



<b>Title</b>	<b>Effects of Lee Silverman voice treatment [LSVT] on Cantonese speakers with Parkinson's disease</b>
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**Effects of Lee Silverman Voice Treatment [LSVT] on Cantonese**

**Speakers with Parkinson's Disease: Acoustic Analysis**

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## **ABSTRACT**

The effects of intensive voice treatment (LSVT) on English-language speakers with Parkinson's Disease (PD) are well documented but studies on Cantonese speakers with PD were very limited. This study is an extension of a previous pilot study which only based on the principles of LSVT on Cantonese-speaking population and with larger size of participants. The first purpose of this study was to investigate the general effects of LSVT using acoustic analysis. The second purpose was to investigate the possible dissociation of fundamental frequency control for intonation and lexical tones. Speech samples were collected from a standard reading passage and maximum sustained vowel phonation from twelve Cantonese PD speakers before and after sixteen individual speech therapy sessions. Quantitative and qualitative analyses indicated improvements in sound pressure level and mean fundamental frequency. However, improvements in standard deviation of fundamental frequency were only shown in qualitative analysis. No significant changes in speech rate and lexical tone production were revealed after receiving LSVT. The results provide further support on the notion of a dissociation of fundamental frequency control of intonation and lexical tone.

**KEYWORD:** Parkinson's disease, LSVT, acoustic, intonation, lexical tone

## INTRODUCTION

Parkinson's disease (PD) is a progressive neurological disorder caused by degenerating substantia nigra cells due to the deficiency of dopamine (Darley, Aronson, & Brown, 1975). Its major characteristics are rest tremor, rigidity, bradykinesia, hypokinesia, akinesia, and postural instability (Duffy, 2005). Apart from these motor signs, Parkinson's disease patients frequently experience hypokinetic dysarthria which affects their voice and speech production (Logemann, Fisher, Boshes & Blonsky, 1978). Reduced loudness, monoloudness, reduced pitch variability, lower pitch level, rough voice, abnormal prosody, voice tremor and reduced speech intelligibility are the most common speech deficits shown by PD patients (Sapir, Ramig, & Fox, 2006).

Previous studies have revealed that surgical, pharmacological and traditional voice therapy have produced unsatisfactory results in terms of the degree of improvement and the long term maintenance of the therapy effectiveness (e.g., Sapir et al., 2006). In contrast, Lee Silverman Voice Treatment (LSVT) is an intensive voice therapy shown to be effective for hypokinetic dysarthric patients (Fox, Morrison, Ramig, & Sapir, 2002). The goal of LSVT is to teach Parkinson's disease individuals to improve their functional verbal communication by enhancing their vocal loudness (Ramig, Pawlas, & Countryman, 1995b). This is established by intensive training on high phonatory tasks which stimulates an increase in vocal fold adduction and respiratory support (Ramig, Countryman, Thompson, & Horii, 1995a).

LSVT is different from traditional therapy and has several key characteristics. First, it is based on simple tasks and a simple instruction (Ramig et al., 1995b). Individuals undergoing

LSVT are stimulated to increase effort in producing loud voice during sustained vowel phonation tasks and in various speech tasks. Their vocal loudness is monitored and a verbal cue 'Think Loud' is given (Sapir et al., 2002). PD individuals benefit from the use of simple instruction as they may encounter difficulties in executing complex tasks. The second characteristic is that high effort therapy helps patients to overcome the problem of hypokinesia or rigidity in the laryngeal and/or respiratory muscles when speaking loud. In addition, an intensive schedule is another unique feature of this voice therapy for PD patients. In line with the theory of motor learning, frequent and intensive practice was essential in establishing a new motor skill, in this case, increasing the phonatory effort level (Schmidt, 1988). Ramig, Countryman, O'Brien, Hoehn, & Thompson (1996) emphasized the importance of adjusting the amplitude of phonatory efforts. The motor output and the generalization at the vocal level after adjustment will be more prominent through the auditory-vocal self monitoring in this high effort therapy. Objective data on patients' performance before and after every session and the whole course of treatment as well as the maintenance of therapy is documented. Patients, families and speech therapists will be reinforced and the patient will also be motivated to generalize the use of increased vocal loudness outside the treatment room (Ramig et al., 1995b).

Various perceptual, acoustic, aerodynamic, videostroboscopic and electroglottographic studies have reported positive outcome of LSVT (See Fox et al., 2002 for a review). PD individuals who have received LSVT demonstrated a marked increase in vocal loudness and sound pressure level across various speech tasks (Sapir et al., 2002). Several studies also

demonstrated LSVT-induced increase, for example, in vocal fold adduction (eg. Smith, Ramig, Dromey, Perez, & Samandari, 1995), pitch variability, subglottal pressure (eg. Ramig & Dromey, 1996) and voice quality (Baumgartner, Sapir, & Ramig, 2001). Regarding the overall communication skills, family members and patients reported satisfactory maintenance after LSVT (Ramig et al., 1995a). Improvements on various speech dimensions were maintained for six months, one year and two years after treatment (Ramig et al., 1996; Ramig et al., 2001; Sapir et al., 2002).

Extensive studies on LSVT have been conducted with English-speaking populations. Cantonese is one of the major languages/dialects used in southern Chinese provinces and in worldwide Chinese communities (Matthews & Yip, 1994) which differs from English. It would be interesting to investigate the efficacy of LSVT on PD patients whose language is Cantonese. Recently, Whitehill and Wong (2007) reported a positive effect in terms of an increase in loudness and intonation in Cantonese-speaking PD patients after receiving intensive voice treatment based on the principles of LSVT. However, it was a small-scale study including four participants and the therapists were not yet certified in LSVT. Hence, the efficacy of LSVT in a Cantonese population on different speech dimensions will be investigated on a larger scale based on the aforementioned pilot study.

Cantonese is a tonal language which is characterized by the feature that the same word can have totally different meanings by varying the levels and contours of the tone (Bauer & Benedict, 1997). There are six lexical tones and their contrasts are determined by fundamental

frequency level and contour differences in Cantonese (Whitehill, Ciocca, & Chow, 2000). In this study, a numerical system developed by Chao (1947) is used to represent the six lexical tones. They are 55 (high level), 35 (high rising), 33 (mid level), 21 (low falling), 23 (low rising) and 22 (low level). The first number is the beginning level of the tone and the second number indicates the finishing level of the tone. For the three level tones (ie. tone 55, tone 33 and tone 22), their pitch levels remain relatively steady. On the other hand, the pitch levels of the three contour tones (ie. tone 25, tone 23 and tone 21) increase or reduce over time (Bauer & Benedict, 1997). Cantonese tones are mainly distinguished by fundamental frequency (F0) and the perception of the tones depends primarily on F0 pattern (Ma, 2000).

Abnormal intonation patterns and lexical tone problems have been identified in Cantonese-speaking congenital dysarthric patients (Ciocca, Whitehill, & Ng, 2002; Whitehill et al., 2000; Whitehill, Ciocca, & Lam, 2001; Whitehill, Ma, & Lee, 2003). A perceptual study conducted by Wong and Diehl (1999) reported that both lexical tone errors and intonation impairments were demonstrated by Cantonese-speaking PD patients. They suggested that it is difficult to identify the lexical tones produced by Cantonese speaking PD patients because their ‘tonal space’ (i.e., the pitch ranges where all the tones situated) was limited and their intonations were perceived as no variation when comparing with normal individuals. In terms of acoustic correlates, both tonal contrasts and intonation depend on laryngeal maneuvering and fundamental frequency control (Whitehill et al., 2001). Whitehill & Wong (2007) hypothesized that intensive voice treatment might reduce the impact of hypokinesia and rigidity in the

laryngeal muscles which would result in enhancing the variations in fundamental frequency. Consequently, pitch variability will be better controlled and the intonation as well as the lexical tone will be improved. The result of this pilot study only showed improvements in intonation but not in lexical tone production. Due to limited number of participants and whose lexical tones were relatively normal pretreatment, the effects of LSVT on lexical tone production warrants further study. Besides, Vance (1976) hypothesized that there might be different mechanisms in the control of intonation and lexical tone production. This hypothesis might explain why improvement was shown in intonation but not in lexical tone after treatment. The current study aims to investigate both the effects of LSVT on lexical tones and this theoretical hypothesis with a larger group of patients.

Investigations of dysarthria based on clinical perceptual rating are more clinically welcomed for making diagnosis and planning therapy (Penner, Miller, Hertrich, Ackermann, & Schumm, 2001). On the other hand, acoustic measures, provide objective information on how the speech variables change before and after therapy and hence can serve as a complement to perceptual judgments (Kent, Kent, Duffy, & Weismer, 1998). The purpose of this study was to investigate the efficacy of LSVT on various speech aspects using acoustic analysis. There is an accompanying perceptual study (in preparation) being conducted with the same data base. The findings of these two studies will support each other. The result of the current study is predicted to be consistent with the findings in the previous studies. That is, sound pressure level, mean fundamental frequency and standard deviation of fundamental frequency will be



improved after receiving LSVT. Although the speech rate of PD patients was always regarded as rapid (Duffy, 2005), there was no research directly studying on how speech rate changes after receiving LSVT and hence more insights will be obtained in this study. Secondly, it is hypothesized that this study will support that there is no improvement in lexical tone production following LSVT, thus providing more evidence to aforementioned hypothesis that there is dissociation between the control of the lexical tone and intonation.

## **METHOD**

### **Participants**

Twelve participants (5 males and 7 females) with idiopathic Parkinson's disease were recruited from the Community Rehabilitation Network and the Hong Kong Parkinson's Disease Foundation. All the participants were native Cantonese speakers although two speakers had some Chou Zhou and Fujian dialects respectively. The mean age of the participants was 63.92 years old range from 56-78 years old. All of the participants received regular medication for Parkinson's disease though one participant changed his anti-Parkinson medicine during the study. Improvements in speech due to dopamine medication are believed to be small and are highly varied across different individuals (Adams & Jog, 2009), hence, this participant was still included in this study. Medication was not changed over the course of treatment for the other participants. A hearing screening was conducted with the criteria of passing at 40 dBHL at 500, 100, 2000 and 4000 Hz in the better ear. All participants passed this screening. No oral structure impairments were observed after carrying out an oral motor examination. In addition,

all the participants passed a screening for apraxia and aphasia based on the Cantonese Aphasia Battery (Yiu, 1992). The participants' characteristics and their anti-Parkinson medications before and after LSVT treatment are listed in Table 1.

**Table 1.** Gender, age, time since diagnosis, medication for Parkinson's disease for participants.

Participant	Gender	Age (years)	Years since diagnosis	Anti-Parkinson medication
1. CWY	Male	56	10	Stalevo
2. FSY	Male	67	6	Sinamet
3. SCW	Male	61	23	Sinamet <sub>2</sub>
4. WSH	Male	60	5	L-dopa
5. WCM	Male	57	5	Sinamet
6. CLY	Female	57	4	Sinamet, Selegiline HC
7. HYH	Female	78	N/A <sub>1</sub>	Sinamet
8. KMP	Female	59	14	Sinamet
9. YYP	Female	65	8	Sinamet
10. LLY	Female	57	14	Sinamet, Benzhexol, Dimetrylopolysiloxane
11. MSS	Female	78	20	Sinamet, Sinamet CR
12. WWY	Female	72	9	Sinamet

Notes:

<sub>1</sub> Information not available

<sub>2</sub> SCW has changed his medication to Bromocritin during the course of treatment

### **Treatment program**

All the participants received traditional LSVT treatment program as specified in LSVT certification course and materials (Ramig et al., 1995b). The treatment was implemented 1 hour per day, 4 days per week for 4 weeks. It was delivered by qualified speech therapists who had recently completed an LSVT certification course. Throughout the treatment, the participants were encouraged to speak with their maximal effort. After every treatment session, home practice and carryover exercises were given so that the use of loud voice with increased

phonatory effort could be maintained outside the clinic room and used in functional communication.

### **Data collection**

***Recording times.*** Pretreatment and post-treatment data collection took place within a month before and after therapy respectively. All the data was collected by speech therapist students under supervision who were not involved in delivering the treatment.

***Speech samples.*** During each recording session, the participants were required to perform various tasks including (1) maximum sustained vowel phonation, (2) maximum fundamental frequency range, (3) reading a standard passage, (4) conversational monologue, (5) divergent naming, and (6) describing a motor task. The Voice Activity and Participation Profile (Ma & Yiu, 2001) was given at the end of each session. Only data from task (1) and (3) was used in this study.

***Recording methods.*** All sound recordings were collected using an Aardvark Direct Mix USB 3 Soundcard and Audacity 1.2.6. in a quiet room with low level of background noise. An AKG C 525 S or Shure SM48 low-noise unidirectional microphone was positioned 10 cm from the participants' lips. The SPL data were collected from ratings of the sound level meter by hand, recorded by the phonetography and it was then digitalized using a sound converter. However, the ambient noise of the sound converter during conversion was very loud and the data from the phonetography could no longer be used. Hence, all SPL data reported was based on the hand-collected measurements in the study only.

## Data analysis

The acoustic variables investigated in this study included sound pressure level (SPL), mean fundamental frequency (mean F0), standard deviation of fundamental frequency (SDF0), speech rate in syllables per second, and fundamental frequency across the time line of a syllable in lexical tone production. Since voice quality has poor to moderate sensitivity to change and reliability, acoustic analysis on voice quality was not investigated (Carding et al., 2004).

***Sound pressure level (SPL).*** Sound pressure level primary correlates with perceptual loudness (Duffy, 2005). SPL was measured by averaging six productions of the participants' maximum vowel phonation at most comfortable pitch and loudness.

***Mean fundamental frequency (mean F0) and standard deviation of fundamental frequency (SDF0).*** Mean fundamental frequency (mean F0) is the primary correlate of mean pitch level and standard deviation of fundamental frequency (SDF0) is used to quantify the level of monotonicity (Whitehill et al., 2001). In the passage reading, the language content and information is more regulated than in conversational speech, therefore comparison across speakers and time points is more possible (Sapir et al., 2002). Thirty seconds were then extracted from the reading starting from the second sentence of the passage in the pre- and post- treatment. Mean F0 and SDF0 values were calculated using the autocorrelation algorithm in Praat software (Version, 5.1, Boersma and Weenink, 2008). The pitch range was set between 75-300 Hz for males and 100-500 Hz for females. For two older female participants whose voices were low-pitched, their voice samples were analyzed using the male pitch ranges.

In order to normalize the speech productions from two genders, the fundamental frequency intervals originally measured in hertz were converted into a logarithmic semitone (ST) scale (Dromey, Kumar, Lang, & Lozano, 2000; Fitzsimons, Sheahan, & Staunton, 2001). For fundamental frequency conversion, the semitone scale with the unit (ST) was defined as

$$ST = 12 * \log(f/f_b) / \log 2 \text{-----} (1)$$

in which  $f_b$  was denoted as the frequency which corresponds to the semitone just below the lowest frequency value ( $f_{\min}$ ) across all the speakers (male and female) (Heylen, Wuyts, Mertens, De Bodt, & Van de Heyning, 2002). In this study, the lowest F0 among the speakers was 80.65 Hz and hence  $f_b$  was defined as 77.8 Hz. For SDF0 conversion, the same scale (1) was used. However, the lowest standard deviation value in hertz was 14.62 and the reference value ( $f_b$ ) was then set as 14.

**Speech rate.** Syllables per second were used as the acoustic variable for speech rate (Tjaden & Wilding, 2004). The speech sample used for analysis was the same as that for mean F0 and SDF0. The speech rate was then calculated after the pauses of each sample were removed. According to Goberman, Coelho, & Robb (2005), a pause was defined as the time which exceeded 50 ms in duration without association of stop closure. The pause was then identified from the wide-band spectrogram and waveform plot display visually with successive windows of approximately 2 seconds. To determine whether a segment was a pause, auditory signals were used as additional information. The total articulation time was measured after all pauses were eliminated. The speech rate was calculated by tabulating the total number of syllables and

dividing by total articulation time.

***Lexical tone production.*** Lexical tone stimuli were extracted from the standard reading passage with three tokens for each lexical tone. These eighteen syllables were analyzed by Praat version 5.1 (Boersma & Weenink, 2008). The voiced segment of each stimulus was identified auditorily by listening to the signal, and visually from a wideband spectrogram and from an amplitude waveform display. Voiced segment, which was defined as the third cycle from the start to the third cycle from the end, was selected for analysis (Whitehill & Wong, 2007; Ma, Ciocca & Whitehill, 2006). Fundamental frequency (F0) was measured at five time points (ie. 0%, 25%, 50%, 75% and 100% of the total duration) and was calculated using the autocorrelation algorithm in Praat software (Version, 5.1, Boersma and Weenink, 2008). By averaging F0 of all the three tokens of each tone at each time point, the tone configuration of each participant was determined. The F0 values were then converted from the hertz unit to semitone based on the aforementioned semitone scale (1) with  $f_b$  value as 77.8 Hz, in order to normalize the interspeaker differences for statistical test (e.g., Dromey et al., 2000).

### **Reliability**

Intra- and inter-rater reliabilities were calculated by repeating the analysis for two speakers by the investigator and a second rater, a Speech & Hearing Science year-4 student. Pearson's correlation was used to calculate the reliability. Intra-rater reliability was 0.99 (2-tailed,  $p < 0.01$ ) and inter-rater reliability was 0.95 (2-tailed,  $p < 0.01$ ).

## RESULTS

### *SPL, mean F0, SDF0 and speech rate*

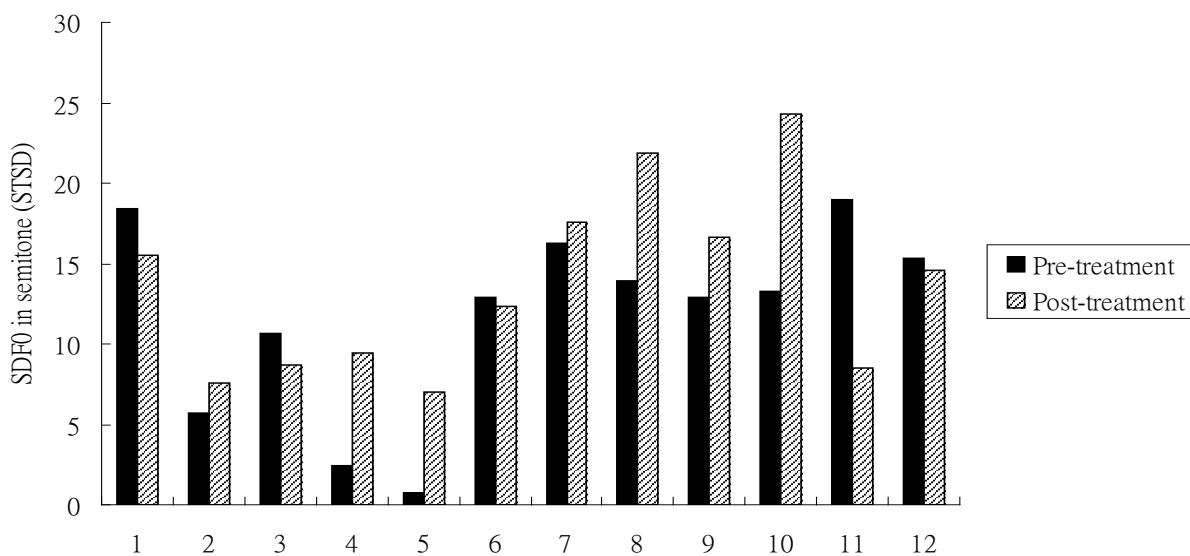
The group means and standard deviations for the outcome measures of sound pressure level (SPL), mean fundamental frequency (mean F0) in semitone unit, fundamental frequency standard deviation (SDF0) in semitone unit and speech rate (syllables per second) for pre- and post treatment conditions are summarized in Table 2. A repeated measure multivariate analysis of variance (MANOVA) was computed for these four acoustic variables. A significant difference was revealed for mean sound pressure level [ $F(1,11) = 54.91, p < 0.0001$ ] and mean fundamental frequency (in semitone) [ $F(1,11) = 8.883, p = 0.0125$ ]. Mean SPL and mean F0 were significantly higher in posttreatment condition than in pre-treatment. Pre- to post-treatment change for mean SPL and mean F0 are plotted in Appendix A1 and A2, respectively. No significant difference was indicated in pre- versus post-treatment in standard deviation of fundamental frequency [ $F(1,11) = 1.239, p = 0.289 > 0.05$ ] and speech rate [ $F(1,11) = 0.009, p = 0.926 > 0.05$ ]. An increase in SDF0 was demonstrated in seven out of the twelve subjects. However, two participants had a decrease in SDF0 of a large magnitude post-treatment. Pre- to post-treatment change for SDF0 and speech rate are plotted in Figure 1 and Appendix A3, respectively.

### *Quantitative analysis of Lexical Tone*

A three way repeated measure ANOVA ( $2 \times 6 \times 5$ ) was used to analyze the lexical tone data with the within-group factors of time (pre- and post- treatment), tone (tone 55, tone 25, tone 33,

**Table 2.** The pre- and post-treatment means (M) and standard deviations (SD) and results of MANOVA for the variables sound pressure level, mean fundamental frequency, standard deviation of fundamental frequency and syllables per second.

Variables	Pretreatment		Post-treatment		F	p
	M	(SD)	M	(SD)		
Mean Sound Pressure Level (dB)	71.3	(7.28)	82.6	(8.68)	54.91	0.000
Mean Fundamental Frequency (ST)	11.6	(3.94)	13.6	(3.99)	8.880	0.013
Standard Deviation of Fundamental Frequency (ST)	11.8	(5.91)	13.7	(5.74)	1.239	0.289
Speech Rate (syllables per second)	3.92	(1.02)	3.92	(0.92)	0.009	0.926



**Figure 1.** Standard deviation of fundamental frequency (SDF0) in semitone during 30-second passage reading sample.

tone 21, tone 23 and tone 22) and time points (0%, 25%, 50%, 75% and 100%). Significant main effects were observed for time [ $F(1,11) = 7.80, p = 0.017 < 0.05$ ], tone [ $F(5, 55) = 17.95, p < 0.000$ ] and time point [ $F(4, 44) = 23.28, p < 0.000$ ]. The main effect of time suggested that the overall mean F0 was higher post-treatment than pretreatment. A statistically significant difference was also indicated in the interaction of tone and time point [ $F(22, 220) = 14.95, p < 0.000$ ]. This confirmed that different tones have different frequencies at different time points and it is not related to the changes in treatment. The main effects of time point, tones and



their interaction effects will not be further discussed in this study. No significant changes in time-tone, time-time point and time-time point-tone interactions were shown. This indicates that treatment effects were the same across all tones and all time points and implies that the F0 contour pattern of each tone had no significant statistical changes from pre to post-treatment.

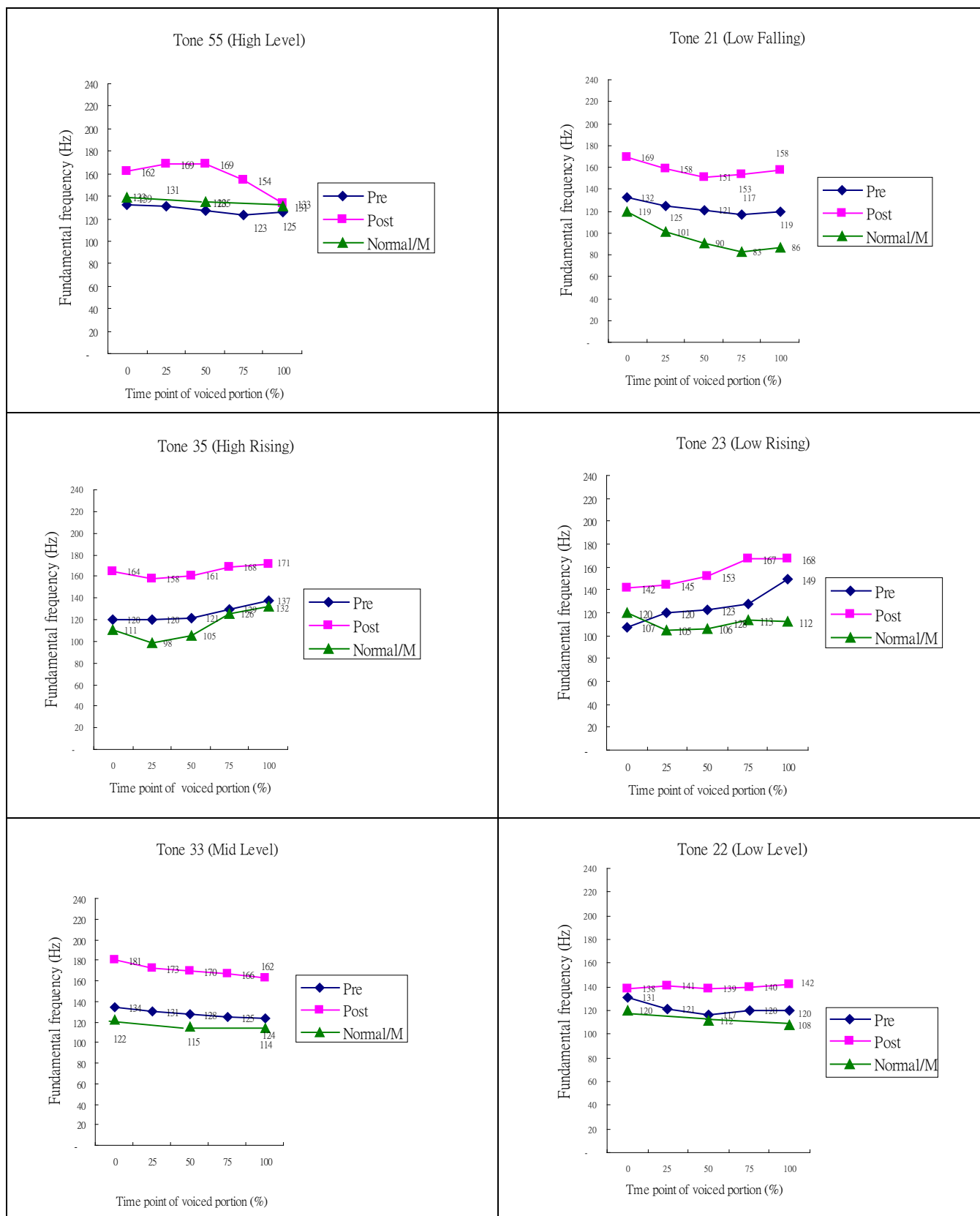
### **Qualitative Analysis of Lexical Tone**

The F0 patterns for all tones for all speakers were examined individually, in order to identify individual changes or patterns across speakers. For the analysis, F0 has not been converted to semitone. All the male speakers generally showed similar F0 heights as the normal male speakers in the pretreatment condition. After treatment, three of the male speakers showed an increase in F0 height with two above normal while there was no change in F0 height for the remaining two. For the female speakers, their F0 heights were generally lower than the norm and remained similar in the pre and post-treatment contours although two of the female speakers exhibited an upward shift of F0 height across all six lexical tones and one showed reduction in F0 height after treatment. Two of the twelve participants demonstrated similar F0 contour patterns pre-and post-treatment as the normal speakers' across all six tones. Figure 2 shows one of the two speakers, WSH, who had normal lexical tone production in both pre and post treatment. The remaining speakers generally showed similar F0 patterns as the normal speakers for the three level tones (i.e., tone 55, 33 and 22) while the contour tones (i.e., tone 35, 21 and 23) were found to be flattened. Among these affected participants, six speakers demonstrated flattening of all contour tones in the pretreatment condition. Three of them

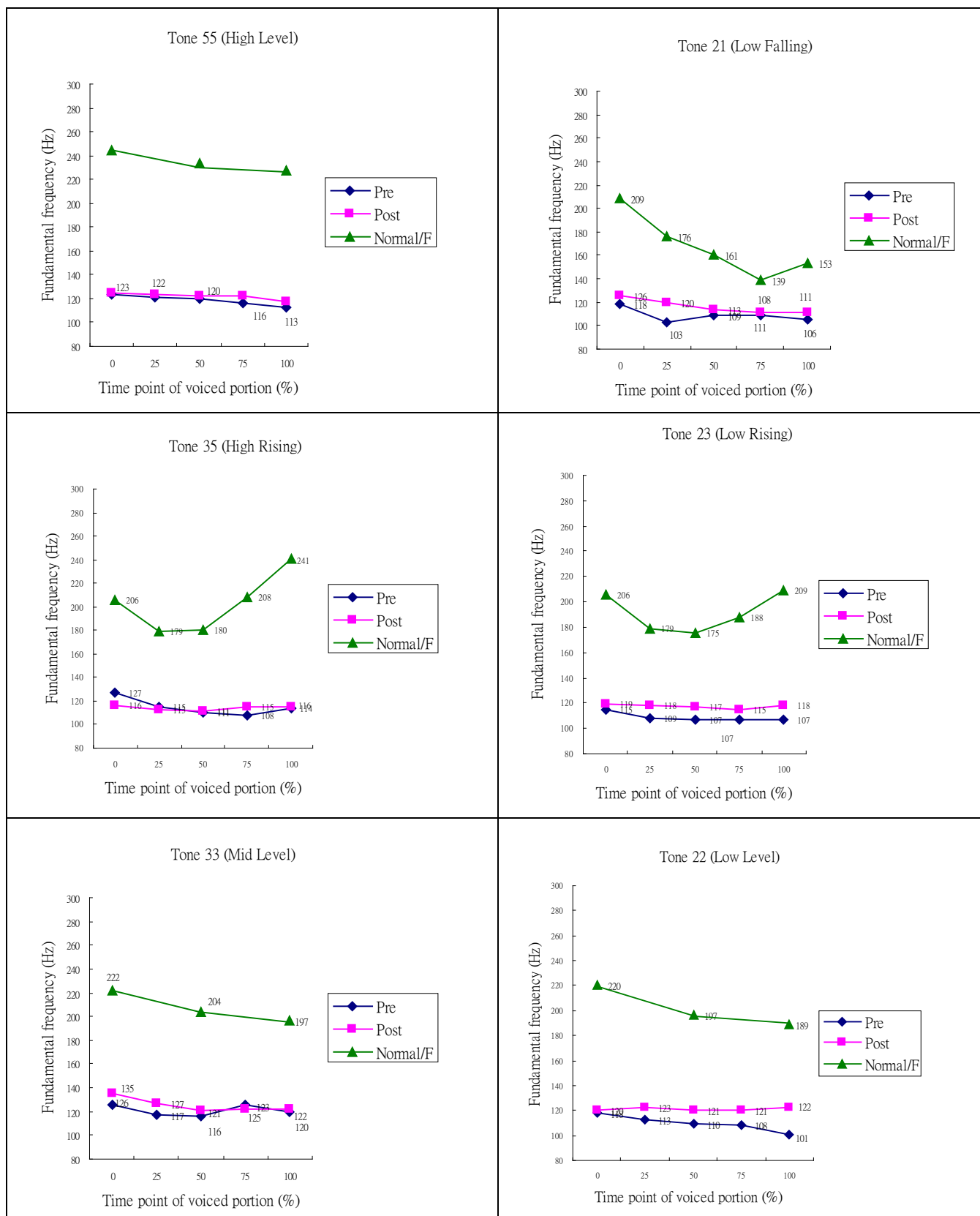
showed no change in the F0 pattern of these contour tones post-treatment while another three showed improvement after treatment although not on all three contour tones. Figure 3 shows a speaker, HYH, whose F0 pattern of the contour tones remained unchanged after treatment. As can be seen, the F0 configurations across all six tones were at a similar F0 height level and similar contour pattern, pre- and post- treatment. Figure 4 shows a speaker, CWY, who has a normal tone contour pattern post- treatment on one of the contour tones (i.e., tone 21). In this figure, there were some abnormal patterns observed (e.g., tone 23 and tone 33 pre-treatment and tone 22 post-treatment). For four of the affected participants who were not yet mentioned, the performance of their lexical tone production was random. That is, normal F0 pattern might be found pretreatment but abnormal/flattened one was shown post-treatment, vice versa (i.e., Appendix B2, B3, B5 & B9). The qualitative analysis of lexical tone indicated that the most affected lexical tones in PD patients pretreatment (i.e., the contour tones) remained flattened after the treatment. The F0 patterns for each tone pre- and post- treatment for all other speakers are shown in the Appendix B1-9.

## **DISCUSSION**

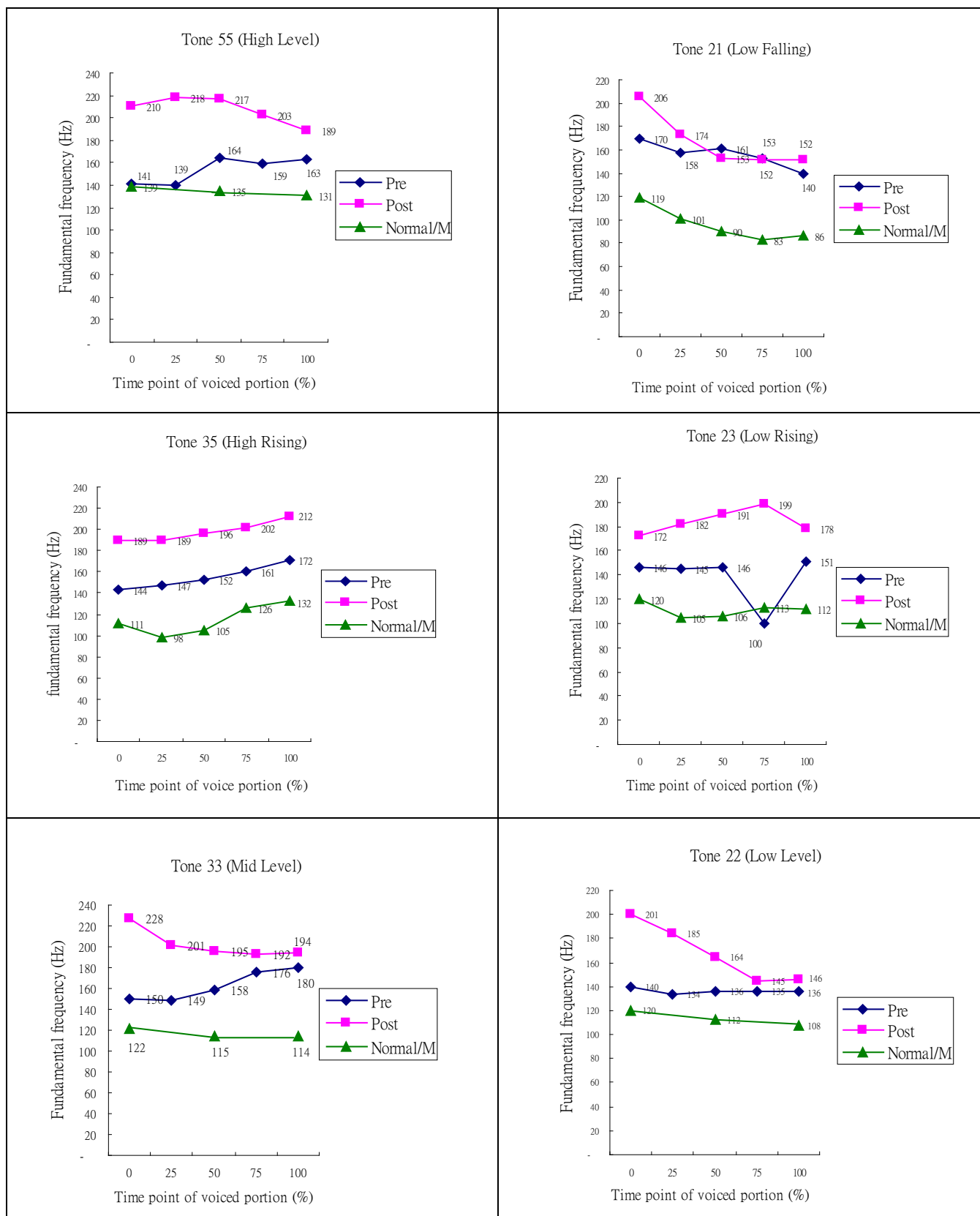
This study examined the effects of Lee Silverman Voice Treatment (LSVT) on sound pressure level (SPL), mean fundamental frequency (mean F0), standard deviation of fundamental frequency (SDF0), speech rate and lexical tone production of Cantonese Parkinson's disease speakers. Some of the results were consistent with previous studies on English speaking PD patients and with the pilot study conducted on Cantonese PD speakers (Whitehill & Wong, 2007).



**Figure 2.** F0 pattern of six lexical tones produced by a 60-year-old male, WSH. Comparison between the pre-treatment values (shown by a diamond), posttreatment values (square) and the F0 values of a normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).



**Figure 3.** F0 pattern of six lexical tones produced by a 78-year-old female, HYH. Comparison between the pre-treatment values (shown by a diamond), posttreatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).



**Figure 4.** F0 pattern of six lexical tones produced by a 56-year-old male, CWY. Comparison between the pre-treatment values (shown by a diamond), posttreatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Increase in sound pressure level and mean fundamental frequency were as expected. They were consistent with the previous studies on English speaking population (e.g., Ramig et al., 1995a) and on Cantonese-speaking population (Whitehill & Wong, 2007). One male participant, CWY, whose mean fundamental frequency was found to be abnormally high after treatment which was 201 Hz (16.5 in semitone). Although there was no normal reference of mean F0 for comparison, the abnormally high pitch shown might be due his misunderstanding that high pitch had to be used in accomplishing loud voice or inappropriate modeling by the clinicians. For clinical implication, clinicians have to ensure the pitch used by the client and the modeling provided are proper.

Insignificant change of SDF0 was shown in the current study which was inconsistent with previous studies on both English-speaking patients (e.g., Ramig et al., 1995a) and Cantonese speaking patients (Whitehill & Wong, 2007). One speculation was the excessive variability within this group of dysarthric speakers (Whitehill et al., 2000). The heterogeneity of the participants might decrease the statistical significant changes although positive findings were found for individual subjects (Ramig et al., 1995a). Hence, qualitative analysis might be more informative than quantitative analysis which compares the group means of the dysarthric patients (Weismer & Liss, 1991). Second, there were five participants who demonstrated a decrease in SDF0, two of them whom had values which decreased in large magnitude after treatment (see Figure 1). After analyzing these two voice samples, it was found that the pretreatment SDF0 values were abnormally high, which were even higher than that of the normal male and female, respectively. CWY whose SDF0 was 18.45 in semitone (normal male: 10.03 in semitone; Whitehill et al., 2000) and MSS whose SDF0 was 18.97 in semitone (normal female: 16.83 in

semitone; Whitehill et al., 2000). This indicated that there was excessive variability in the F0 of these two patients before treatment. In contrast, most of the other participants in this study showed abnormally reduced F0 variability before treatment. In addition, the pretreatment jitter values of these two speakers were found to be higher than post-treatment. High jitter value represents more variations in fundamental frequency at different time points within the voice sample (Greene & Mathieson, 1989). Praat, the software used for speech sample analysis, automatically analyzed the segments with aperiodic noise and a 'pseudo' value of fundamental frequency could have been calculated. Consequently, the value of SDF0 might be affected by the irregularity of F0 inducing high values of SDF0 for these two participants. This also implies that SDF0 might not solely indicate the changes in intonation. Moreover, harsh voice quality, which might partially correlate to jitter value, was reported to be improved by LSVT by Baumgartner et al. (2001). Reduction in jitter value indicates decrease in the irregularity of F0. Less aperiodic noise was then analyzed by Praat resulting in the reduction of SDF0 value after treatment. Overall, as seven out of twelve participants showed improvement in SDF0, it is still reasonable to claim that LSVT was effective in improving the intonation of most PD individuals in this study. Besides, the above observation also raises an interesting question on the use of software to analyze disordered voice sample. Kent, Vorperian, Kent, & Duffy (2003) suggested that if the voice sample was excessively aperiodic, it would be inappropriate for analysis unless the minimum criteria of the algorithm used were fulfilled. However, it is possible that there was no an ideal algorithm that suited all the voice samples within a study. Further investigation on this issue is warranted in identifying a more valid measure of acoustic variables.

Few studies were conducted on how speech rate changed after LSVT. In this current study, no significant change in speech rate was found. It is believed that LSVT, which mainly focuses on increasing respiratory support and phonatory effort, did not generalize to speech rate modification. Since no researches were conducted on speech rates of normal Cantonese-speaking individuals using the calculation method as in this study, no comparison on the speech rate could be made between the PD patients and the normal speakers before and after treatment. The speech rates of participants were determined perceptually. It was found that two participants' speech rates (i.e., SCW and YYP) were abnormally fast while another two (i.e., CLY and WWY) were considered to be abnormally slow pretreatment. However, no significant changes were found comparing pre- and post-treatment no matter the speech rates were accelerated or slowed. It is recommended that normal participants should be recruited so that comparison between PD patients and norms could be made upon the use of same calculation method.

The result of insignificant improvement on lexical tone production was consistent with the findings of the pilot study in Cantonese-speaking PD patients (Whitehill & Wong, 2007). Impaired lexical tone production was noted pretreatment especially for the contour tones in this study. This was contrary to the findings of Whitehill, Ma & Lee (2003) that the production of lexical tone was almost intact in hypokinetic dysarthric patients but agreed with Wong & Diehl (1999) that impaired lexical tone was found in PD patients, although both were perceptual studies. In this study, most participants showed flattened F0 configuration of the contour tones though some participants demonstrated abnormal F0 patterns which can be seen in Figure 4. The statistical results indicated an increase in fundamental frequency across all tones and time points. No



interaction effect was found between treatment, tones and time points. Qualitative analysis also revealed that there was no change in the tone contours for most participants pre- and post-treatment. To conclude, lexical tone production has not been improved after LSVT for majority of participants although three of them showed improvements on some contour tones.

Intonation and lexical tone production were both controlled by the changes in fundamental frequency. However, accurate intonation production requires the control of F0 at the sentential level but accurate lexical tone production requires the control of F0 at syllabic level (Gandour, Petty & Dardarananda, 1988). The degree of improvements after LSVT was different for these two speech dimensions. F0 variability improvement was shown by over half of the participants, while impaired lexical tones, especially the contour tones, showed almost no improvement. This supports the claims of some researchers that there is dissociation between intonation and lexical tone. Vance (1976) hypothesized that dissociation of intonation and lexical tone was due to the control of different subsystems. That is, intonation was controlled by subglottal pressure changes while tones were produced by the laryngeal movements. However, he offered no empirical evidence for this hypothesis. A more recent study by Strik & Boves (1995) hypothesized that both laryngeal muscles and subglottal pressure contributed to the downtrend of F0 (i.e., falling of F0) at sentential level with evidence. This is possible that intonation is controlled by laryngeal muscles and subglottal pressure. Nevertheless, subglottal pressure changes do not correspond well to pitch change at syllabic level (Ohala, 1978; cited in Xu, 2004) and hence it would imply that changes in F0 pattern in lexical tone production are mainly controlled by laryngeal activity. Previous studies suggested that subglottal pressure was significantly enhanced after LSVT at syllabic level (Ramig & Dromey,

1996), however, its change over sentences or phrases was not yet investigated. Besides, studies on the underlying physiological mechanisms of intonation and lexical tone production were still very limited, more evidences to verify this hypothesis are essential.

It is important to point out several limitations in the current study. First, although some normative data was available for reference, further studies should include a control group in which the age and gender were comparable to the participants in the treatment group (Spielman, Ramig, Mahler, Halpem & Gavin, 2007). Secondly, twelve participants in this study were not 'balanced' in terms of their speech and nonspeech characteristics or severity of symptoms. The results of this study might not represent all the PD patients with various characteristics. More participants at different stages of PD might be recruited. Third, the current study only documented the immediate effect of LSVT but not the long term maintenance of the therapeutic outcome, and only examined a few acoustic outcome variables. Further studies might investigate the short- and long-term perceptual, acoustic and physiological improvement in, speech intelligibility, phonatory and articulatory functions as well as the overall communication of the participants in Cantonese-speaking PD population. Last but not least, the lexical tone samples were extracted from various positions in the connected speech sample. Ma et al. (2006) reported that the tone level and the tone contour will be affected by the intonation in tonal language like Cantonese. In further studies, it would be more appropriate to extract the lexical tone production from a standard statement so that the influence of intonation towards the tone production across different samples would be minimized. Li, Lee, & Qian (2004) recommended a method to normalize the fundamental frequency in order to separate the tone contours at syllable level from that at the

phrase level. This method might be beneficial for the analysis of tone contour.

In conclusion, the current study was primarily consistent with the findings shown in English-speaking PD population. However, it is different for one of the variables (i.e., changes in SDF0) comparing with English speaking populations. This might attribute to the small subject size and variability among individuals. This study provides more evidence on the effects of intensive voice treatment (LSVT) on Cantonese speaking PD patients. There is further evidence for a possible dissociation between tone and intonation. In terms of clinical implications, this unique voice treatment offers improvement in many aspects of speech and voice production for this population.

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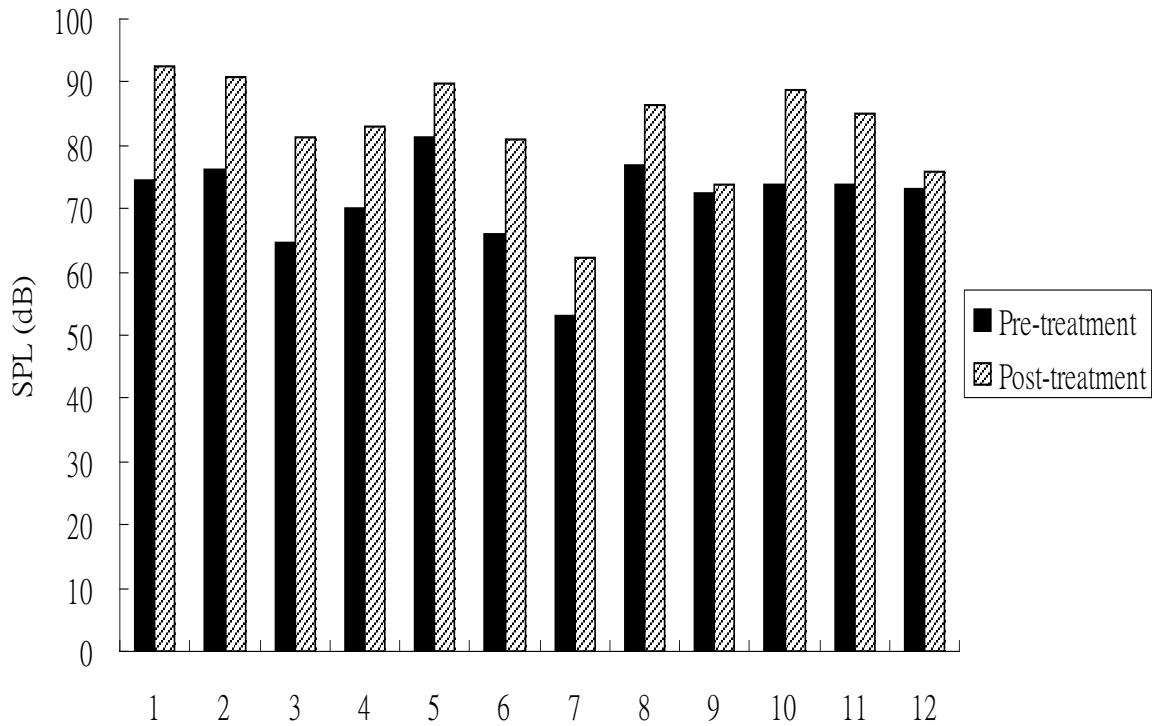
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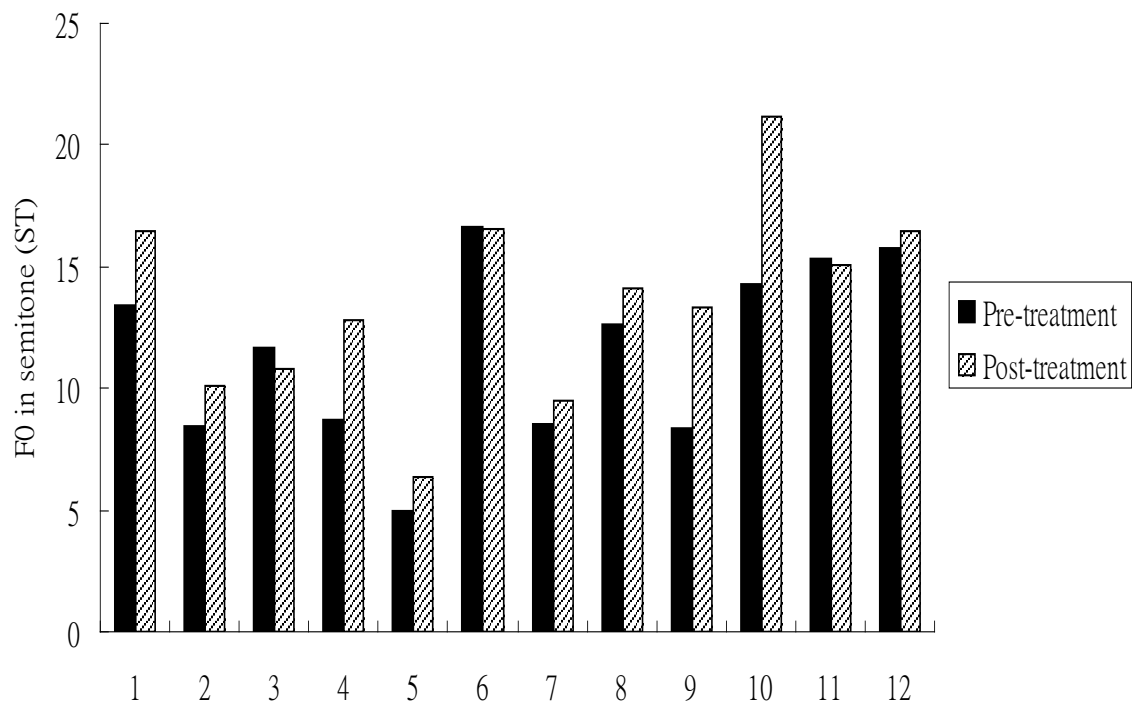
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## APPENDIX

Appendix A1. Mean sound pressure level (SPL) during the maximum /a/ phonation.

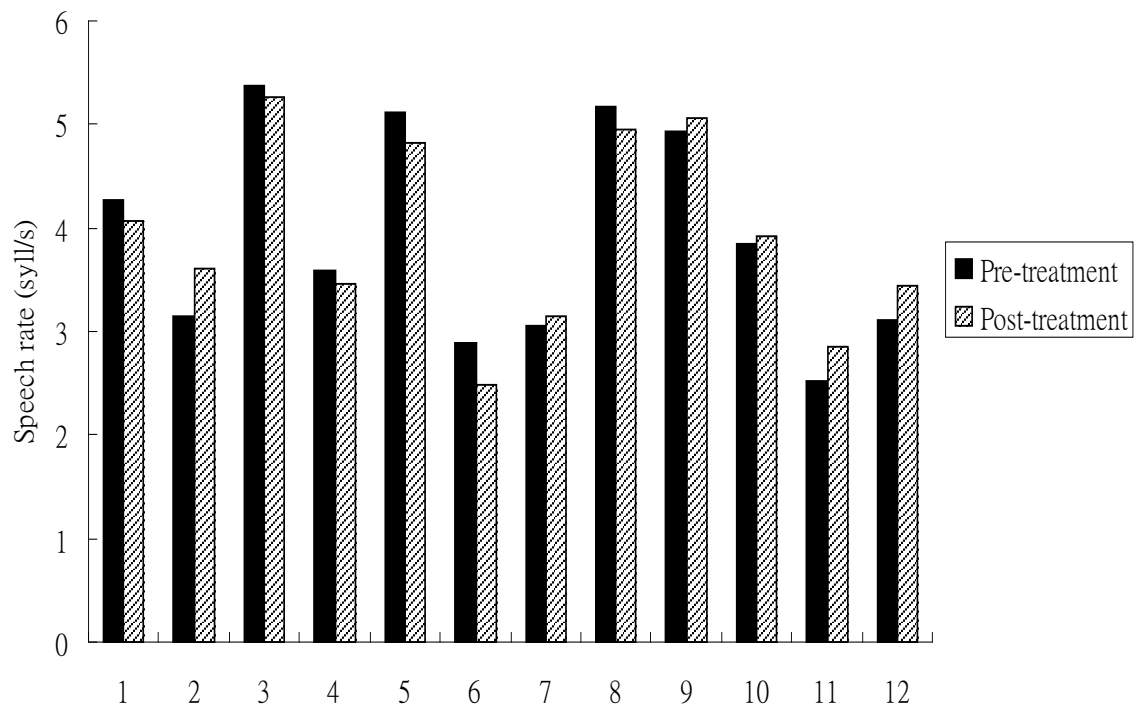


Appendix A2. Mean fundamental frequency (F0) in semitone during 30-second passage reading sample.

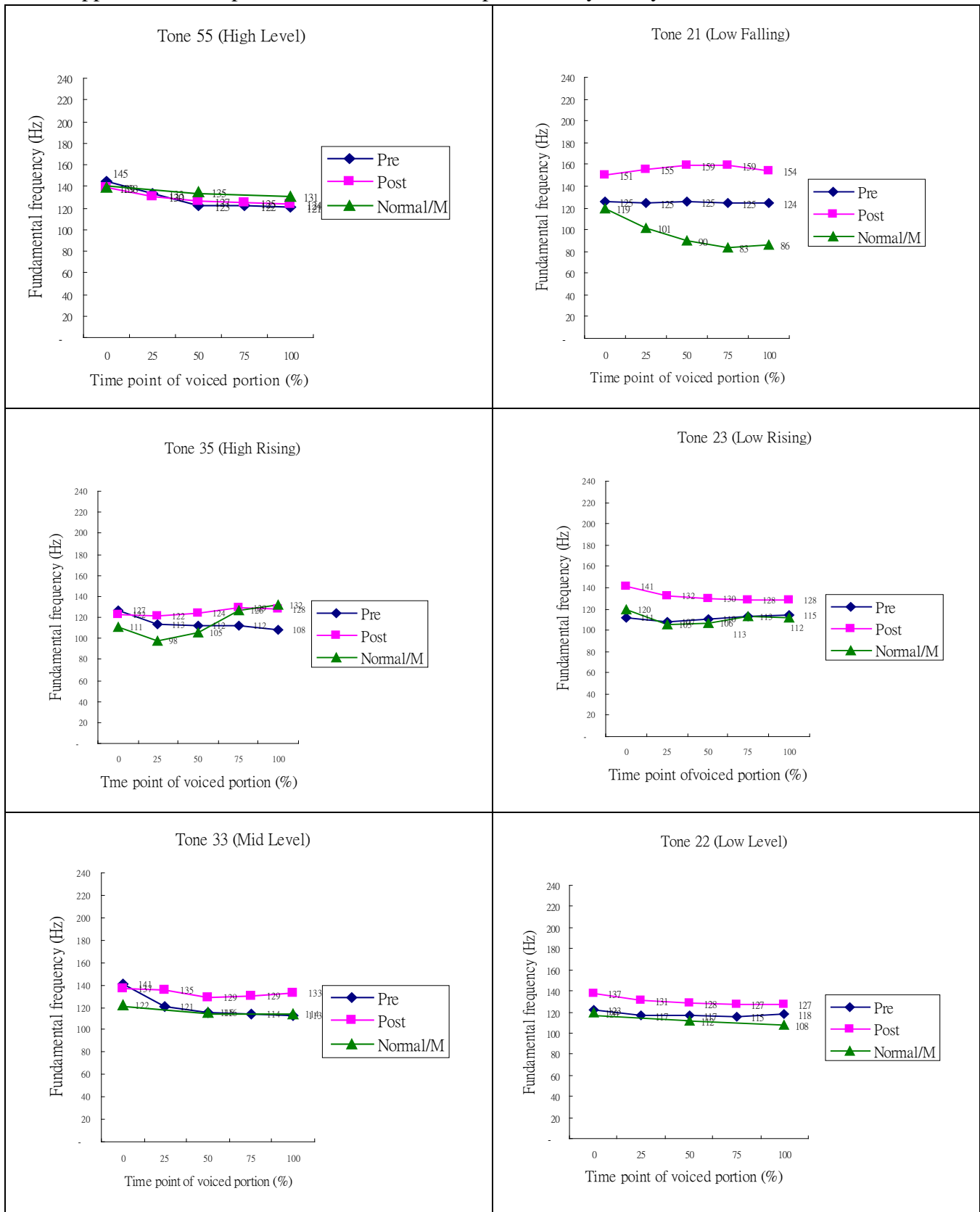




Appendix A3. Speech rate in syllables per second during 30-second passage reading sample.

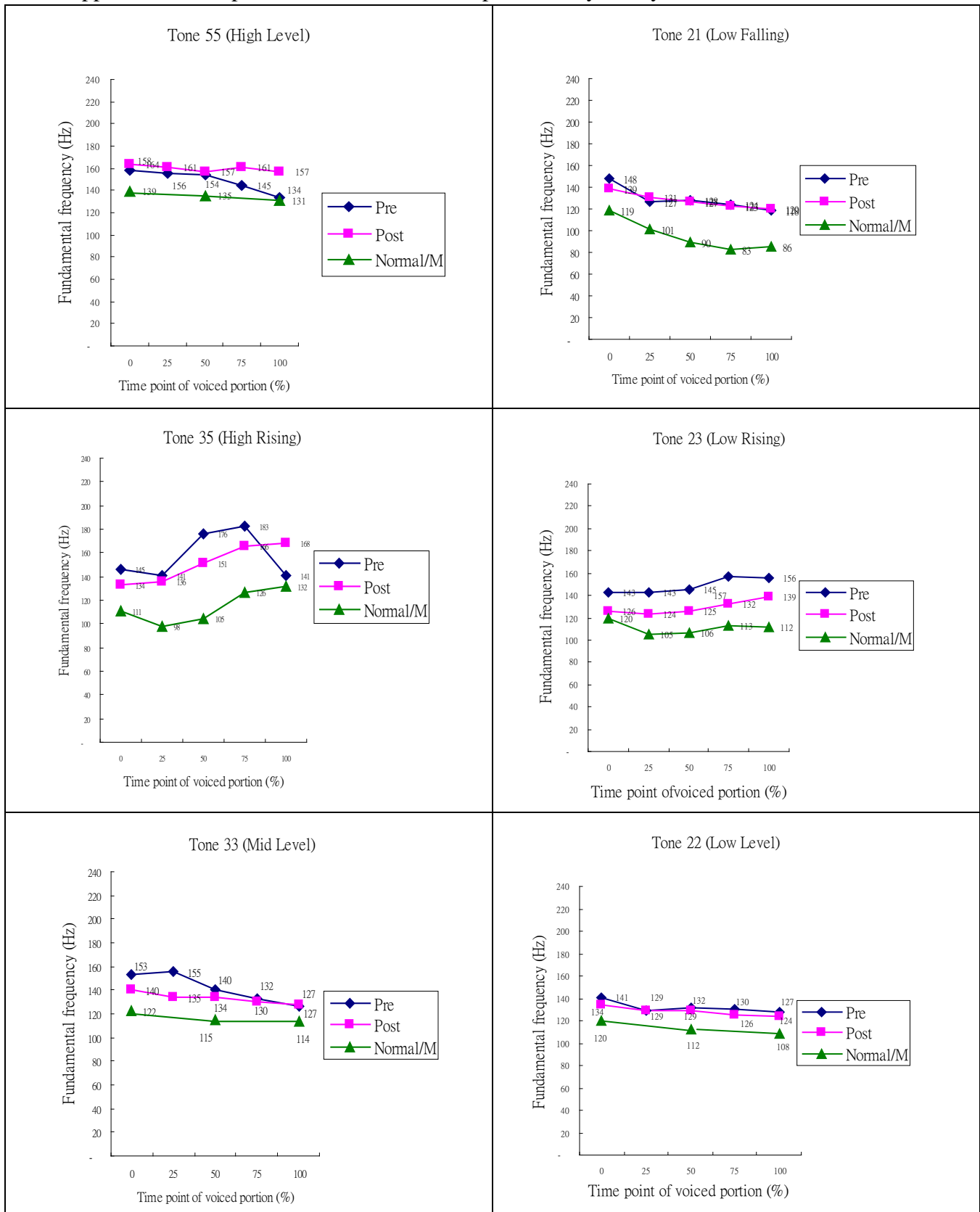


Appendix B1. F0 pattern of six lexical tones produced by a 57-year-old male, FSY.



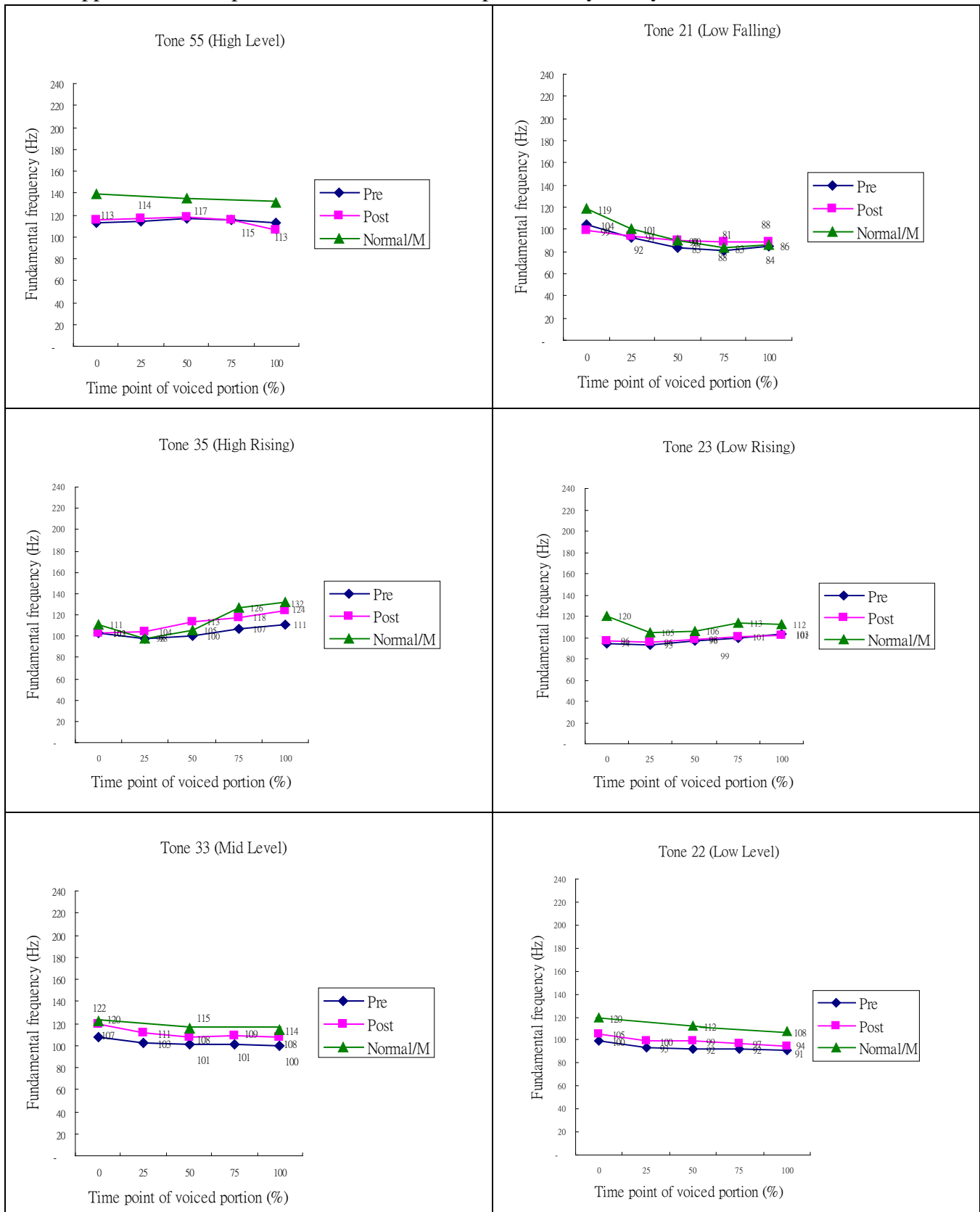
Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Appendix B2. F0 pattern of six lexical tones produced by a 61-year-old male, SCW.



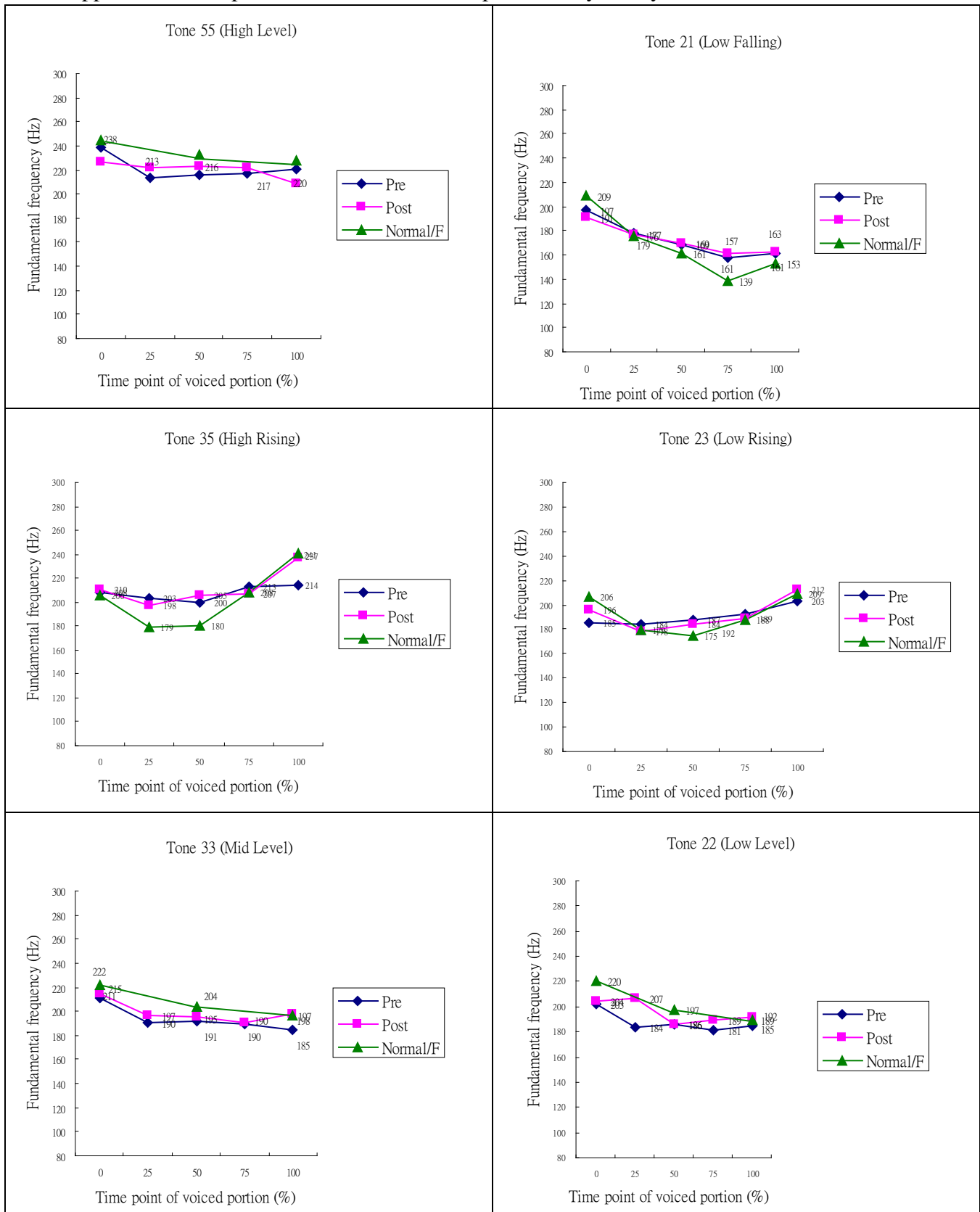
Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Appendix B3. F0 pattern of six lexical tones produced by a 57-year-old male, WCM



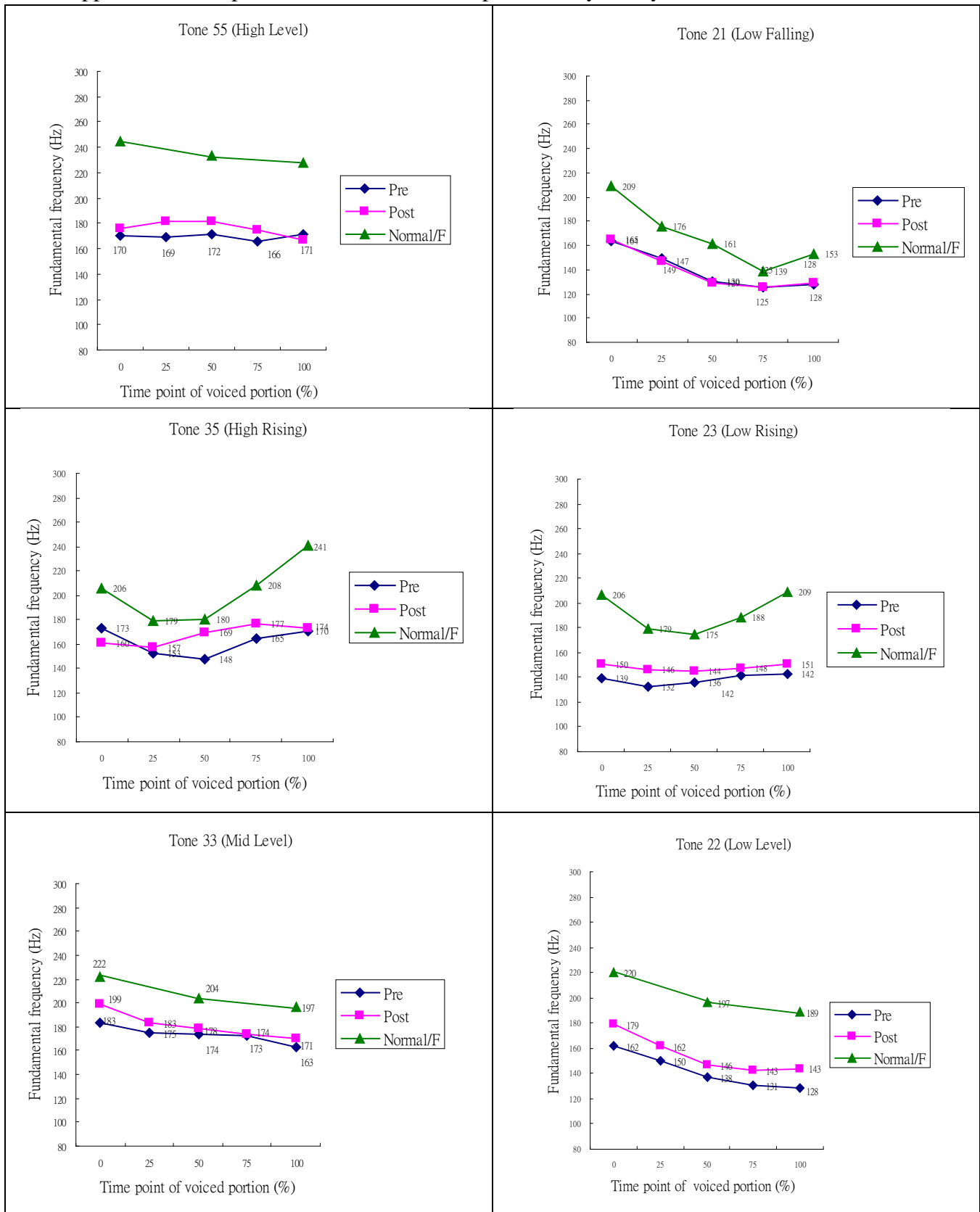
Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Appendix B4. F0 pattern of six lexical tones produced by a 57-year-old female, CLY



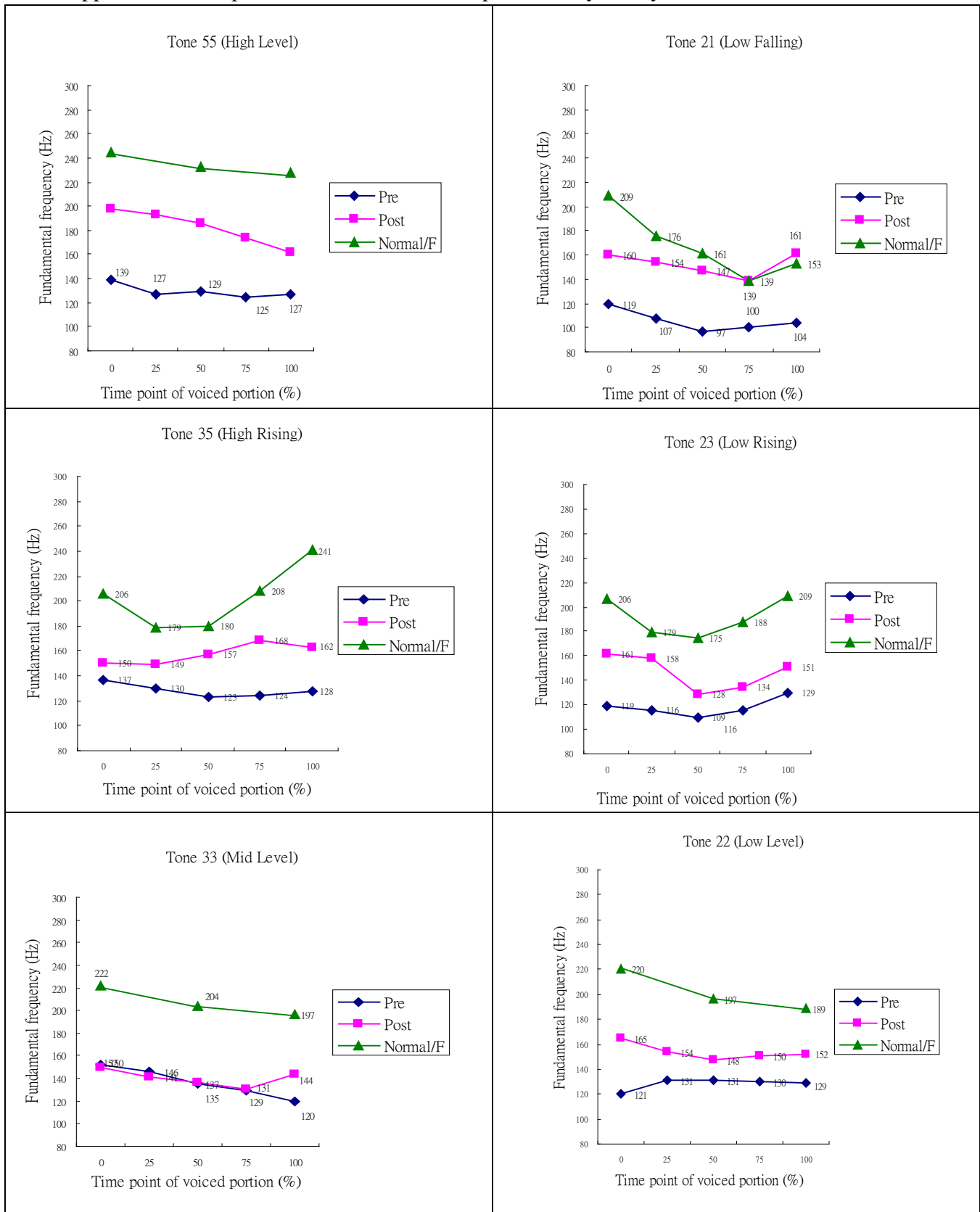
Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Appendix B5. F0 pattern of six lexical tones produced by a 59-year-old female, KMP.



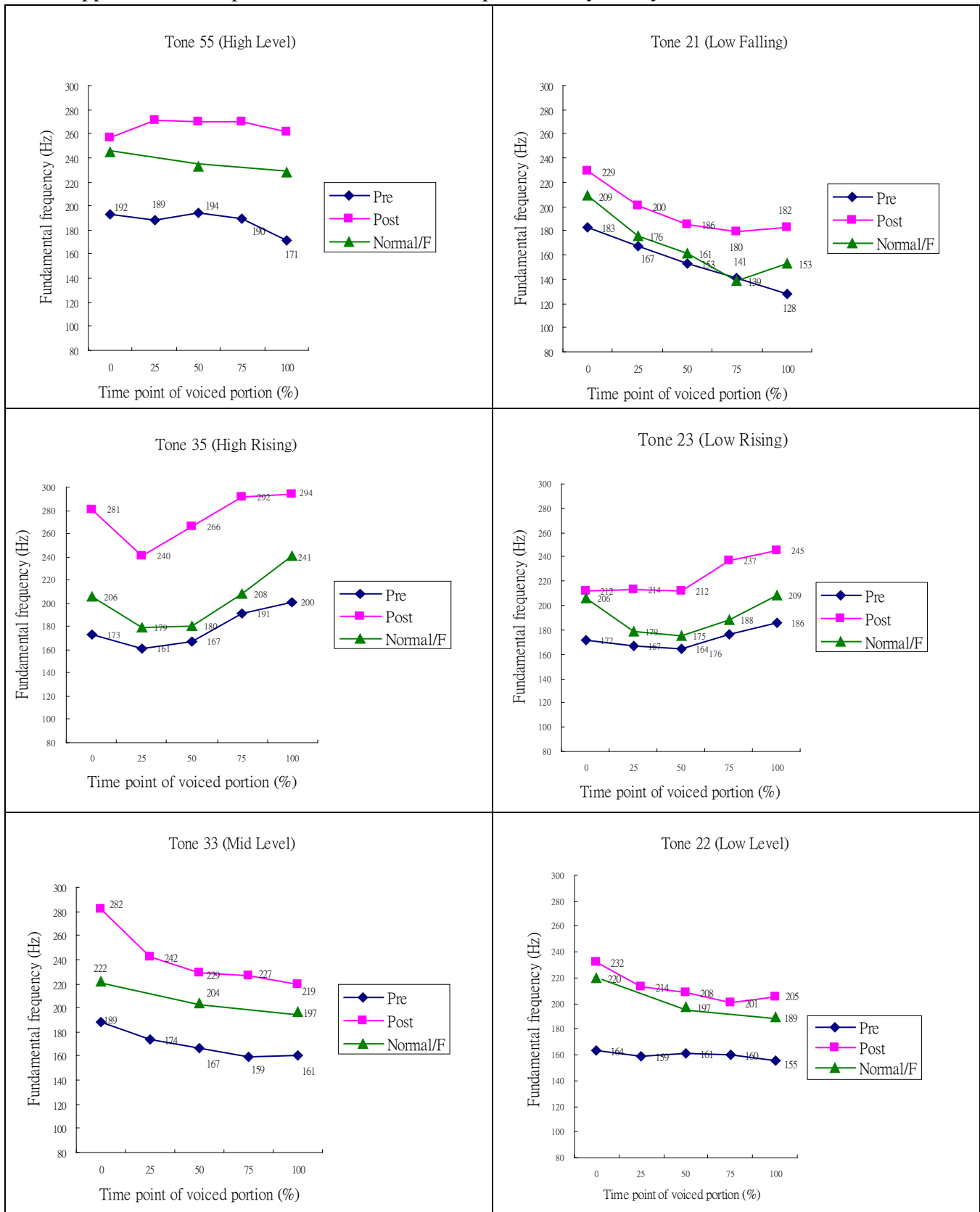
Comparison between the pre-treatment values (shown by a diamond), posttreatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Appendix B6. F0 pattern of six lexical tones produced by a 65-year-old female, YYP



Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

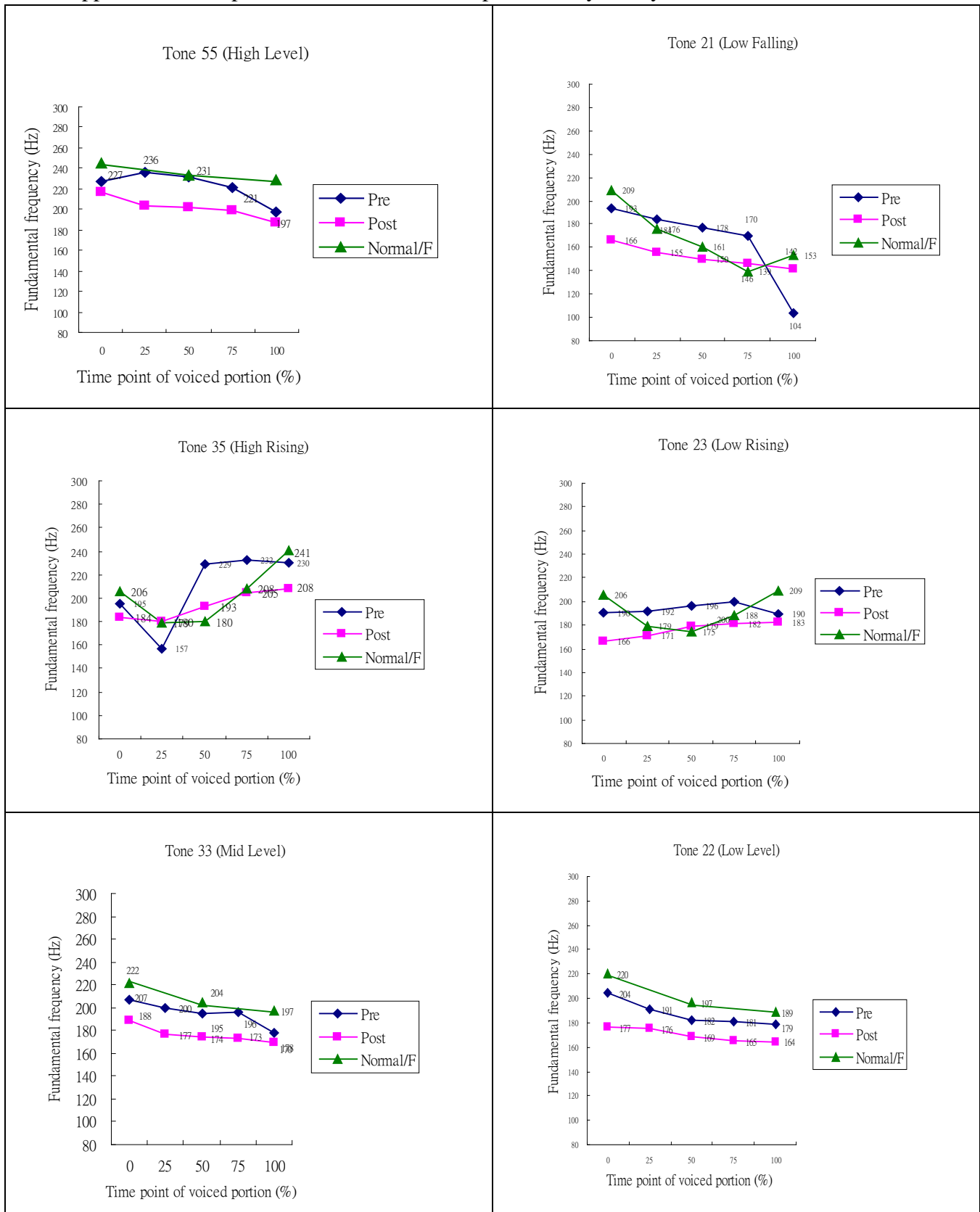
Appendix B7. F0 pattern of six lexical tones produced by a 57-year-old female, LLY.



Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

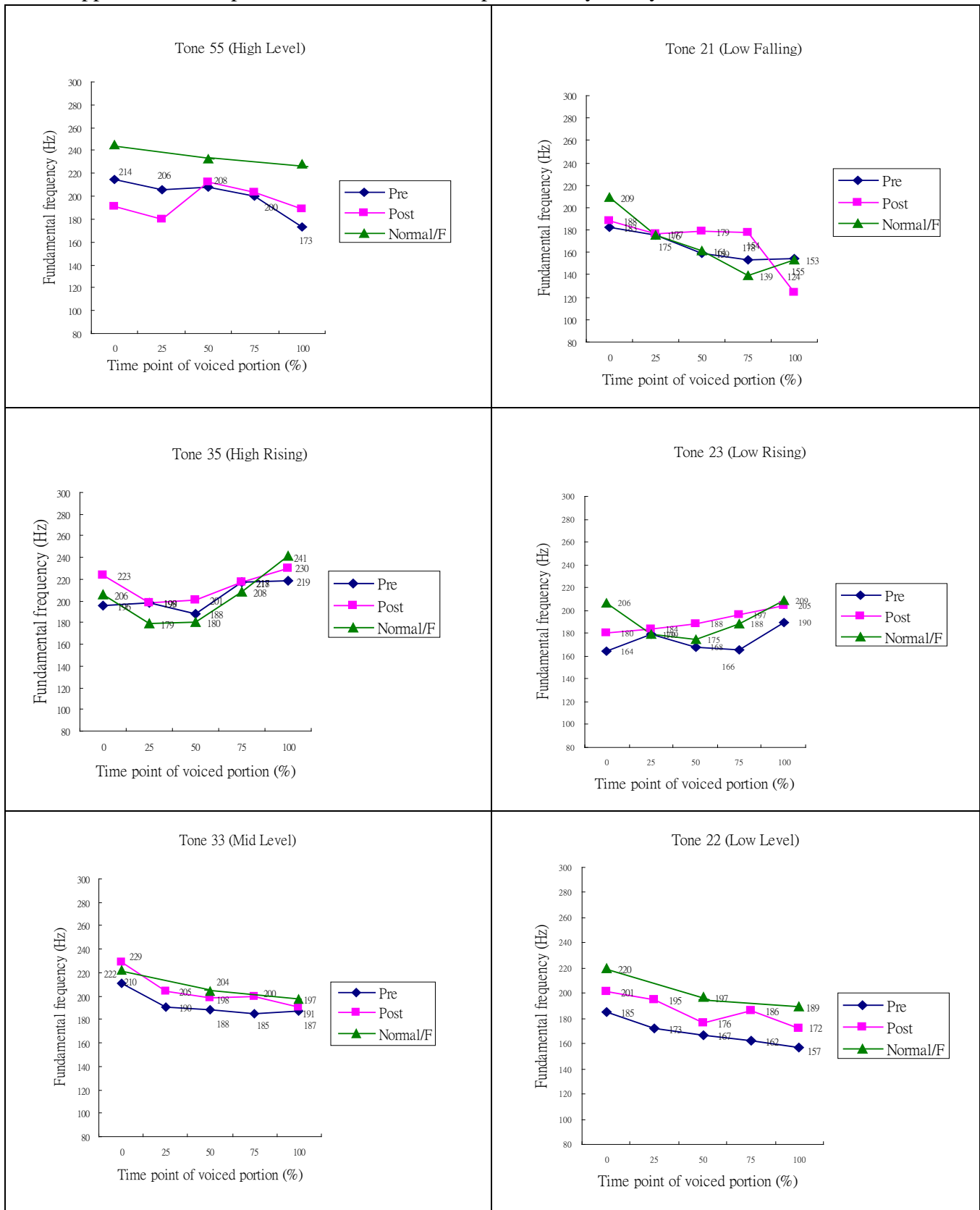


Appendix B8. F0 pattern of six lexical tones produced by a 78-year-old female, MSS.



Comparison between the pre-treatment values (shown by a diamond), posttreatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

Appendix B9. F0 pattern of six lexical tones produced by a 72-year-old female, WWY.



Comparison between the pre-treatment values (shown by a diamond), post-treatment values (square) and the F0 values of normal male speakers (triangle). The values of the normal speakers are according to Whitehill et al. (2000) and Whitehill et al. (2001) cited in Whitehill & Wong (2007).

