Tongue Kinematics in Diphthong Production in Ningbo Chinese*

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Abstract

This paper investigates some kinematic aspects of the tongue articulators during diphthong production in Ningbo Chinese. Acquired EMA data from six speakers show that the average velocity and the peak velocity of the lingual articulators roughly characterize the Ningbo diphthongs, given that the falling diphthongs and rising diphthongs are considered separately. The time to peak velocity serves as a better criterion in distinguishing the falling diphthongs from rising diphthongs. Generally, peak velocities of the lingual articulators occur late in falling diphthongs while occur early in rising diphthongs. The short diphthong production is characterized by an acceleration of the lingual articulator. And results suggest that the time to peak velocity is quite constant under the duration reduction.

1. Introduction

Diphthongs can be thought of as a vocalic sound that contains two targets, and can thus be described in terms of their targets and the movement connecting them. Dynamic aspects are of great importance to diphthong production. It is well documented in the literature that diphthongs are characterized by an invariant F2 rate of change (e.g., [1], [2]). And the acoustic study of Ningbo diphthongs ([3]) also shows that the F2 rate of change is one of the main attributes that contributes to the characterization of Ningbo diphthongs. But there are some shortcomings to use the F2 rate of change for studying diphthong dynamics. First, the F2 rate of change only captures the acoustic consequence of tongue movement in the front/back dimension but totally neglects the contribution of tongue movement in the high/low dimension. Second, the F2 rate of change is a combined result from several articulators such as tongue, lips, jaw, etc. Moreover, the F2 rate of change can merely characterize diphthongs in languages that just have a few falling diphthongs such as English ([1]), Mathili ([4]), etc., whereas it faces with serious problems in accounting for languages that have rich inventories of diphthongs such as Spain ([5]), Standard Chinese and Chinese dialects ([3], [6]; [7]). Furthermore, previous studies on diphthong dynamics were mainly in the acoustic and perceptual domains, and little has been done to explore diphthong dynamics from the articulatory perspective. Kent & Moll ([8]) made an attempt to investigate the tongue articulation of diphthongs based on the cinefluorographic data and found there is a constraint on the velocity of articulatory movement during diphthong production. However, their discussion was limited to the average lingual velocity data.

This paper investigates some dynamic aspects of diphthong production in terms of tongue kinematics. Lingual kinematic features such as the mean velocity, the peak velocity, and the time to peak velocity were examined to develop a purely tongue-based account for the diphthong production.

2. Methodology

Six speakers, 4 male and 2 female, provided the speech data. The test material covers all diphthongs in Ningbo Chinese: seven normal-length diphthongs [αι αυ ↲ψ ια ιο υα υE] that appear in the (C)D position and three short diphthongs [ιε υα ψο] that appear in the (C)D/ position (C stands for consonant and D for diphthong). Meaningful monosyllabic words were used as test words. All the test words have a high level tone and a zero initial, i.e. without an initial consonant.

Male Speaker 1 and 2 were recorded using Carstens EMA AG100 system and the other speakers were recorded using the AG 200 system. And synchronized audio signals were also recorded simultaneously. The receiver coils were mounted on the three tongue points (tongue dorsum, tongue mid and tongue tip), the jaw (the gum ridge at the lower teeth), and lips. And the gum ridge at the upper teeth and the bridge of the nose were used as reference sensors for the data correcting in the recording using the AG 200 system. Tongue kinematics was based on the kinematics of the principal tongue point or points involved in the diphthong production. And the nearest tongue point to the constriction location of a particular diphthong element was considered as the principal tongue articulator: the tongue mid (TM) point for the front diphthong elements [ι ψ ε E] and the tongue dorsum (TD) point for the low and back diphthong element [α ↲ ο υ α(/) ο(/)] ([↲] was treated as a back diphthong element because its quality is close to [□] according to our acoustic research and its lingual configuration is similar to the back vowels as well according to the static articulatory results). For the diphthongs involving one principal tongue point, discussion of tongue kinematics is focused on that particular tongue point, e.g., the TM point for the diphthong [ιε] or the TD point for the diphthongs [αυ υα], and for the diphthongs involving two different tongue points, discussion is based on both the TD and TM points. And all presented data are averaged from five repetitions.

3. Results and Discussion

3.1. Average velocity

The average velocity is expressed as the mean displacement of the lingual articulator (mm) per time unit (s), indicating the mean rate of lingual gestural changes in the vocal tract. The average velocity results are summarized in Tables 1a-f, where M-TD and M-TM denote spatial distances that TD and TM travel from diphthong onset to offset respectively, and V-TD and V-TM denote average velocities of TD and TM respectively.

First consider the falling diphthongs. [αι] has a great range of both TD and TM movements. And generally TM has a much greater range of spatial movement than TD, about 11 mm to 20 mm vs. 8 mm to 17 mm, which results in a greater average velocity of TM in all speakers. Different to [αι], the lingual movement reduces greatly for [αυ] in all speakers: about 6 mm to 11 mm for TD and 5 mm to 8 mm for TM. As a result, [αυ] has a much smaller lingual average velocity of TD/TM than [αι] does in all speakers. Another falling diphthong [↵ψ] is generally recorded a great range of lingual movement: about 7 mm to 13 mm for TD and 10 mm to 17 mm for TM. And it generally has comparatively smaller ranges of TD and TM movements and consequently smaller average velocities than [αι] in most speakers.

Second, consider the normal-length rising diphthongs. Diphthongs [ια] and [υα] are articulatorily reverse to the falling diphthongs [αι] and [αυ] respectively. As can be seen from the tables, it is difficult to distinguish [ια] from [αι] and [υα] from [αυ] in terms of the average velocity. The articulation of [ιο] involves a great range of lingual movement (about 10 mm to 17 mm for TD and 10 mm to 19 mm for TM) and consequently a great average velocity in all speakers except FS 3. The diphthong [υE] manifests great inter-speaker variations. And there is no general pattern detected. This is probably due to the fact that the lingual configuration for the diphthong element [E] is more variable.

Third, consider the three short diphthongs. [υα/] and [υα] is a short vs. normal-length minimal pair. [υα/] generally has a relatively smaller range of TD movement than its normal-length counterpart does in all speakers except in MS 2. However, the average velocities of TD for [υα/] are unexceptionally greater than those for [υα] in all speakers. [ψο/] can roughly be viewed as a short counterpart to the normal-length [ιο]. But different to the [υα/]/[υα] pair, the lingual spatial movements for [ψο/] are not always smaller than those for [ιο]. That is, short diphthongs are not necessarily associated with a lingual spatial compression. [ψο/] generally has a much greater average velocity of TM than [ιο] in all speakers, though this relation does not always hold for TD. [ιε/] involves a TM movement ranging from about 6 mm to 9 mm among speakers, which is similar to the TM movement range for [αυ]. But [ιε/] has a considerably greater average velocity of TM than [αυ] does in all speakers. So it is tenable to sum up from above discussion that short diphthongs are characterized by a greater average velocity of the principal lingual articulator(s).

3.2. Peak velocity and time to peak velocity

The peak velocity is the measured positive velocity peak occurred between the two targets of diphthong elements where there are acceleration minima. The time to peak velocity expresses when the peak velocity occurs in the time domain, which denotes the critical turning point of the lingual gestural change. To normalize the durational differences among different diphthongs, the time to peak velocity is also given in percentage. Results of the peak velocity and time to peak velocity are summarized in Tables 2a-f.

Roughly speaking, the peak velocity data show a similar pattern to that of the average velocity. That is, Ningbo diphthongs can be roughly characterized in terms of the peak velocities if the falling diphthongs are considered separately from the normal-length rising diphthongs. However, it is difficult to distinguish the rising diphthongs from the falling diphthongs in terms of the peak velocities. Due to the space limit, here, the discussion will be focused on the time to peak velocity, which serves as a better criterion in distinguishing the rising diphthongs from the falling diphthongs. As shown clearly by the percentage data from the tables, [αι] has greater values of time to peak velocity of both TD and TM than [ια] and [αυ] has a greater value of time to peak velocity of TD than [υα] in all speakers. And though there exist some inter-speaker differences, falling diphthongs usually have a greater value of time to peak velocity in percentage while rising diphthongs a smaller value. In other words, peak velocities usually occur later in falling diphthongs while occur earlier in normal-length rising diphthongs. And an examination of the articulatory data with corresponding acoustic data reveals that the peak velocity generally occurs during the spectral transition. That is, gestural changes results in spectral changing. (In [3], it is reported that acoustically falling diphthongs in Ningbo have a steady state for the onset element of about 1/3 duration of the entire diphthong but the rising diphthongs have no or neglectable steady state for the onset element.)

The short rising diphthongs are characterized by a generally greater value of time to peak velocity in percentage than the normal-length rising diphthongs. This is well manifested by a comparison between the short diphthong [υα/] and its normal-length counterpart [υα]. Meanwhile it can be observed from the tables that the short diphthongs do not necessarily have smaller time to peak velocity values in ms than the normal-length rising diphthongs. For instance, in MS 3 and 4 and the two female speakers, [υα/] has a similar time to peak velocity value with or even a greater time to peak velocity value than [υα]. This suggests that the great syllable reduction for the short diphthongs (in Ningbo, the short diphthongs are about 50% shorter in duration than the normal-length diphthongs) merely has limited effect on the time to peak velocity, and the time to peak velocity in ms is quite constant under the syllable reduction.

4. Conclusion

Both the average velocity and the peak velocity data can roughly characterize the Ningbo diphthongs, given that falling diphthongs and rising diphthongs are considered separately. But they both fail to distinguish the rising diphthongs from falling diphthongs. The time to peak velocity serves as a better criterion in distinguishing the falling diphthongs from rising diphthongs, namely falling diphthongs generally have a greater value of time to peak velocity while rising diphthongs a smaller value, especially in terms of the percentage data. In other words, peak velocities usually occur late in falling diphthongs while occur early in rising diphthongs. Articulatorily the peak velocity occurs during the gestural changing from diphthongs' onset lingual configuration to the offset configuration, and acoustically it occurs during the spectral transition.

Short diphthongs are characterized with greater average velocities vis-à-vis normal-length diphthongs, indicating that the lingual articulator is accelerated under syllable reduction. And short diphthongs have greater values of time to peak velocity in percentage than but similar values of time to peak velocity in ms with the corresponding normal-length rising diphthongs. This implies that the time to peak velocity, rather than the articulator velocity, is relatively constant under the duration reduction.

5. References

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Table 1a: The average velocities of the lingual articulators (TD and TM) for the Ningbo diphthongs (MS. 1)

Diph.	M-TD		M-TM		V-TD		V-TM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
[αι]	8.1	0.7	14.2	1.0	27.8	6.8	48.2	8.4
[αυ]	9.7	1.1	7.0	1.8	25.3	3.2	18.1	4.5
[↲ψ]	12.7	1.1	16.3	1.4	30.5	3.5	39.2	4.1
[ια]	7.9	1.1	15.4	1.1	24.6	3.2	47.9	2.9
[ιε/]	4.2	1.5	6.3	1.6	24.9	5.3	38.5	7.6
[ιo]	11.8	4.9	12.2	1.4	33.4	15.0	33.5	4.3
[ψo/]	11.2	0.4	16.1	1.0	75.4	10.8	107.2	9.8
[υα]	5.9	0.9	3.4	0.5	21.7	3.8	12.6	2.3
[υα/]	3.8	0.7	2.0	1.2	33.3	5.1	17.5	8.8
[υE]	12.8	3.1	6.5	1.7	44.0	10.6	22.5	6.2

Table 1b: The average velocities of the lingual articulators (TD and TM) for the Ningbo diphthongs (MS. 2)

Diph.	M-TD		M-TM		V-TD		V-TM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
[αι]	14.5	1.2	20.2	1.9	39.9	6.9	55.6	8.8
[αυ]	6.4	1.0	6.4	1.3	16.9	2.3	17.0	3.4
[↲ψ]	7.2	0.8	10.1	1.5	20.0	5.1	28.1	7.7
[ια]	10.6	0.9	14.6	2.0	39.1	9.6	54.1	15.7
[ιε/]	5.9	1.0	6.4	1.0	41.8	4.2	45.2	3.7
[ιo]	9.7	1.4	14.8	1.6	27.7	6.2	42.1	8.1
[ψo/]	12.1	1.0	14.3	0.8	87.7	12.9	103.8	12.4
[υα]	3.8	0.7	3.3	0.7	11.5	3.6	10.1	3.5
[υα/]	4.3	0.6	4.0	0.8	31.9	3.7	30.2	7.6
[υE]	5.4	2.0	5.0	1.6	18.0	7.8	16.5	6.7

Table 1c: The average velocities of the lingual articulators (TD and TM) for the Ningbo diphthongs (MS. 3)

Diph.	M-TD		M-TM		V-TD		V-TM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
[αι]	13.9	0.9	15.4	1.1	89.6	14.5	99.4	16.3
[αυ]	5.9	0.7	6.1	0.4	40.6	2.9	42.7	7.0
[↲ψ]	13.3	1.0	13.6	1.1	71.7	10.0	72.8	9.2
[ια]	16.8	0.8	17.6	0.3	99.7	10.4	104.9	9.2
[ιε/]	9.2	1.0	8.9	0.6	80.1	5.7	77.2	7.5
[ιo]	14.3	1.1	9.7	1.0	100.7	13.8	68.4	8.9
[ψo/]	12.5	1.8	11.0	1.3	94.4	17.7	83.2	14.7
[υα]	6.0	1.6	4.3	1.1	37.6	9.5	28.1	10.2
[υα/]	2.8	0.9	1.3	0.3	40.9	10.1	19.3	4.4
[υE]	7.6	1.8	5.7	1.5	60.2	16.5	45.9	17.2

Table 1d: The average velocities of the lingual articulators (TD and TM) for the Ningbo diphthongs (MS. 4)

Diph.	M-TD		M-TM		V-TD		V-TM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
[αι]	17.5	1.6	20.6	1.3	113.2	5.0	133.8	2.5
[αυ]	11.3	0.4	8.4	1.3	64.7	8.2	48.8	12.2
[↲ψ]	12.5	2.2	17.7	2.6	93.7	11.9	132.4	12.1
[ια]	11.1	0.4	19.2	0.3	71.6	6.1	124.6	8.7
[ιε/]	5.5	0.8	8.3	1.1	60.1	7.1	90.9	7.8
[ιo]	16.8	1.2	18.6	1.1	93.7	5.7	104.8	14.4
[ψo/]	11.8	1.8	18.1	3.0	91.7	15.6	139.0	18.7
[υα]	7.8	0.9	3.6	0.6	51.6	5.6	23.9	3.5
[υα/]	6.7	1.1	3.2	1.0	58.1	7.0	27.3	6.1
[υE]	18.4	0.4	14.9	0.6	140.9	10.3	114.5	7.2

Table 1e: The average velocities of the lingual articulators (TD and TM) for the Ningbo diphthongs (FS. 1)

Diph.	M-TD		M-TM		V-TD		V-TM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
[αι]	17.5	1.6	20.6	1.3	113.2	5.0	133.8	2.5
[αυ]	11.3	0.4	8.4	1.3	64.7	8.2	48.8	12.2
[⅃ψ]	12.5	2.2	17.7	2.6	93.7	11.9	132.4	12.1
[ια]	11.1	0.4	19.2	0.3	71.6	6.1	124.6	8.7
[ιε/]	5.5	0.8	8.3	1.1	60.1	7.1	90.9	7.8
[ιo]	16.8	1.2	18.6	1.1	93.7	5.7	104.8	14.4
[ψo/]	11.8	1.8	18.1	3.0	91.7	15.6	139.0	18.7
[υα]	7.8	0.9	3.6	0.6	51.6	5.6	23.9	3.5
[υα/]	6.7	1.1	3.2	1.0	58.1	7.0	27.3	6.1
[υE]	18.4	0.4	14.9	0.6	140.9	10.3	114.5	7.2

Table 1f: The average velocities of the lingual articulators (TD and TM) for the Ningbo diphthongs (FS. 2)

Diph.	M-TD		M-TM		V-TD		V-TM	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
[αι]	9.5	0.5	11.7	1.0	53.7	4.6	66.3	4.1
[αυ]	7.0	1.3	8.0	0.7	38.4	6.0	44.4	6.4
[⅃ψ]	8.4	0.9	10.0	0.8	46.0	5.8	55.1	6.9
[ια]	7.0	0.4	10.9	0.7	44.7	4.5	70.0	5.4
[ιε/]	6.2	0.6	7.1	0.4	45.5	4.0	51.9	4.9
[ιo]	7.5	0.7	6.0	0.4	35.1	1.6	28.5	2.1
[ψo/]	6.2	2.1	7.0	2.9	50.0	8.4	56.5	11.3
[υα]	7.1	0.7	4.0	0.4	39.5	1.4	22.4	2.9
[υα/]	6.8	1.1	4.2	0.9	60.6	10.3	37.4	7.5
[υE]	12.8	0.9	10.0	0.8	98.7	11.9	76.7	7.8

Table 2a: Peak Velocity (PV) and Time to Peak Velocity of TD and/or TM for the Ningbo diphthongs (MS. 1)

Diphthongs		PV (TD)	Time to PV (TD)		PV (TM)	Time to PV (TM)	
		mm/s	ms	%	mm/s	ms	%
[αι]	Mean	102	208	48%	120	230	53%
	SD	25	14	5%	15	43	8%
[αυ]	Mean	65	362	73%			
	SD	15	76	14%			
[⅃ψ]	Mean	132	323	56%	97	321	55%
	SD	31	26	5%	14	37	5%
[ια]	Mean	97	134	27%	132	132	26%
	SD	17	22	3%	12	37	6%
[ιε/]	Mean				102	138	60%
	SD				30	27	9%
[ιo]	Mean	112	178	35%	94	186	37%
	SD	10	36	6%	10	40	7%
[ψo/]	Mean	142	116	52%	214	107	48%
	SD	27	20	8%	24	21	9%
[υα]	Mean	44	125	26%			
	SD	4	61	13%			
[υα/]	Mean	46	105	48%			
	SD	3	37	18%			
[υE]	Mean	94	124	24%	55	172	33%
	SD	42	8	2%	19	43	8%

Table 2b: Peak Velocity (PV) and Time to Peak Velocity of TD and/or TM for the Ningbo diphthongs (MS. 2)

Diphthongs		PV (TD)	Time to PV (TD)		PV (TM)	Time to PV (TM)	
		mm/s	ms	%	mm/s	ms	%
[αι]	Mean	100	278	56%	126	272	55%
	SD	19	42	6%	31	41	6%
[αυ]	Mean	63	274	55%			
	SD	11	73	13%			
[⅃ψ]	Mean	63	118	25%	75	120	26%
	SD	5	24	5%	12	27	7%
[ια]	Mean	109	130	23%	133	126	22%
	SD	10	17	3%	24	15	2%
[ιε/]	Mean				87	98	47%
	SD				17	21	7%
[ιo]	Mean	111	146	27%	147	150	28%
	SD	18	16	4%	17	8	2%
[ψo/]	Mean	169	113	56%	171	113	56%
	SD	26	24	3%	28	23	3%
[υα]	Mean	48	113	20%			
	SD	8	30	6%			
[υα/]	Mean	64	78	37%			
	SD	13	27	12%			
[υE]	Mean	58	66	12%	59	83	16%
	SD	15	15	3%	17	43	8%

Table 2c: Peak Velocity (PV) and Time to Peak Velocity of TD and/or TM for the Ningbo diphthongs (MS. 3)

Diphthongs		PV (TD)	Time to PV (TD)		PV (TM)	Time to PV (TM)	
		mm/s	ms	%	mm/s	ms	%
[αι]	Mean	208	136	63%	215	143	66%
	SD	18	20	8%	19	10	3%
[αυ]	Mean	151	115	55%			
	SD	17	40	20%			
[⅃ψ]	Mean	166	138	57%	157	146	60%
	SD	13	31	12%	9	16	6%
[ια]	Mean	202	73	27%	216	77	28%
	SD	17	8	4%	13	6	2%
[ιε/]	Mean				139	81	48%
	SD				14	12	6%
[ιo]	Mean	177	84	36%	135	107	46%
	SD	7	18	8%	15	10	4%
[ψo/]	Mean	195	79	49%	168	81	51%
	SD	21	24	10%	25	14	6%
[υα]	Mean	115	67	24%			
	SD	11	32	12%			
[υα/]	Mean	147	99	63%			
	SD	37	41	22%			
[υE]	Mean	161	51	22%	122	54	23%
	SD	40	15	6%	27	12	4%

Table 2e: Peak Velocity (PV) and Time to Peak Velocity of TD and/or TM for the Ningbo diphthongs (FS. 1)

Diphthongs		PV (TD)	Time to PV (TD)		PV (TM)	Time to PV (TM)	
		mm/s	ms	%	mm/s	ms	%
[αι]	Mean	132	102	49%	148	107	51%
	SD	6	16	5%	9	16	5%
[αυ]	Mean	88	64	35%			
	SD	10	24	13%			
[⅃ψ]	Mean	132	102	50%	129	101	49%
	SD	8	23	9%	10	24	10%
[ια]	Mean	151	81	35%	186	64	28%
	SD	6	9	4%	20	9	3%
[ιε/]	Mean				128	79	56%
	SD				12	2	5%
[ιο]	Mean	111	91	39%	120	99	43%
	SD	18	20	9%	10	19	8%
[υα]	Mean	100	62	26%			
	SD	7	10	3%			
[υα/]	Mean	119	62	40%			
	SD	11	14	9%			
[υE]	Mean	148	80	30%	131	148	80
	SD	7	11	3%	11	7	11

Table 2d: Peak Velocity (PV) and Time to Peak Velocity of TD and/or TM for the Ningbo diphthongs (MS. 4)

Diphthongs		PV (TD)	Time to PV (TD)		PV (TM)	Time to PV (TM)	
		mm/s	ms	%	mm/s	ms	%
[αι]	Mean	217	95	40%	255	99	41%
	SD	28	9	3%	40	11	3%
[αυ]	Mean	103	104	42%			
	SD	6	37	11%			
[⅃ψ]	Mean	153	74	36%	216	75	36%
	SD	25	17	7%	31	12	4%
[ια]	Mean	184	100	37%	278	97	36%
	SD	40	8	2%	25	10	3%
[ιε/]	Mean				164	97	64%
	SD				18	23	15%
[ιο]	Mean	188	111	39%	217	129	46%
	SD	9	22	6%	10	22	6%
[ψο/]	Mean	152	89	52%	235	91	53%
	SD	21	12	9%	45	14	10%
[υα]	Mean	95	62	24%			
	SD	14	25	8%			
[υα/]	Mean	102	80	44%			
	SD	14	17	10%			
[υE]	Mean	262	79	30%	234	81	31%
	SD	14	32	11%	20	33	11%

Table 2f: Peak Velocity (PV) and Time to Peak Velocity of TD and/or TM for the Ningbo diphthongs (FS. 2)

Diphthongs		PV (TD)	Time to PV (TD)		PV (TM)	Time to PV (TM)	
		mm/s	ms	%	mm/s	ms	%
[αι]	Mean	99	140	58%	111	139	57%
	SD	8	11	3%	11	11	3%
[αυ]	Mean	69	113	43%			
	SD	13	25	10%			
[⅃ψ]	Mean	84	102	39%	96	106	40%
	SD	19	18	6%	18	21	7%
[ια]	Mean	115	116	33%	146	100	28%
	SD	5	13	3%	7	15	4%
[ιε/]	Mean				105	67	40%
	SD				8	15	6%
[ιο]	Mean	89	157	51%	73	163	53%
	SD	14	33	6%	8	37	7%
[ψο/]	Mean	109	103	53%	111	96	50%
	SD	15	24	8%	19	23	8%
[υα]	Mean	83	84	25%			
	SD	6	15	3%			
[υα/]	Mean	101	94	42%			
	SD	7	24	8%			
[υE]	Mean	196	87	30%	162	87	30%
	SD	23	14	3%	19	14	3%

* In *Proceedings of Interspeech-Eurospeech 2005*, pp. 1029-1033, Lisbon, Portugal, 2005.