	6.61	2.02	1.00
Range	165.3 – 185.0	164.0 – 185.0	160.0 – 164.0	160.0 – 162.0
Mean weight (kg)	61.34	62.19	53.63	53.57
SD	6.08	3.85	8.19	6.17
Range	54.3 – 70.0	56.8 – 67.1	47.8 – 63.0	47.7 – 60.0

Procedures

i) Acoustic Reflection Assesment

The whole procedures of data collection were implemented in a sound-isolated room on 5/F, Prince Philip Dental Hospital. The vocal tract dimensions of the participants were measured with AR technology (Eccovision Acoustic Pharyngometer; Hood Laboratories, Pembroke), according to the operator manual. All participants seated upright in a chair in a quiet room and breathed by mouth through a mouthpiece attached on a wave tube. The mouthpiece was placed with the incisors against the flange, the tongue under the crossbar and the lips over the flange, forming a seal. Participants were instructed to imitate the production of /a/ sound silently to maintain a neutral, consistent oral configuration during measurement. The wave tube was positioned parallel to the ground and it directed the acoustic wave into the participant's vocal tract during measurement. The reflected wave was then recorded by a microphone attached on the tube. Three cross sectional area-distance curves delineating the vocal tract were obtained and one of them was selected for analysis based on the following criteria: (1) the positions of the oral pharyngeal juncture (OPJ) of the mouth-breathing curve and nose-breathing curve were best matched. OPJ is the area which the oral and pharyngeal cavities communicate. Anatomically, it is bounded superiorly by the soft palate, laterally by the anterior faucial pillars, and inferiorly by the tongue dorsum (Zemlin, 1998); (2) the fluctuation of the curve, caused by airflow changes, was the smallest.

The selected curve was divided into oral region (from the incisors to the anterior margin of OPJ) and pharyngeal region (from the soft palate to the glottis) by hand-marking, as defined by the manufacturer. Six vocal tract dimensional parameters, i.e. oral length, oral volume, pharyngeal length, pharyngeal volume, total vocal tract length and total vocal tract volume, were obtained from the curve for each participant.

ii) Acoustic recording

For acoustic measurements, the participants were required to produce 4 sustained vowels /a/, /Y/, /i/ and /u/ at their comfort levels of pitch and loudness for around 5 seconds each. These four vowels were selected as they represent extreme tongue placements and are called the corner vowels (Titze, 1994). They provided insights on the relationship between articulation and the vocal tract dimensions. Samples of continuous speech of around 30 seconds were also obtained by asking the participants to introduce themselves (e.g. talking about their personal background, hobbies and what would they do on that day). All speech samples were recorded in stereo format into a computer (Toshiba Satellite M50) through a high-quality stereo headset (Sennheiser PC 131), at sampling frequency of 44100 Hz.

iii) Acoustic analysis

Praat is a computer program for speech analysis and synthesis. It was downloaded for free from www.praat.org and was used to analyze a 20-second portion of each recorded continuous speech samples to obtain the mean speaking fundamental frequency (Fo). The three formant frequencies (F1, F2 and F3) were also obtained from 3-second middle portion of each sustained vowel production, to eliminate the onset and offset effects of voicing (Xue & Deliyski, 2001).

iv) Reliability of measurements

Three participants from each group were randomly selected for re-analysis of the vocal tract dimensional parameters by a second examiner in order to measure the inter-examiner reliability. Three participants from each group were also randomly selected for re-analysis of the vocal tract dimensional parameters by the same original examiner to measure the intra-examiner reliability.

Pearson correlation coefficients were tested and there were significant correlations ($p < .05$) for all measured vocal tract parameters in the two reliability tests. The results of inter-examiner and intra-examiner reliability tests are listed in Table 2.

Table 2. Inter- and intra-examiner reliability test results for the vocal tract parameters.

	Inter-examiner reliability (n = 6)		Intra-examiner reliability (n = 6)	
	Pearson correlation *r*	Level of significance *p*	Pearson correlation *r*	Level of significance *p*
OL (cm)	.943	.005	.931	.007
PL (cm)	.988	.000	.984	.000
TL (cm)	.969	.001	.997	.000
OV (cc)	.896	.016	.928	.008
PV (cc)	.989	.000	.973	.001
TV (cc)	.938	.006	.917	.010

Abbreviations: OL, oral length; PL, pharyngeal length; TL, total vocal tract length; OV, oral volume; PV, pharyngeal volume; TV, total vocal tract volume.

Note. All the Pearson correlations are significant at .05 level.

RESULTS

Table 3 shows a summary of means and standard deviations for the six vocal tract parameters, i.e. oral length, pharyngeal length, total vocal tract length, oral volume, pharyngeal volume and total vocal tract volume, of the Class III malocclusion group and control group. Table 4 summarizes the means and standard deviations of the fundamental frequency (Fo) of continuous speech and the first three formant frequencies (F1, F2, F3) of the four vowels /a/, /Y/, /i/ and /u/ of the two groups. Non-parametric inferential statistical procedure, Mann-Whitney Test, was used to analyze the differences in the six vocal tract parameters and acoustic measurements between the two groups, with males and females analyzed separately.

Table 3. Descriptive statistics for vocal tract dimensional parameters in Class III malocclusion and control group.

	Male				Female			
	Class III malocclusion (n =8)		Control (n = 8)		Class III malocclusion (n =3)		Control (n = 3)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
OL (cm)	11.29	0.58	9.64	1.02	10.20	0.35	9.27	1.19
PL (cm)	8.39	1.37	9.90	1.51	6.37	1.27	8.17	2.31
TL (cm)	19.68	1.09	19.54	1.36	16.57	1.20	17.44	1.12
OV (cc)	70.98	8.73	51.58	11.46	45.18	11.15	41.11	10.73
PV (cc)	26.25	6.35	33.69	10.96	22.73	6.16	19.70	3.81
TV (cc)	97.23	8.37	85.27	16.10	67.91	10.97	60.81	6.94

Abbreviations: OL, oral length; PL, pharyngeal length; TL, total vocal tract length; OV, oral volume; PV, pharyngeal volume; TV, total vocal tract volume.

Table 4. Descriptive statistics for acoustic measurements in Class III malocclusion and control group.

	Male				Female			
	Class III malocclusion (n =8)		Control (n = 8)		Class III malocclusion (n =8)		Control (n = 8)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Fo (Hz)	114.34	14.09	113.36	8.93	182.33	12.33	198.36	23.50
/a/								
F1 (Hz)	671.99	83.38	705.70	70.49	840.14	112.83	858.48	198.77
F2 (Hz)	1118.93	121.84	1235.84	133.66	1515.77	198.70	1365.27	158.71
F3 (Hz)	2677.85	202.69	2810.08	164.74	3120.05	432.17	3117.91	86.90
/Y/								
F1 (Hz)	539.45	39.24	541.23	44.88	689.75	79.47	631.96	75.52
F2 (Hz)	1988.83	128.07	1935.99	208.09	2137.31	129.51	2220.97	139.37
F3 (Hz)	2677.14	181.82	2676.81	213.43	3020.08	156.66	3113.31	144.45
/i/								
F1 (Hz)	292.14	22.23	288.75	35.79	408.07	88.58	453.54	28.43
F2 (Hz)	2168.13	115.36	2195.25	191.35	2787.34	145.71	2542.66	148.97
F3 (Hz)	3007.71	175.27	3047.49	261.46	3549.37	194.76	3394.76	137.27
/u/								
F1 (Hz)	505.88	102.03	396.96	60.84	381.32	26.35	423.79	55.63
F2 (Hz)	1680.92	555.17	1167.75	609.29	946.47	109.02	850.65	43.21
F3 (Hz)	2964.24	447.56	2789.87	270.53	2821.00	200.25	2718.35	93.15

Abbreviations: Fo, fundamental frequency; mF1, mean first formant frequency; mF2, mean second formant frequency; mF3, mean third formant frequency

For the vocal tract dimensional parameters, the results showed significant differences in vocal tract dimensions between the Class III malocclusion group and control group in oral length (U = .500, p = .001) and oral volume (U = 7.000, p = .009) in males, with the level of significance set at .05. All males with Class III malocclusion had greater oral length and oral volume than their counterparts in control group. The means of vocal tract length and volume measurements of males in the two groups are shown in Figure 1 and 2. Nevertheless, there was no significant difference in all vocal tract dimensional parameters between the two female groups. Females with Class III malocclusion seemed to have greater oral length and oral volume than the control counterparts, as shown from the means. However, the differences between two groups were not significant in females. The discrepancy between the male and female results might be the influence of limited female participants.

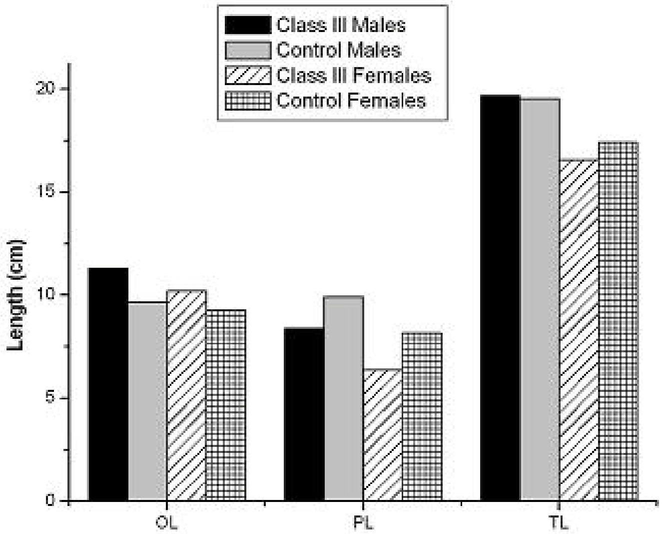

Figure 1. Oral length, pharyngeal length and total vocal tract length of males in Class III malocclusion group and control group. (*Abbreviations: OL, oral length; PL, pharyngeal length; TL, total vocal tract length.)*

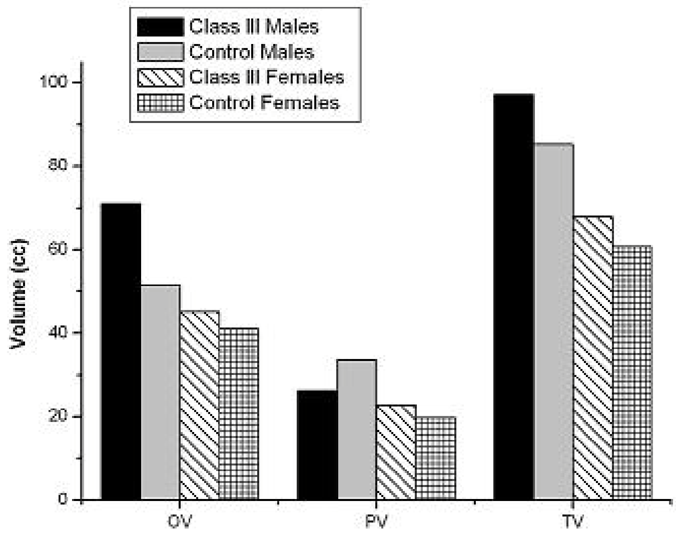

Figure 2. Oral volume, pharyngeal volume and total vocal tract volume of males in Class III malocclusion group and control group. (*Abbreviations: OV, oral volume; PV, pharyngeal volume; TV, total vocal tract volume.*)

For the acoustic measurements, no significant difference in Fo was found between the two male groups and between the two female groups. Significant difference in F1 of vowel /u/ (U = 13.000, p = .046) was found between males with Class III malocclusion and their cohorts. The group means indicated that males with Class III malocclusion had a higher F1 of vowel /u/ than males in the control group. Females showed no significant difference in the three formant frequencies of all the four vowels among the two groups. Figure 3 and 4 show the mean F1 and mean F2 of the four vowels for males and females, with mean F1 as the y-axis and mean F2 as the x-axis. Reduced vowel shape was indicated in males with Class III malocclusion. The locations of the mean F1 and F2 of /a/, /Y/ and /i/ were similar, and discrepancy occurred at /u/. Nevertheless, females showed similar vowel shapes in both groups.

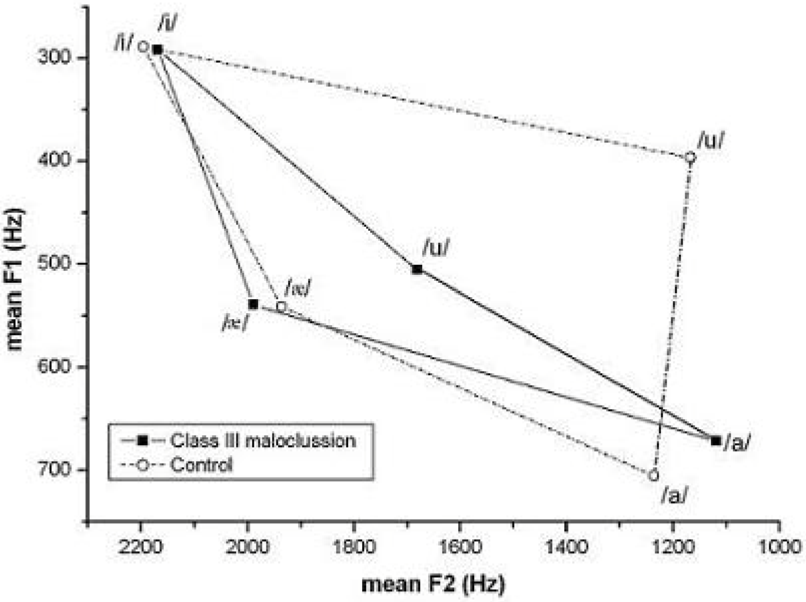

Figure 3. <u>The mean F1-mean F2 vowel chart of /a/, /Y/, /i/ and /u/ for males in Class III malocclusion group and control group.</u>

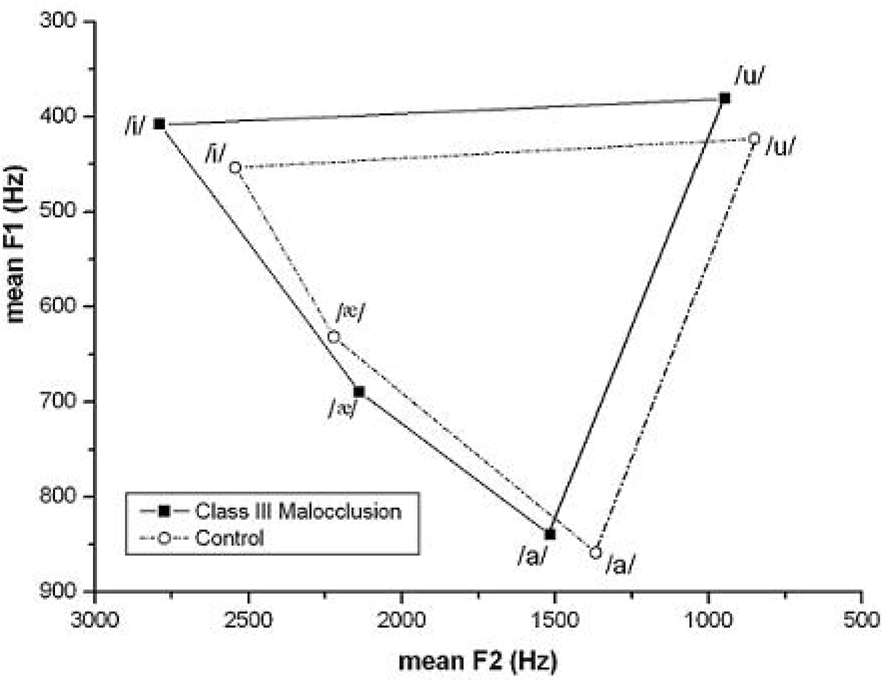

Figure 4. <u>The mean F1- mean F2 vowel chart of /a/, /Y/, /i/ and /u/ for females in Class III malocclusion group and control group.</u>

The distributions of F1 and F2 of the four vowels of males in the two groups are plotted in Figure 5. The F1-F2 distribution of /u/ seemed to be relatively more scattered than /a/, /Y/ and /i/, and overlapped with the formant region of /Y/, for males in Class III malocclusion.

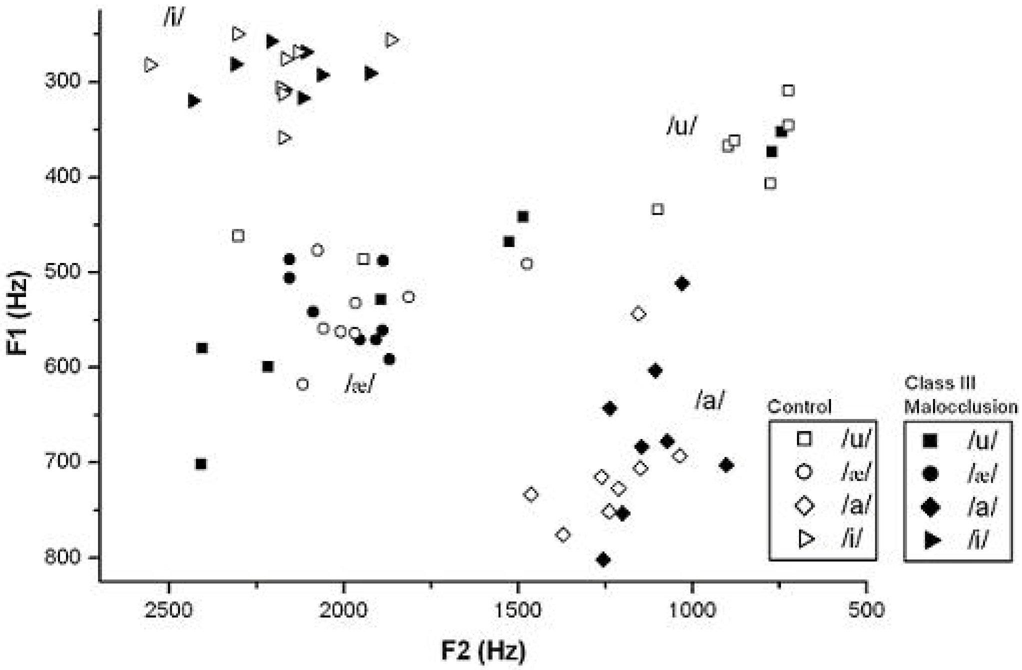

Figure 5. Formant map of F1 and F2 of the four vowels of males in Class III malocclusion group (n = 8) and control group (n = 8).

DISCUSSION

No previous study has been done to objectively measure the vocal tract dimensional data for speakers with Class III malocclusion. This study acted as a pilot study and provided preliminary data about this aspect.

The findings of this study showed that males with Class III malocclusion may have different vocal tract configuration from those with normal occlusion. The differences occurred in oral cavity only. It was found that males with Class III malocclusion had significantly longer oral length and larger oral volume than their counterparts in the control group. For females, the descriptive data indicated that the oral length and oral volume in Class III malocclusion group seemed to be larger than the control group (see Table 3), although the difference was not significant. This gender difference may be the consequence of the limited female participants in this study, making the female data not representative and the two genders were not adequately comparable.

Previous study by Guyer, Ellis, McNamara Jr and Behrents (1986), using lateral cephalometric radiographs, reported that Class III malocclusion had significantly more retrusive maxilla and more protrusive mandible, compared with normal occlusion. Mouakeh (2001) also had similar findings in his study that patients with Class III malocclusion had significantly smaller maxillary length and slightly increased mandibular length. Based on our findings, it could be hypothesized that since the mouthpiece was placed with the participant’s incisors against the flange during AR measurement, the protrusion of mandible with protruded lower incisors in Class III malocclusion might have contributed to increment in the measured oral length. In addition, the degree of mandibular protrusion might be greater than the degree of maxillary retrusion in Class III malocclusion, making the resultant oral volume increased. However, these are only hypothetical and further researches are required to investigate the proportion of mandibular protrusion and maxillary retrusion in this population.

No significant difference was reported in the dimensions of pharyngeal cavity between the two groups. It may indicate that Class III malocclusion is the result of maxillo-mandibular relationship and has impacts on the configuration of oral cavity only, without extending effects to the pharyngeal cavity.

Xue (1999) found higher F1, F2 and F3 in children with Class III malocclusion than the normal cohorts in his study. He hypothesized that in Class III malocclusion, the protruding lower jaw would result in a relatively more elevated larynx, which makes the total vocal tract length shortened. However, the findings of longer and larger oral cavity in Class III malocclusion in this study are different from Xue's (1999) hypothesis. This discrepancy may be due to the very young age of participants (aged 7 to 8) in Xue's (1999) study. The growth of Class III malocclusion involves significant increments in mandibular length during late maturation period, until young adulthood (Baccetti et al., 2007). This may account for the greater oral length and oral volume found for young adults with Class III malocclusion in this study.

The source-filter theory states that, the sound source is the glottal airflow which contributes to vocal folds vibration, and the sound will then be acoustically filtered by the vocal tract (Titze, 1994). According to this theory, changes in the source characteristics and changes in the filter function of the vocal tract are independent with each other. This was delineated in our findings that there was no significant difference in fundamental frequency Fo between the Class III malocclusion group and the control group (for both males and females), but there was significant difference in the first formant frequency F1 for vowel /u/ between males in the two groups. Fo is only determined by the rate of vibration of the vocal folds, but not affected by the vocal tract dimensional properties (Zemlin, 1998). Therefore, the differences in vocal tract dimensions between the two groups should not bring any differences in Fo between the groups.

Formant frequencies are the frequencies at which the vocal tract filter allows maximum energy through (Lieberman & Blumstein, 1988) and they are thus affected by the vocal tract configuration. The perception and classification of vowels are based on the two lowest formant frequencies (Titze, 1994). A vowel's own unique energy distribution characterizes the particular vowel and it is the consequence of the cross-sectional area and length of the vocal tract (Zemlin, 1998). Therefore, any alterations in vocal tract dimensions in speakers with Class III malocclusion would be expected to bring concomitant acoustic changes. Acoustic analysis has been, therefore, long applied to infer the physiological functions of speech mechanisms in the past studies.

The acoustic findings of this study demonstrated no significant differences in F1, F2 and F3 of all the four vowels between the two groups, except F1 of /u/ in males. The descriptive data showed that the mean F1 of /u/ of males is higher in Class III malocclusion group than in control group. The mean F2 of /u/ of males with Class III malocclusion is also higher than those with normal occlusion, although not significantly (See Table 4). The production of /u/ involves lip protrusion, which increases the vocal tract length (Zemlin, 1998). The formant frequencies are thus lowered, according to the inverse relationship between vocal tract length and formant frequencies demonstrated in the tube resonator model (Titze, 1994). It could be hypothesized, based on our findings, that the protruded mandible and retruded maxilla in Class III malocclusion may restrict the lip protrusion during production of /u/. The increment in vocal tract length is thus reduced and so the formant frequencies are higher than in subjects with normal occlusion. The F1 and F2 of /a/, /Y/ and /i/, nevertheless, showed no significant differences between the groups and this may imply the compensating ability for the vocal tract functional changes in subjects with Class III malocclusion when producing these three vowels.

The F3 of all the four vowels showed no significant difference between two groups in both genders. It was suggested that F3 is related to tongue configuration (Lieberman & Blumstein, 1988) and the tongue tip positions (Zemlin, 1998), and it is unrelated to vocal tract dimensions. Therefore, no impacts of Class III malocclusion and vocal tract dimensional changes would contribute to differences in F3 between the two groups.

The four vowels /a/, /Y/, /i/ and /u/ are called corner vowels, as they represent extreme tongue placements and form the corners in the vowel chart (Titze, 1994). The mean F1-mean F2 vowel chart of the four vowels indicated a reduced vowel space for males with Class III malocclusion (See Figure 3). The locations of the mean F1 and F2 of /a/, /Y/ and /i/ were similar, and discrepancy occurred at /u/. The reduced vowel space may imply that Class III malocclusion, with characteristic maxillo-mandibular relationship, may have resulted in restricted range of motion of articulators, which may in turn affect speech intelligibility and cause perceptual differences from speakers with normal occlusion. The reduction of vowel space was not evident in females, in which the shapes of the vowel space are similar for both Class III malocclusion and control groups. This may be again due to the limited number of female subjects, which may not be able to show any differences among the groups.

The formant map of males shown in Figure 5 indicated that the F1-F2 distributions of /a/, /Y/ and /i/ were in similar locations among the groups and were relatively concentrated in both groups. However, the F1-F2 distribution of vowel /u/ seemed to be relatively more scattered and overlapped with the formant region of /Y/, for males in Class III malocclusion. This may imply that there is greater individual difference in /u/ production, which may be the consequence of different individual abilities of articulatory compensation of this vowel, in speakers with Class III malocclusion. Individual differences in resonance properties are, therefore, resulted. Since vowels are specified by the two lowest formant frequencies (F1 and F2) of the vocal tract (Titze, 1994), the intelligibility of /u/ in speakers with Class malocclusion may be also influenced if /u/

does not occupy a clearly defined F1-F2 formant region from other vowels. However, Figure 5 only leaded us to make tentative hypotheses based on a relatively limited number of male participants. Additional studies involving larger sample are needed before we could provide further evidence on our hypotheses.

This study is limited by the small total number of participants which limits the generalizability of the findings and weakens the power of statistical analysis. In addition, the numbers of participants for both genders were not equal, which made the investigation of gender effect difficult. Furthermore, there were total of 5 participants in this study having nose allergy. It may have impacts on the AR measurement of vocal tract dimensions, although no studies have provided evidence on this.

Future physiological studies should involve larger number of participants, with different age groups, to further investigate if the malocclusion only affects the configuration of oral cavity but not pharyngeal cavity, and to delineate the dimensional relationship of vocal tract during growth and the concomitant acoustic changes. In addition, other vowels which involve intermediate tongue placement compared with the four corner vowels investigated in the present study, could be explored acoustically in future researches to obtain a more comprehensive vowel chart and observe the acoustic impacts on variety of vowels. Finally, perceptual analysis is needed to study the perceptual impacts of changes in vocal tract configuration on the speaker’s speech. The implications may help speech-language pathologists to monitor the oral mechanisms for speech production in speakers with Class III malocclusion.

CONCLUSION

The present study has provided preliminary evidence on the morphological effects of Class III malocclusion on vocal tract, using AR technology. It also gave insights on the resonance changes related to the vocal tract dimensional changes, in speakers with this particular type of malocclusion. The characteristic maxillo-mandibular relationship in Class III malocclusion may contribute to alterations in oral dimensions. Lip protrusion may be restricted during production of /u/, contributing to the significant difference in F1 of /u/. The restricted range of motion of articulators may have contributed to the reduced vowel space. In addition, the more scattered F1-F2 formant map for /u/ in males with Class III malocclusion may suggest greater individual differences in this vowel production and possible impacts on vowel intelligibility.

ACKNOWLEDGMENTS

I would like to express my gratitude to Dr. Steve Xue for his guidance and advice. I would also like to thank Dr. Lawrence Ng for his advice on statistical analysis, and Dr. Tara Whitehill, Dr. Nabil Samman and Miss In Ho for their help in subject recruitment. I also appreciate all the subjects for their kindness and willingness to participate in this study. Finally, I would like to thank Raymond for his technical support.

REFERENCES

Baccetti, T., Reyes, B. C., & McNamara Jr, J. A. (2007). Craniofacial changes in Class III malocclusion as related to skeletal and dental maturation. American Journal of Orthodontics and Dentofacial Orthopedics, 132(2), 1-12.

Brooks, L. J., Castile, R. G.., Glass, G.. M., Griscom, N. T., Wohl, M. E., & Fredberg, J. J. (1984). Reproducibility and accuracy of airway area by acoustic reflections. *Journal of Applied Physiology, 57(3)*, 777-787.

Brown, I. G., Zamel, N., & Hoffstein, V. (1986). Pharyngeal cross-sectional area in normal men and women. *Journal of Applied Physiology, 61*, 890-895.

Corey, J. P., Gungor, A., Nelson, R., Fredberg, J., Lai, V. (1997). A comparison of the nasal cross-sectional areas and volumes obtained with acoustic rhinometry and magnetic resonance imaging. *Otolaryngology-Head and Neck Surgery, 117*, 349-354.

D' Urzo, A. D., Lawson, V. G., Vassal, K. P., Rebuck, A. S., Slusky, A. S., & Hoffstein, V. (1987). Airway area by acoustic response measurements and computerized tomography. *The American Review of Respiratory Disease*, *135*, 392-395.

D' Urzo, A. D., Rubinstein, I., Lawson, V. G., Vassal, K. P., Rebuck, A. S., Slutsky, A. S., & Hoffstein, V. (1988). Comparison of glottic areas measured by acoustic reflections vs. computerized tomography. *Journal of Applied Physiology, 64*, 367-370.

Daskalogiannakis, J. (2000). *Glossary of Orthodontic Terms*. Berlin: Quintessence Publishing Co. Inc.

English, J. D., Buschang, P. H., & Throckmorton, G. S. (2001). Does Malocclusion Affect Masticatory Performance? *The Angle Orthodontist, 72(1)*, 21–27.

Fredberg, J. J., Wohl, M. E. B., Glass, G.. M., & Dorkin, H. I. (1980). Airway area by acoustic reflections measured at the mouth. *Journal of Applied Physiology, 48*, 749-758.

Guyer, E. C., Ellis, E. E., McNamara Jr., J. A., & Behrents, R. G. (1986). Components of Class III Malocclusion in Juveniles and Adolescents. *The Angle Orthodontist, 56(1),* 7-30.

Hassan, T., Naini, F., & Gill, D. (2007). The Effects of Orthognathic Surgery on Speech: A Review. *Journal of Oral and Maxillofacial Surgery, 65(12),* 2536-2543.

Hatzakis, G. E., Karsan, N., Cook, J., Schloss, M., & Davis, G. M. (2003). Acoustic reflectance of pharyngeal structures in children. *International Journal of Pediatric Otorhinolaryngology, 67*, 373-381.

Henry, F. J. (1994). *Concise illustrated dental dictionary* (2nd ed.). Oxford: Wright.

Hilberg, O., Jensen, F. T., & Pedersen, O. F. (1993). Nasal airway geometry: comparison between acoustic reflections and magnetic resonance scanning. *Journal of Applied Physiology, 75*, 1811-1819.

Hoffstein, V., & Fredberg, J. J. (1991). The acoustic reflection technique for non-invasive assessment of upper airway area. *European Respiration Journal, 4*, 602-611.

Hu, W., Zhou, Y., & Fu, M. (1997). Effect of skeletal Class III malocclusion on speech articulation. *Zhonghua Kou Qiang Yi Xue Za Zhi, 32(6),* 344-6.

Jones, M. L., & Oliver, R. G. (1994). *Walter and Houston's Orthodontic Notes* (5th ed.). Oxford: Wright.

Kamal, B. G. I., (2001). Normal standard curve for acoustic pharyngometry. *Otolaryngology – Head and Neck Surgery, 124(3)*, 323-330.

Lew, K. K., Foong, W. C., & Loh, E. (1993). Malocclusion prevalence in an ethnic Chinese population. *Australian Dental Journal, 38(6),* 442-449.

Lieberman, P., & Blumstein, S. E. (1988). *Speech physiology, speech perception, and acoustic phonetics*. Cambridge: Cambridge University Press.

Min, Y. G., & Jang, Y. J. (1995). Measurements of Cross-sectional Area of the Nasal

Cavity by Acoustic Rhinometry and CT Scanning. *Laryngoscope, 105*, 757-759.

Mouakeh, M. (2001). Cephalometric evaluation of craniofacial pattern of Syrian children with Class III malocclusion. *American Journal of Orthodontics and Dentofacial Orthopedics, 119(6)*, 640-649.

Niemi, M., Peltomaki, T., & Aaltonen, O. (2006). Acoustic Comparison of Vowel Sounds Produced Before and After Orthognathic Surgery for Mandibular Advancement. *American Association of Oral and Maxillofacial Surgeons, 64*, 910-916.

O' Gara, M., & Wilson, K. (2007). The Effects of Maxillofacial Surgery on Speech and Velopharyngeal Function. *Clinics in Plastic Surgery, 34(3)*, 395-402.

Samman, N., Tong, A. C., Cheung, L. K., & Tideman, H. (1992). Analysis of 300 dentofacial deformities in Hong Kong. *International Journal of Adult Orthodontics and Orthognathic Surgery, 7(3)*, 181-185.

Titze, I. R. (1994). *Principles of voice production*. Englewood Cliffs, NJ: Prentice-Hall.

Vallino, L. D., & Tompson, B. (1993). Perceptual characteristics of consonant errors associated with malocclusion. *Journal of Oral Maxillofacial Surgery, 51(8)*, 850-856.

Wang, L. L., Yang, J. F., Chen, J., Liu, X. O., Fan, C. H., & Liu, J. (2006). Correlation analysis on the malocclusion and articulation of skeletal angle III malocclusion in mixed dentition. *Hua Xi Kou Qiang Yi Xue Za Zhi, 24(4)*, 318-20.

Whitehill, T. L., Samman, N., Wong, L. L. N., & Ormiston, I. (2001). Speech Errors Associated with Dentofacial Abnormalities in Cantonese Speakers. *Journal of Medical Speech-Language Pathology, 9(3)*, 177-190.

Williams, M. D., Sarver, D. M. Sadowsky, P. L., & Bradley, E. (1997). Combined Rapid Maxillary Expansion and Protraction Facemask in the Treatment of Class III Malocclusion in Growing Children: A Prospective Long-Term Study. *Seminars in Orthodontics, 3(4)*, 265-274.

Witzel, M. A., Ross, R. B., Munro, K. (1980). Articulation before and after facial osteotomy. *Journal of Maxillofacial Surgery, 8*, 195-202.

Xue, S. A. (1999). Speaking fundamental frequency and resonance characteristics of young children with Class III malocclusions in North China. *Asia Pacific Journal of Speech, Language and Hearing, 4,* 53-58.

Xue, S. A., & Deliyski, D. (2001). Effects of aging on selected acoustic voice parameters: preliminary normative data and educational implications. *Educational Gerontology, 27*, 159-168.

Xue, S. A., & Hao, G. J. P. (2003). Changes in the human vocal tract due to aging and the acoustic correlates of speech production: A pilot study. *Journal of Speech, Language, and Hearing Research, 46*, 687-701.

Xue, S. A., & Hao, G. J. P. (2006). Normative Standards for Vocal Tract Dimensions by Race as Measured by Acoustic Pharyngometry. *Journal of Voice, 20(3),* 391-400.

Xue, S. A., Hao, G. J. P., & Mayo, R. (2006). Volumetric measurements of vocal tracts for male speakers from different races. *Clinical Linguistics & Phonetics, 20(9),* 691-702.

Xue, S. A., Jiang, J., Lin, E., Glassenberg, R., & Mueller, P. B. (1999). Age-related changes in human vocal tract configurations and the effects on speakers' vowel formant frequencies: a pilot study. *Logopedics Phoniatrics Vocology, 24*, 132-137.

Zemlin, W. R. (1998). *Speech and Hearing Science: Anatomy and Physiology*. Boston: Allyn and Bacon.

Zhang, M., Mcgrath, C., & Hagg, U. (2006). The impact of malocclusion and its treatment on quality of life: a literature review. *International Journal of Paediatric Dentistry, 16(6),* 381-387.

APPENDICES

Appendix 1. The questionnaire for every participant about their background.

倒及牙對青少年聲道結構的影響研究

參加者個人背景問卷

感謝閣下參與是項探討倒及牙對青少年聲道結構及聲音共振的影響研究。在開始進行儀器測量前，請先完成以下問卷，部分問題可能涉及閣下的私隱，所有資料只作研究用途，個人資料將絕對保密。完成後請在右下方簽署作實。

第一部分: 請填寫以下資料:

姓名	
性別	
年齡	
身高	cm
體重	kg
聯絡電話	

第二部分: 請在正確的位置填上✓:

	是	否
1) 你是否有任何說話能力的問題?		
2) 你是否有任何聽力問題?		
3) 你是否有任何呼吸系統問題?		
4) 你是否曾經有任何神經受創?		
5) 你是否曾經有兔唇/裂顎或其他面頰骨異常?		
6) 你是否曾經接受面部/口部/顎骨的手術?		
7) 你是否曾經接受箍牙?		
8) 現在，你是否患有傷風/感冒/鼻敏感/上呼吸道感染?		

請確認以上資料，並簽署作實。

參加者簽署: ______________________________

日期: ______________________________

Appendix 2. Consent form for every participant.

言語及聽覺科學部

Division of Speech and Hearing Sciences

Faculty of Education

香港大學 THE UNIVERSITY OF HONG KONG

同意書

倒及牙對青少年聲道結構的影響

這是一項關於聲道的學術研究，旨在探討倒及牙對青少年聲道結構及聲音共振的影響，以助將來對倒及牙人仕的言語治療發展。

閣下需要完成一份有關個人背景的問卷(需時約五分鐘)。在完成問卷的過程中，部分問題可能涉及閣下的私隱。然後研究員會為閣下進行一個簡單的聽力測試(需時約五分鐘)，並使用先進的聲波反射儀器測量閣下的聲道結構(需時約五分鐘)，此儀器只運用聲波，並不會對身體造成傷害。最後，你會被指示讀四個單音和一段簡單的語音，研究員會使用電腦程式 PRAAT 來分析閣下的基頻和共振峰頻率(需時約十分鐘)，此過程將會被錄音。

是次研究並不為閣下提供任何個人利益，但所搜集數據將對研究倒及牙對語音的影響提供寶貴的資料。是次參與純屬自願性質，所收集的資料只作研究用途，個人資料將絕對保密，閣下亦可以隨時退出此研究。如閣下對是項研究有任何問題，請現在提出。

如日後閣下對是項研究有任何查詢，請與研究員香港大學言語及聽覺科學四年級學生林慧聆小姐聯絡(電話: 9812 8602)。如閣下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)。

如閣下明白以上內容，並願意參與是項研究，請在下方簽署。

姓名：______________________________

簽署：______________________________

日期：______________________________