Phonation Models of Tone and Diatone in Mandarin*

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Abstract

This paper is concerned with the study on the phonation models of tone and diatone in Mandarin. The method used in this study has 3 parts: 1) extracting glottal signal by inverse filtering; 2) extracting phonation parameters from glottal signal in time domain; 3) modeling the phonation natures of tones and diatones by polynomial curve fitting. There are 3 conclusions, which are 1) there are 3 types of phonation pulses, which are single peak pulse, double-peak pulse and tri-peak pulse; 2) F0 is in the inverse ratio of PR1 and PP1, which reflects the basic phonation natures of tones and diatones in Mandarin; 3) PR2 and PR3 have correlation with PP2 and PP3, which reflects the personal changes of phonation natures in different conditions.

1. Introduction

Chinese is a typical tone language, which has many dialects. Mandarin is the most popularly used Chinese, which has 4 basic tones and 20 diatones including the 4 compositions of 4 basic tones and the neutralized tones. The 4 basic tones are: 1) tone 1 or 'high level' tone described as 55 by the 5 letter tone system (Chao Yuanren, 1930); 2) tone 2 or 'rising' tone described as 35; 3) tone 3 or 'low' tone described as 214 when isolated and 211 when in running speech; 4) tone 4 or 'falling' tone described as 51. The neutralized tone is usually called tone 5 whose tone value depends on the basic tone before it. Since the most important parameter of tone is fundamental frequency (F0), almost all researchers pay their attention to F0 of Mandarin tones, and many contributions have been achieved in the phonetic study.

The tones of Mandarin have been acoustically identified by a famous Chinese scholar, Liu Fu, who described the 4 basic tones by acoustical parameters (Liu Fu, 1924). The tones of the disyllabic word have been studied by Wu Zongji (Wu Zongji, 1980), who described the tones of the disyllabic words as 15 diatones. Along with the development of speech science and technology, the knowledge of phonetics becomes more and more important in co-related scientific fields and has been examined in applicant speech system, such as text-to-speech system. In order to synthesize the speech more naturally, the diatones have been studied by Kong Jiangping and Lv Shinan. They have modeled the diatones and several sub-diatones by VQ (Kong Jiangping and Lv Shinan, 1998).

According to the theory of acoustics, speech production can be divided into 3 parts, which are 1) speech source, 2) resonance and 3) lip radiation (Fant, 1960). Pitch and tone belong to speech source, since the fundamental frequency is an acoustical parameter of speech source in time domain. As is well known, speech source has many other parameters, such as phonation parameters, which can reflect very important nature of speech source in speech production. Although phonation types in Mandarin are not significantly important in distinguishing meanings, they are significantly important in speech synthesis. This paper is concerned with the modeling of phonation natures of tone and diatone in Mandarin.

2. Research method

The method in this research includes 3 parts: 1) extracting glottal signal by inverse filtering; 2) extracting phonation parameters from glottal signal in time domain; 3) modeling the phonation natures of tone and diatone by polynomial curve fitting.

2.1. Inverse filtering

The method in obtaining the glottal signal is the inverse filtering of speech waveform. The first experiment on inverse filtering at KTH has been done by Fant (Fant, 1959). The study of continuous inverse filtering has been reported in a series of papers by Fant (1979a, 1979b, 1980, 1982a, 1982b, 1986). Other studies on inverse filtering, which contribute much to this technique, are those by Rothenberg (1973,1983), Ananthapadmanabha et al (1982), Fant et al. (1985b, 1987, 1988) and Lin (1990). For inverse filtering, two methods should be mentioned here. They are the 'Iterative Adaptive Inverse Filtering' and the 'Pitch-Synchronous Iterative Adaptive Inverse Filtering'. (Alku et al, 1991; Alku ,1991).

In this study, the inverse filtering of extracting glottal signal from speech waveform is used, which has 2 parts: 1) extracting the parameters of F0, formants and bandwidth by LPC; 2) inverse filtering the speech sound through a group of filters.

The LPC model is an 'AR (auto-regressive) model'. The principle is defined as:

$$s(n) = \sum_{k=1}^{p} a_k s(n-k) + Gu(n) \qquad (1)$$

The method of inverse filtering used in this study is the cascade inverse filtering (Gold and Rabiner, 1968; Klatt and Klatt, 1990). See the following equation.

$$y(nT) = A' x(nT) + B' x(nT-T) + C' x(nT-2T) \qquad (2)$$

where *x(nT-T)* and *x(nT-2T)* are the previous two samples of the output, *x(nT)*, and the constants *A'*, *B'* and *C'* are defined by the following equations:

$$A' = \frac{1.0}{A} \qquad (3) \qquad\qquad A = 1. - B - C \qquad (4)$$

$$B' = \frac{-B}{A} \qquad (5) \qquad\qquad B = e^{(-\pi BW \cdot T)} \cos(2\pi FT) \qquad (6)$$

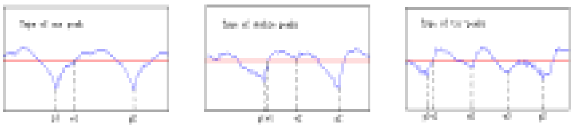
$$C' = \frac{-C}{A} \qquad (7) \qquad\qquad C = e^{(-2\pi BW \cdot T)} \qquad (8)$$

In order to filter the speech samples inversely, an inverse filtering system has been establised. In this system, there are 5 inverse filters, which are used for the inverse filtering of 5 formants, and a pair of inverse filters, which are designed for the inverse filtering of nasal formant and anti-formant. There are 2 main steps in the inverse filtering: 1) initializing the formant central frequency and bandwidth by co-variance LPC; 2) modifying these parameters automatically or manually according to FFT spectrum untill the speech glottal source are obtained.

The tones and diatones are sampled in 16 bits, 11025 Hz. The LPC order is usually 12. The vowel of these samples are [a]. The materials of 4 speakers, two males and two females who are around 40 years old, are analyzed. Since some of the phonation parameters appear in different positions in a tone or diatone, such as PP1, PP2, PR1 and PR2, the main parameters and their contours given in the tables and figures are the parameters of male 1's.

2.2. Definition of parameter

After the analysis of glottal pulses extracted from the speech signal, we have found that there are three types of glottal pulse. They are single peak pulse, double peak pulse and tri-peak pulse. See Fig. 1.



a b c

Figure 1: *Plot 'a' displays the type of single peak pulse. Plot 'b' displays the type of double-peak pulse. Plot 'c' displays the type of tri-peak pulse.*

According to the types of pulse, the phonation parameters are defined as follows:

The definition of F0:

F0=1/p1p2

The definition of PR and PP in single peak pulse:

PR1= (v1p2/p1v1)*(100/100); PP1= (v1p2/p1p2)*(100/100)

The definition of PP and PR in double-peak pulse:

PR1= (v1p2/p1v1)*(100/100); PP1= (v1p2/p1p2)*(100/100)

PR2= (v2p2/p1v2)*(100/100); PP2= (v2p2/p1p2)*(100/100)

The definition of PP and PR in tri-peak pulse:

PR1= (v1p2/p1v1)*(100/100); PP1= (v1p2/p1p2)*(100/100)

PR2= (v2p2/p1v2)*(100/100); PP2= (v2p2/p1p2)*(100/100)

PR3= (v3p2/p1v3)*(100/100); PP3= (v3p2/p1p2)*(100/100)

2.3. Modeling

According to the types of pulses, the phonation parameter PP1 and PR1 are used for modeling single peak pulse. PP2 and PR2 are used for modeling double peak pulse. PP3 and PR3 are used for modeling tri-peak pulse.

3. Phonation model of tone

The phonation natures of 4 basic tones are discussed through the coefficients of polynomial curve fitting and the contours of phonation parameter are displayed for description.

3.1. Tone 1 (high level)

Tone 1 is a high level tone. From Fig. 2, it can be seen that the 3 parameter contours are level. From Table 1, we can see that the 3 slopes are negative, and their values are small. Although the slope of contour PR1 is large, the intercept is also large, so the contour still looks level.

Table 1: *The coefficients of tone 1.*

Parameter	Curvature	Slope	Intercept
F0	0.0329	-0.8359	136.5584
PP1	0.0151	-0.3552	85.9487
PR1	0.6395	-14.8981	608.9103

a b

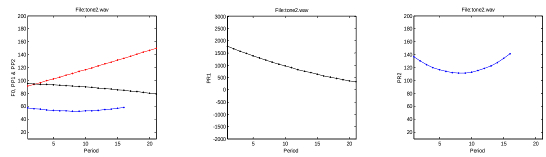
Figure 2: *The contours of parameters of tone 1. F0 and PP1 are in plot 'a', and PR1 is in plot 'b'.*

3.2. Tone 2 (rising)

Tone 2 is a rising tone. From Fig. 3, we can see that the contour of F0 is rising. The contours of PP1 and PR1 are falling. The contours of PP2 and PR2 are falling-rising. From Table 2, we can see that the slope of F0 is positive and the others are negative.

Table 2: *The coefficients of tone 2.*

Parameter	Curvature	Slope	Intercept
F0	0.0107	2.6886	88.7079
PP1	-0.0203	-0.3418	95.4075
PP2	0.0992	-1.646	59.4923
PR1	1.5	-104.9	1878.6
PR2	0.486	-7.9594	144.066



a b c

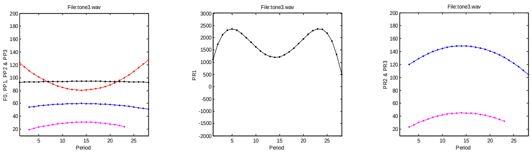
Figure 3: *Plot 'a' displays the contours of F0, PP1 and PP2. Plot 'b' and 'c' display the contours of PR1 and PR2.*

3.3. Tone 3 (low)

Tone 3 is a low falling-rising tone. From Fig. 4, we can see that the contour of F0 is falling-rising. The contour of PP1 is level. The contours of PP2 and PP3 are rising-falling. The contour of PR1 looks like double peaks. The contours of PR2 and PR3 are rising-falling. The contours are modeled by the coefficients in Table 3. There are 4 coefficients for PR1 in tone 3, which are -2, 9.1, -166.3, 1049 and 230.

Table 3: *The coefficients of tone 3.*

Parameter	Curvature	Slope	Intercept
F0	0.2453	-6.9387	129.715
PP1	-0.0085	0.2486	92.5857
PP2	-0.0463	1.1158	53.2314
PP3	-0.0923	2.2762	17.0623
PR2	-0.2312	5.6423	114.2099
PR3	-0.1712	4.2179	19.0954



a b c

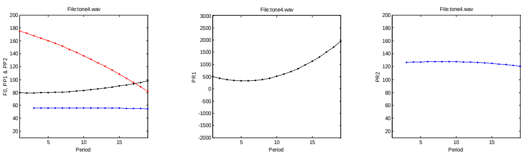
Figure 4: *Plot 'a' displays the contours of F0, PP1, PP2 and PP3. Plot 'b' displays the contour of PR1. Plot 'c' displays the contours of PR2 and PR3.*

3.4. Tone 4 (falling)

Tone 4 is a falling tone. From Fig. 5, we can see that the contour of F0 is falling. The contours of PP1 and PR1 are rising. The contours of PP2 and PR2 are level-falling and rising-falling. From Table 4, we can see that the slopes of F0, PP1 and PR1 are negative and the slopes of PP2 and PR2 are positive.

Table 4: *The coefficients of tone 4.*

Feature	Curvature	Slope	Intercept
F0	-0.101	-3.1627	178.5208
PP1	0.0697	-0.3785	79.811
PP2	-0.0106	0.118	55.7052
PR1	8.7346	-93.992	577.5498
PR2	-0.059	0.7084	125.587



a b c

Figure 5: *Plot 'a' displays the contours of F0, PP1 and PP2. Plot 'b' and 'c' display the contours of PR1 and PR2.*

From the analysis of 4 basic tones, we can see that the glottal pulses in tone 1 are single peak pulses. Tone 2 and 4 have two types of peak pulses. Tone 3 has three types of pulses. The analysis above also shows that the coefficients of polynomial curve fitting can describe the parameter contours well. By this way, not only the phonation natures of tones can be discussed and described, but also the phonation natures of tones can be reconstructed for the engineering purpose.

4. Phonation model of diatone

The phonation natures of 20 diatones are discussed in this section. According to the first tone, the 20 diatones can be classified into 4 groups. For the sake of space of this paper, the figure of parameter contours for each diatones is not given, and the coefficient tables of polynomial curve fitting are given. 'Para', 'Ct', 'Sp' and 'Ip' stand for 'parameter', 'curvature', 'slope', and 'intercept' respectively. '1' and '2' stand for the first and second syllables respectively.

4.1. Diatone 1+1, 2, 3, 4 and 5

In this subsection, the phonation natures of the first diatone group are discussed. There are 5 diatones altogether. The first tone in the diatones of this group is tone 1.

Tone 1 in the first tone of this diatone group is a high level tone. From Table 5-9, we can see that the slopes are negative except those in diatone 14. The curvatures are positive except those of PP1 and PR1 in diatone 14. The contours are all high level. The phonation natures of tone 1 in this diatone group are as same as those of basic tone 1.

Table 5: *The coefficients of diatone 11.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.054	-1.4	145.81	0.02	-0.62	144.21
PP1	0.043	-1.21	89.75	0.01	-0.34	84.61
PR1	2.169	-58.1	816.78	0.41	-12.48	549.96

Tone 1 in the second tone of diatone 11 is a high level tone. From Table 5, we can see that the 3 slopes are negative. The 3 curvatures are positive. The contours are high level. The phonation natures are as same as those of basic tone 1.

Table 6: *The coefficients of diatone 12.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.03	-0.34	140	-0.09	4.4	88.07
PP1	0.03	-0.62	85	0.01	-0.92	95.57
PP2				0.2	-2.7	59.74
PR1	1.23	-22.39	566	4.6	-153.1	1753
PR2				0.95	-12.57	144.37

Tone 2 in the second tone of diatone 12 is a rising tone. From Table 6, we can see that the slope of F0 is positive, but the curvature is negative. The slopes of PP1, PR1, PP2 and PR2 are negative, but the curvatures are positive. So the contour of F0 is rising. The contours of PP1 and PR1 are falling. The contours of PP2 and PR2 are all falling-rising. The phonation natures are as same as those of basic tone 2.

Table 7: *The coefficients of diatone 13.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.11	-1.85	146	0.16	-3.41	98.86
PP1	0.01	-0.62	88.3	-0.04	0.67	93.33
PP2				0.1	-0.23	51.72
PP3				0.1	0.82	8.61
PR1	0.98	-34.21	746	-13	262	1308
PR2				0.33	0.36	104.5
PR3				0.25	0.1	10.76

Tone 3 in the second tone of diatone 13 is a low falling tone. From Table 7, we can see that the slopes of F0 and PP2 are negative and the others are positive. The curvatures of PP1 and PR1 are negative and the others are positive. So the contour of F0 is falling. The contours of PP1, PP2, PP3, PR1, PR2 and PR3 are all rising. The phonation natures are not as same as those of basic tone 3.

Table 8: *The coefficients of diatone 14.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.01	0.05	134	-0.03	-3.64	160
PP1	-0.06	1.09	83.1	0.04	-0.19	87.97
PP2				0.16	-2.92	66.41
PP3				0.27	4.17	8.29
PR1	-3.06	56.26	478	15.5	-177.6	1114
PR2				0.77	-14.38	180.8
PR3				1.16	3.14	10.41

Tone 4 in the second tone of diatone 14 is a falling tone. From Table 8, we can see that the slopes of PP3 and PR3 are positive and the others are negative. The curvature of F0 is negative and the others are positive. The contour of F0 is falling. The contours of PP1, PP3 and PR3 are rising. The contours of PP2, PR2 and PR1 are rising-falling. The nature is not exactly as same as that of basic tone 4.

Table 9: *The coefficients of diatone 15.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.05	-1.22	155.3	1.6	-24.04	176.36
PP1	0.02	-0.4	85.9	0.22	0.04	84.3
PP2				0.66	-4.26	52.57
PR1	1.21	-23.51	638.4	68.83	-329.	909.48
PR2				2.43	-15.8	110

Tone 5 in the second tone of diatone 15 is a falling tone. From Table 9, we can see that the slope of PP1 is positive and the others are negative. The curvatures are all positive. The contour of F0 is falling. The contour of PP1 is rising. The contours of PP2, PR1 and PR2 are rising-falling.

4.2. Diatone 2+1, 2, 3, 4 and 5

In this subsection, the phonation natures of the second diatone group are discussed. There are 5 diatones altogether. The first tone in the diatones of this group is tone 2.

Tone 2 in the first tone of this diatone group is a rising tone. From Table 10-14, we can see that the some slopes are positive and the others are negative. Some of curvatures are positive and the others are negative. The 5 contours of F0 in the first tone are rising. The contours of PP1 and PR1 are falling. The contours of PP2 and PR2 are falling-rising in diatone 22, 23, 24 and 25. The contours of PP2 and PR2 are falling in diatone 21. The parameters of PP3 and PR3 appear in the diatone 23. They are falling. So tone 2 in the first tone of this diatone group is not exactly as same as that of basic tone 2.

Table 10: *The coefficients of diatone 21.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.09	1.259	95.38	0.04	-0.87	142.15
PP1	-0.01	-0.39	96.43	0.03	-0.71	89.37
PP2	-0.07	0.168	55.06			
PR1	4.2	-178.6	2458.2	1.53	-41.78	833.04
PR2	-0.23	-0.02	123.97			

Tone 1 in the second tone of diatone 21 is a high level tone. From Table 10, we can see that the 3 slopes are negative and the 3 curvatures are positive. The 3 contours look level. The phonation natures of tone 1 in this diatone group are as same as those of basic tone 1.

Table 11: *The coefficients of diatone 22.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	-0.03	3.34	94.86	0.03	1.09	99
PP1	0.002	-0.99	97.72	-0.03	-0.007	94.1
PP2	0.12	-1.55	58.35	0.06	-0.65	54.5
PR1	12.3	-331	2769.8	-1.1	-43.3	1611
PR2	0.62	-8.12	139.8	0.28	-3.13	119.9

Tone 2 in the second tone of diatone 22 is a rising tone. From Table 11, we can see that the slope of F0 is positive, and the others are negative. The curvatures of F0, PP2 and PR2 are positive and the others are negative. So the contour of F0 is rising. The contours of PP1 and PR1 are falling and the contours of PP2 and PR2 are falling-rising. The phonation natures of tone 2 are as same as those of basic tone 2.

Table 12: *The coefficients of diatone 23.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	-0.06	4.93	87.23	0.98	-13.26	122.71
PP1	0.02	-0.64	95.81	-0.28	2.51	90.32
PP2	0.17	-1.75	58.59	-0.22	4.08	44.51
PP3	-0.28	0.43	29.09	-1.61	15.03	-1.96
PR1	3.6	-117	1907	-101	917.33	292.67
PR2	0.94	-9.91	142.2	-0.89	19.33	72.84
PR3	-0.51	0.65	41.19	-2.84	26.32	-12.18

Tone 3 in the second tone of diatone 23 is a low falling tone. From Table 12, we can see that the slope of F0 is negative and the others are positive. The curvature of F0 is negative and the others are positive. The contour of F0 is falling. The contours of PP1, PP2, PR1 and PR2 are rising. The contours of PP3 and PR3 are falling-rising. The phonation natures are not as same as those of basic tone 3.

Table 13: *The coefficients of diatone 24.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.08	3.11	92.13	0.08	-7.17	158.9
PP1	-0.06	-0.06	95.01	0.03	1.56	75.3
PP2	0.13	-1.57	55.48	0.37	-3.51	54.2
PR1	0.9	-129	1992	21.67	-110.31	487.5
PR2	0.59	-7.12	124.12	1.62	-15.36	119

Tone 4 in the second tone of diatone 24 is a falling tone. From Table 13, we can see that the slope of PP1 is positive and the others are negative. The curvatures are all positive. The contour of F0 is falling. The contour of PP1 is rising. The contours of PP2, PR1 and PR2 are rising-falling. The phonation natures are not exactly as same as those of basic tone 4.

Table 14: *The coefficients of diatone 25.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.19	1.22	95.59	0.98	-16.28	160.27
PP1	-0.13	0.68	93.78	0.16	-0.62	89.34
PP2	0.07	-0.7	54.8	0.4	-3.2	53.09
PR1	-4.3	-55.9	1906.4	39	-223.2	1057.1
PR2	0.34	-3.34	121.26	1.59	-12.61	112.53

Tone 5 in the second tone of diatone 25 is a falling tone. From Table 14, we can see that the slopes are all positive. The curvatures are all negative. The contour of F0 is falling. The contour of PP1 is rising. The contours of PP2, PR1 and PR2 are rising-falling.

4.3. Diatone 3+1, 2, 3, 4 and 5

In this subsection, the phonation natures of the third diatone group are discussed. There are 5 diatones altogether. The first tone in the diatones of this group is tone 3.

Tone 3 in the first tone of this diatone group has tow different forms of F0. From Table 15-19, we can see that the some of the slopes are negative and the others are positive. Some of the curvatures are positive and the others are negative. The contours of F0 in diatone 31, 32, 34 and 35 are falling. The contour of F0 in diatone 33 is rising. The contours of PP1 and PR1 in diatone 31 and 32 are rising. The contours of PP1 and PR1 in diatone 33 are falling, in diatone 34 are falling-rising, and in diatone 35 are rising-falling. The contours of PP2 and PR2 in diatone 32 and 35 are rising. The contours of PP2 and PP2 in diatone 31 and 33 are falling-rising. The contours of PP2 and PR2 in diatone 34 are rising-falling. The contours of PP3 and PR3 in diatone 31 and 35 are rising. The contours of PP3 and PR3 in diatone 32, 33 and 34 are rising-falling.

Table 15: *The coefficients of diatone 31.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.17	-4.44	112.18	-0.04	0.54	136.95
PP1	-0.03	0.78	91.56	-0.02	0.61	81.69
PP2	0.08	-1	55.65			
PP3	0.05	-0.01	17.49			
PR1	-8.36	243.34	861.63	-0.67	16.77	479.2
PR2	0.4	-4.92	125.97			
PR3	0.08	-0.12	21.51			

Tone 1 in the second tone of diatone 31 is also a high level tone. From Table 15, we can see that the 3 slopes are positive. The 3 curvatures are negative. So the contours look level .The phonation natures of tone 1 are as same as those of basic tone.

Table 16: *The coefficients of diatone 32.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.26	-5.97	120.41	-0.03	3.66	87.65
PP1	-0.03	0.69	91.31	-0.04	-0.11	94.64
PP2	-0.02	0.54	52.48	0.10	-0.40	56
PP3	-0.54	5.03	7.25			
PR1	-7.25	190.96	882.69	6.5	-191	2128
PR2	-0.08	2.73	109.88	0.64	-2.82	128.2
PR3	-0.76	7.1	6.86			

Tone 2 in the second tone of diatone 32 is a rising tone. From Table 16, we can see that the slope of F0 is positive and the others are negative. The curvatures of F0 and PP1 are negative and the others are positive. So the contours of F0, PP2 and PR2 are rising. The contours of PP1 and PR1 are falling. The natures are not as same as those of basic tone 2.

Table 17: *The coefficients of diatone 33.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.09	3.11	88.96	0.008	-1.54	90.25
PP1	-0.01	-0.65	95.46	0.028	-0.09	94.09
PP2	0.18	-2.81	63.57	0.195	0.12	52.79
PP3				0.685	-4.16	32.63
PR1	4	-152.5	1840.5	14.6	-73.9	1670.6
PR2	0.94	-14.79	168.13	1.264	-0.88	113.1
PR3				1.356	-8.19	48.04

Tone 3 in the second tone of diatone 33 is falling. From Table 17, we can see that the slope of PP2 is positive and the others are negative. The curvatures are all positive. The contour of F0 is low falling. The contours of PP1, PP2, PR1 and PR2 are rising. The contours of PP3 and PR3 are falling-rising. The phonation natures are not as same as those of basic tone 3.

Table 18: *The coefficients of diatone 34.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.38	-7.82	120.1	-0.35	0.47	152.49
PP1	0.024	-0.46	95.29	0.07	-0.15	83.55
PP2	-0.08	1.04	53.78	-1.47	13.11	28.87
PP3	-0.23	3.41	14.55			
PR1	5.5	-105	1884.4	13.11	-114	709.1
PR2	-0.41	5.49	115.88	-4.97	37.55	66.35
PR3	-0.41	6.01	15.42			

Tone 4 in the second tone of diatone 34 is a falling tone. From Table 18, we can see that the slope of PP1 and PR1 are negative and the others are positive. The curvatures PP1 and PR1 are positive and the others are negative. The contour of F0 is falling. The contours of PP1, PP2 and PR2 are rising. The contours of PR1 is rising-falling. The phonation natures are not exactly as same as those of basic tone 4.

Table 19: *The coefficients of diatone 35.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.20	-4.52	103.8	-0.18	3.43	115
PP1	-0.01	0.14	94.59	-0.001	-0.32	93.66
PP2	0.02	-0.002	57.06			
PP3	-0.08	2.00	21.11			
PR1	-4.3	56.2	1821	4.1	-122.9	1714
PR2	0.11	-0.32	133.9			
PR3	-0.12	3.62	26.36			

Tone 5 in the second tone of diatone 35 is a high level tone. From Table 19, we can see that the slope of F0 is positive and the others are negative. The curvature of PR1 is positive and the others are negative. The contour of F0 is rising-falling. The contour of PP1 and PR2 are falling.

4.4. Diatone 4+1, 2, 3 and 4

In this subsection, the phonation natures of the fourth diatone group are discussed. There are 5 diatones altogether. The first tone in the diatones of this group is tone 4.

Tone 4 in the first tone of this diatone group is a falling tone. From Table 22-24, we can see that some of slopes are negative and the others are positive. Some of the curvatures are negative and the others are positive. The contours of F0 are all falling. The contours of PP1 and PR1 in diatone 41, 43, 44 and 45 are rising. The contours of PP1 and PR1 in diatone 42 are falling-rising. The contours of PP2 and PR2 in diatone 41 are falling. The contours of PP2 and PR2 in diatone 42 are rising. The contours of PP2 and PR2 in diatone 43 and 45 are falling-rising. The contours of PP2 and PR2 in diatone 44 are rising-falling and falling.

Table 20: *The coefficients of diatone 41.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	-0.006	-3.96	151.5	-0.003	0.09	129.42
PP1	0.02	0.02	88.52	0.018	-0.33	87.96
PP2	0.05	-0.91	55.86			
PR1	0.78	19.33	728	1.09	-19.84	729.2
PR2	0.26	-4.35	126			

Tone 1 in the second tone of diatone 41 is also a high level tone. From Table 20, we can see that the slope of F0 is positive, and curvature is negative. The slopes of PP1 and PR1 negative, and curvatures are positive. The phonation natures of tone 1 are as same as those of basic tone 1.

Table 21: *The coefficients of diatone 42.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.19	-8.91	175.38	0.02	2.18	88.69
PP1	0.14	-1.13	86.24	-0.06	0.66	92.93
PP2	-0.36	5.47	34.45	0.07	-1.11	55.98
PR1	18.15	-172.8	890.7	-2.9	-16.6	1770
PR2	-0.34	9.48	75.95	0.33	-4.96	126.24

Tone 2 in the second tone of diatone 42 is a rising tone. From Table 21, we can see that the slope of F0 and PP1 are positive and the others are negative. The curvatures of F0, PP2 and PR2 are positive and the others are negative. So the contour of F0 is rising. The contours of PP1 and PR1 are falling. The contours of PP2 and PR2 are all falling-rising.

The phonation natures are as same as those of basic tone 2.

Table 22: *The coefficients of diatone 43.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	-0.16	-0.37	156.73	0.50	-8.98	113.83
PP1	0.04	-0.56	88.36	-0.02	0.51	93.05
PP2	0.33	-3.35	59.67	0.36	-2.93	54.82
PP3				-0.35	6.46	9.81
PR1	3.76	-47.25	788.08	-2.8	170.7	1236
PR2	1.52	-15.54	144.33	1.75	-14.1	123.52
PR3				-0.4	10.36	8.38

Tone 3 in the second tone of diatone 43 is a low falling tone. From Table 22, we can see that the slope of F0, PP2 and PR2 are positive and the others are negative. The curvatures of F0, PP2 and PR2 are positive and the others are negative. The contour of F0 is low falling. The contours of PP1, PP3, PR1 and PR3 are rising. The contours of PP2 and PR2 are falling-rising. The phonation natures are not as same as those of basic tone 3.

Table 23*: The coefficients of diatone 44.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	0.10	-5.93	169.72	0.04	-5.13	162.72
PP1	0.01	0.06	88	0.02	0.20	85.56
PP2	-0.39	4.68	38.24	-0.11	2.53	41.82
PR1	0.31	21.06	694.02	8.85	-71.43	773.77
PR2	-0.29	1.05	104.57	0.55	-2.38	106.86

Tone 4 in the second tone of diatone 44 is a falling tone. From Table 23, we can see that the slopes of PP1 and PP2 are positive and the others are negative. The curvature of PP2 is positive and the others are negative. The contour of F0 is falling. The contours of PP1, PP2, PR1 and PR2 are rising. The phonation natures are not exactly as same as those of basic tone 4.

Table 24*: The coefficients of diatone 45.*

Para	Ct1	Sp1	Ip1	Ct2	Sp2	Ip2
F0	-0.13	-1.01	168.99	0.64	-9.09	108.7
PP1	0.004	0.63	79.73	-0.0002	0.23	94.98
PP2	0.46	-4.07	62.22	-0.061	2.28	49.42
PP3				-0.55	5.91	12.99
PR1	3.15	-12.61	464.59	-6	182.4	1773
PR2	2.41	-21.2	160.32	0.13	9.04	97.53
PR3				-0.89	9.8	13.45

Tone 5 in the second tone of diatone 45 is a low falling tone. From Table 24, we can see that the slope of F0 is negative and the others are positive. The curvatures of F0 and PR2 are positive and the others are negative. The contour of F0 is falling and the other contours are rising.

5. Discussion and conclusions

After the study of phonation natures in the tones and diatones in Mandarin, we have found that the phonation natures are very complicated in time domain and there are also many other phenomenon and natures which should be explained in time domain. In the study of phonation types in the minority languages in China, we also found that tones always have relationship with phonation types acoustically and historically. In those languages, the phonation types can distinguish different meanings and the different phonation types can also be regarded as the different tone qualities. So we think that the study on phonation natures of tones is significant in linguistic fields. Although this paper is only a preliminary study on the phonation natures in time domain, we have drawn 3 preliminary conclusions: 1) there are 3 types of phonation pulses, they are single peak pulse, double-peak pulse and tri-peak pulse in the tone and diatone; 2) F0 is generally in the inverse ratio of PR1 and PP1, which is the basic phonation nature of tone and diatone; 3) PR2 and PR3 have correlation with PP2 and PP3, but also reflect personal phonation natures in different conditions.

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