

A Study on the Aerodynamics of Mongolian Tense and Lax Vowels

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Abstract—This paper describes the speech aerodynamic characteristics of the standard Mongolian tense and lax vowel based on the experimental method, and finds the elastic change of the vowel and the movement of the tongue position are influence on aerodynamic parameters like airflow rate, glottal resistance, vocalized efficiency and etc. From the relationship between the elasticity of the vowel and the position of the tongue base, verify that the standard Mongolian elastic and tongue root position changes have a mutual relationship.

Keywords—tense vowel; lax vowel; standard Mongolian; speech aerodynamics

I. INTRODUCTION

In traditional Mongolian grammar works, vowels have positive and negative properties. Generally speaking, negative is lax vowel, and positive is tense vowel. Regarding the opposition characteristics of tense and lax, the famous Mongolian scholar Qing Getai pointed out: "When speak the tense vowel, the upper of the throat is tense and the tongue is retracted. The Lax vowel is the opposite [1]. In addition, when the closed tense vowel in Mongolian is pronounced, the oral opening is larger and the tongue is later than the corresponding lax vowel. Mr. Daobu described the pronunciation characteristics of the tense vowels in the Mongolian Concise: "The pharyngeal muscles are tight and the tone is louder when pronounced [2]." Mr. Bao Huaichao also did the analysis of related acoustics, it is believed that in Mongolian, the biggest feature of tense vowel is the increase of F1 (lower tongue position) and the increase of F2 energy, which makes the tone more loud [3]. So what is elastic of the Mongolian vowel in terms of physiology? There are two main explanations. The first is: when tense vowel is pronounced, the vocal muscles, especially the pharyngeal and tongue root muscles, have a certain degree of tension, the vocal organs have a larger stroke, and the vocal tract changes more with respect to the quiescent state; when lax vowel is pronounced, the situation is opposite. In addition, the tense vowels also exhibit longer duration and higher tongue position in some languages [4]. The second explanation is that tension is characterized by a tight throat and glottis. According to the second understanding, the tension of the vowel belongs to the category of vocalization, it is also called the tight throat vowel. Regarding the type of tightness, differences are mainly focused on the first interpretation of tense and lax vowel. The focus of the divergence is whether the vocal muscle tension can

become an independent pronunciation mechanism. The main reason for disagreement is that in a language that is considered to have a vowel tightness, the vowel tightness is often related to the position of the tongue [5]. The relationship between the elastic of the vowel and the position of the base of the tongue is different in vary languages. In some languages, ATR vowels are tense vowels, while in other languages ATR vowels show tension, and which category of Mongolian belongs to is exactly what needs to be explored.

II. EXPERIMENT METHOD

A. Pronunciation Material

Based on the standard Mongolian phoneme system, the list is as follows.

TABLE I. STANDARD MONGOLIAN PHONEME SYSTEM TABLE

	Short vowel	long vowel
tense vowel	[ɑ] [ɪ], [ɔ] [ʊ]	[ɑ:] [ɪ:], [ɔ:] [ʊ:]
Lax vowel	[ə] [e], [i] [ʉ]	[ə:] [e:], [i:] [ʉ:]

Select the vowels at the beginning of the word as much as possible. The 16 vowels contained in the standard Mongolian can be used as the prefix, and thus 80 words with the vowel as the prefix are selected, and 5 words are selected for each sound.

B. Pronunciation Partner

Wuyun Gaowa, female, 26 years old, Inner Mongolia, Mongolian master of linguistics, Mongolian standard sound is pure, no vocal diseases.

C. Equipment Use and Method

Phonatory Aerodynamic System can extract of pitch, sound pressure, air pressure and airflow, and can calculate the average pronunciation airflow rate, sound pressure level, fundamental frequency, vital capacity, glottal impedance, subglottic pressure. During the collection process, the air inlet tube is generally placed in the mouth of pronunciation partner. We selected professional recording studio to recording. Generally, after a sound is read, there must be a relatively long pause, roughly after about 1-2 minutes, etc.

D. Air flow and Pressure Signal Analysis and Extraction of Language Aerodynamic Parameters

In this paper, by means of the combination of the spectrogram and airflow and air pressure, the spectrogram and air pressure signals are made, and the position of the vowel is found through the region where the vowel formant appears. Finally, the PAS software will be used to marked vowel position and extracted the parameters. Figure 1 is a diagram of the two-syllable words [ɔlig] and the air flow and pressure signal.

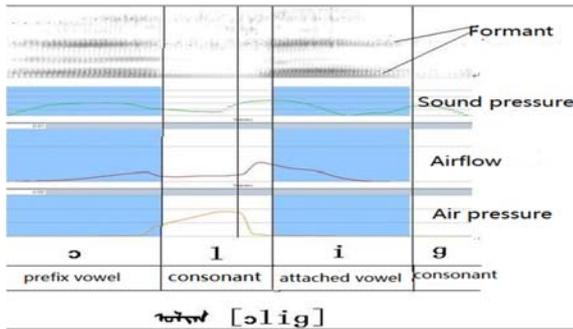


FIGURE I. SCHEMATIC DIAGRAM OF VOWEL AERODYNAMIC PARAMETER EXTRACTION

Part of the speech aerodynamic parameters of the vowel are extracted, (1) *the maximum airflow rate*: is the maximum speed at which the airflow flows out of the glottis when the vowel is uttered, and is physiologically the maximum degree of opening of the glottis. (2) *The duration of occurrence*: is the duration of the vowel, which is physiologically expressed as the time length of vocal cord vibrates. (3) *The average airflow rate*: is the average amount of airflow out per unit time, which is physiologically related to the average openness of the glottis. (4) *The vocal power* indicates the acoustic energy that the human vocal system converts into aerodynamics. (5) *The glottal resistance* indicates the obstruction of the glottis to the airflow during the vocal activity, the greater the glottal resistance, the higher the glottis tightness. The vocal efficiency is expressed as the ratio of acoustic energy to aerodynamic energy, which is physiologically expressed as the ratio of airflow energy to sound energy. When the vocal energy and the average airflow are constant, the vocal efficiency and the subglottic pressure are inversely proportional, so that the pressure under the glottis can be converted by the vocal efficiency, the vocal energy, and the average airflow rate.

III. RESEARCH RESULT

For 80 words that can as a word prefix of the 16 vowels in the standard Mongolian, we extracted six aerodynamic parameters of the first vowel, and average the parameters of the same vowel from the different words to obtain the following vowel speech aerodynamic parameter table, in which the upper 8 acts as a tight vowel and the lower 8 acts as a loose vowel.

TABLE II. VOWEL SPEECH AERODYNAMIC PARAMETER TABLE

			Maximum airflow rate PEA ⁽¹⁾ (Lit/Sec) ⁽²⁾	Length of vocalization EAD ⁽³⁾ (Sec) ⁽⁴⁾	Average airflow rate BA ⁽⁵⁾ (Lit/Sec) ⁽⁶⁾	Sound power AP ⁽⁷⁾ (watts) ⁽⁸⁾	Glottal resistance AR ⁽⁹⁾ (ds/cmS) ⁽¹⁰⁾	Vocal efficiency AE ⁽¹¹⁾ (%) ⁽¹²⁾
tense vowel	short	a ⁽¹⁾	0.23 ⁽²⁾	0.07 ⁽⁴⁾	0.12 ⁽⁶⁾	0.14 ⁽⁸⁾	50.12 ⁽¹⁰⁾	298.17 ⁽¹²⁾
		ɪ ⁽¹⁾	0.49 ⁽²⁾	0.05 ⁽⁴⁾	0.28 ⁽⁶⁾	0.08 ⁽⁸⁾	30.92 ⁽¹⁰⁾	357.22 ⁽¹²⁾
		ɔ ⁽¹⁾	0.21 ⁽²⁾	0.06 ⁽⁴⁾	0.11 ⁽⁶⁾	0.23 ⁽⁸⁾	116.40 ⁽¹⁰⁾	104.81 ⁽¹²⁾
	long	o ⁽¹⁾	0.12 ⁽²⁾	0.07 ⁽⁴⁾	0.07 ⁽⁶⁾	0.28 ⁽⁸⁾	138.24 ⁽¹⁰⁾	98.62 ⁽¹²⁾
		ɑ ⁽¹⁾	0.16 ⁽²⁾	0.13 ⁽⁴⁾	0.09 ⁽⁶⁾	0.17 ⁽⁸⁾	88.57 ⁽¹⁰⁾	208.50 ⁽¹²⁾
		u ⁽¹⁾	0.40 ⁽²⁾	0.11 ⁽⁴⁾	0.25 ⁽⁶⁾	0.10 ⁽⁸⁾	37.13 ⁽¹⁰⁾	299.37 ⁽¹²⁾
lax vowel	short	ɑ ⁽¹⁾	0.17 ⁽²⁾	0.12 ⁽⁴⁾	0.10 ⁽⁶⁾	0.26 ⁽⁸⁾	132.07 ⁽¹⁰⁾	90.54 ⁽¹²⁾
		ɔ ⁽¹⁾	0.09 ⁽²⁾	0.14 ⁽⁴⁾	0.05 ⁽⁶⁾	0.31 ⁽⁸⁾	155.98 ⁽¹⁰⁾	83.31 ⁽¹²⁾
		e ⁽¹⁾	2.03 ⁽²⁾	0.06 ⁽⁴⁾	1.82 ⁽⁶⁾	2.17 ⁽⁸⁾	17.31 ⁽¹⁰⁾	698.78 ⁽¹²⁾
	long	e ⁽¹⁾	1.57 ⁽²⁾	0.05 ⁽⁴⁾	1.21 ⁽⁶⁾	2.88 ⁽⁸⁾	15.66 ⁽¹⁰⁾	713.20 ⁽¹²⁾
		i ⁽¹⁾	1.31 ⁽²⁾	0.06 ⁽⁴⁾	1.04 ⁽⁶⁾	3.25 ⁽⁸⁾	10.37 ⁽¹⁰⁾	1283.76 ⁽¹²⁾
		u ⁽¹⁾	3.44 ⁽²⁾	0.07 ⁽⁴⁾	3.10 ⁽⁶⁾	1.08 ⁽⁸⁾	22.59 ⁽¹⁰⁾	398.20 ⁽¹²⁾
long	ɑ ⁽¹⁾	2.89 ⁽²⁾	0.12 ⁽⁴⁾	2.55 ⁽⁶⁾	2.38 ⁽⁸⁾	20.03 ⁽¹⁰⁾	726.33 ⁽¹²⁾	
	e ⁽¹⁾	2.77 ⁽²⁾	0.11 ⁽⁴⁾	2.43 ⁽⁶⁾	3.04 ⁽⁸⁾	19.11 ⁽¹⁰⁾	747.12 ⁽¹²⁾	
	i ⁽¹⁾	1.54 ⁽²⁾	0.12 ⁽⁴⁾	1.18 ⁽⁶⁾	3.63 ⁽⁸⁾	12.30 ⁽¹⁰⁾	1389.56 ⁽¹²⁾	
		u ⁽¹⁾	3.69 ⁽²⁾	0.13 ⁽⁴⁾	3.35 ⁽⁶⁾	1.22 ⁽⁸⁾	25.84 ⁽¹⁰⁾	421.48 ⁽¹²⁾

Note: The parameter unit in parentheses

A. Vowel Aerodynamic Parameter Characteristics

From Table 2, we can see the basic range of the six parameters of the standard Mongolian vowel and the variation of the aerodynamic parameters of the vowel speech of different classes.

1) Maximum Airflow Rate

The maximum airflow rate of the standard Mongolian vowel is between 0.09 Lit/Sec—3.69 Lit/Sec, and the smallest of Maximum airflow rate value is the tight long vowel [ɔ:], the largest is the loose long vowel [u:]. The size relationship is: lax long vowels > lax short vowels > tense short vowels > tense long vowels. It can be seen that the tightness of the vowel and the maximum opening degree of the glottis have a certain relationship. When the vowel is loose, the opening degree of the glottis will be relatively large, and the air flow flowing through the unit time will be bigger. At the same time, the change of the maximum airflow rate has a certain relationship with the duration of the vowel. When the vowel is tight, the opening degree of the glottis is small, so the maximum airflow rate of lax long vowels is the largest.

2) Length of Vocalization

The duration of vowel sounds in Mongolian is not too obvious from the perspective of tightness. The duration of short vowels is basically same, and the range is between 0.5-0.7 Sec. Generally, long vowel is generally twice times that of short vowels, which is basically consistent with the results of previous studies.

3) Average Airflow Rate

The average airflow rate of vowels in Mongolian is between 0.05 Lit/Sec—3.35 Lit/Sec, and the variation of average airflow rate and the maximum airflow rate are same.

4) Sound Power

The vocal power of the vowel in Mongolian is between 0.08 watts and 3.63 watts, where the lax long vowel [i] has the highest sound power, the tense short vowel [ɪ] is the smallest. The specific size relationship is: lax long vowels > lax short vowels > tight long vowels > tight short vowels. It can be seen

that the magnitude of the vocal power and the tightness and length of the vowels have a certain relationship. When the muscles are relatively tight and the vocal organ has a large stroke, the vocal power will be relatively small, and the aerodynamic shift of the respiratory system will have a lower acoustic energy.

5) *Glottic Resistance*

The glottal resistance of Mongolian vowels is between 155.98 and 10.37 ds/cm⁵, where the tight long vowel [o:] has the highest glottal resistance, and the loose short vowel [i] is the smallest. The overall size relationship is: tight long vowels > tight short vowels > loose long vowels > loose short vowels. It can be seen that the magnitude of the glottal resistance, the vowel's tightness and length have a certain relationship. When the muscles are relatively slack and the vocal organ movement is small, the glottal resistance will be relatively small, and the glottis will have a weaker resistance to the airflow.

6) *Vocal Efficiency*

The vocal efficiency of vowels in Mongolian is between 83.31ppm and 1389.56ppm, and the loose vowels are larger than the tight vowels. The total size relationship is: loose long vowels > loose short vowels > tight short vowels > tight long vowels. At the same time, according to the vocal efficiency = vocal power × average airflow rate / glottal depression, the subglottal pressure = vocal power × average airflow rate / vocal efficiency pressure, and the relationship between the vocal power, the average airflow rate, and the vocal efficiency obtained above, It can be introduced that the magnitude of the glottal pressure is :tight long vowels > tight short vowels > loose short vowels > loose long vowels. According to this, it can be seen that the pressure under the glottis of the Mongolian elastic vowel is indeed different, and the change of duration will also affect the glottal pressure.

Generally, when the voice is tightened, the glottal pressure and glottal resistance are higher, and the glottal vocal efficiency and vocal power are not high. This is because most of the glottis aerodynamic force is used to overcome the glottal impedance and is not used to generate sound. When the voice is tightened, the situation is opposite. In Table 2, the Mongolian vowels meet these characteristics, which indicates that the Mongolian language is characterized by a tight voice, but the glottal resistance and glottal pressure are not too high, so we regard the Mongolian tight vowel as a normal sound. The lax vowels have a flow rate of about 3 Lit/Sec per second. It exceeds the normal 1.6 Lit/Sec standard, so we see it as a leaky sound. Above we have made a general narrative of the aerodynamic characteristics of vowels, and Mongolian vowels can be divided into tight short vowels, tight long vowels, loose short vowels and loose long vowels. So when the tightness and length are different, the aerodynamic characteristics will be the main content of our discussion below.

B. *Analysis the Characteristics of Airflow and Pressure of Tight and Loose Vowel*

In Mongolian, the vowels can be divided into loose vowels and tight vowels. Above we describe the changes in speech aerodynamic parameters according to the tightness of the

vowels, and the parameters are loose or tight. And what is the relationship between the changes in the parameters of the loose or tight vowels and the changes in the tongue position?

1) *Analysis the Characteristics of Air Flow and Pressure of Tense Vowel*

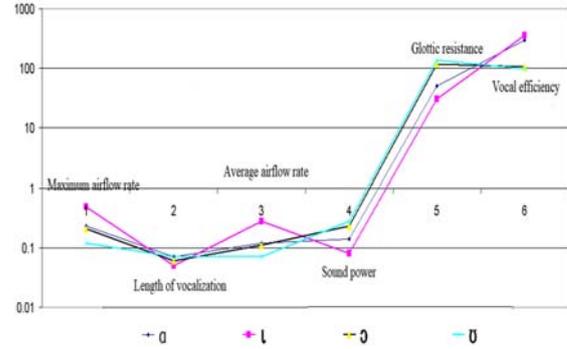


FIGURE II. TIGHT SHORT VOWEL AIR FLOW AND PRESSURE MAP

In Figure 2, the aerodynamic parameters of the tight short vowel [a], [ɪ], [ɔ], [u] are compared, and the maximum airflow rate and average airflow rate of [ɪ] are the largest, and [u] is minimum. The vocal power and glottal resistance of [u] are the largest, [ɪ] is the smallest. In vocal efficiency, [ɪ] is the largest and the smallest is [u]. The overall relationship is: for airflow rate, [ɪ] > [a] > [ɔ] > [u], on the sound power and glottal resistance [u] > [ɔ] > [a] > [ɪ], for the vocal efficiency, [ɪ] > [a] > [ɔ] > [u]. Therefore, we find in tense short vowels, the changes of various parameters have a certain relationship with the tongue position. The airflow rate and vocalization efficiency decrease with the backward shift and elevation of the tongue position, while the vocal power and glottis resistance increases as the tongue moves backward and rises.

2) *Analysis the Characteristics of Air Flow and Pressure of Lax Vowel*

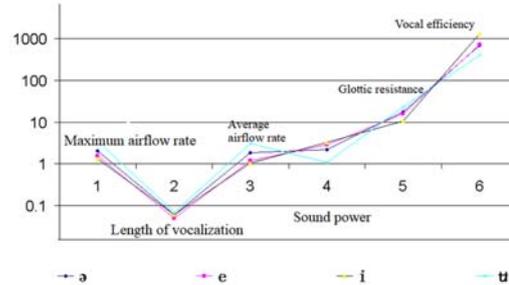


FIGURE III. LOOSE SHORT VOWEL AIR FLOW AND PRESSURE MAP

In Figure 3, the six aerodynamic parameters of the loose short vowel [a], [e], [i], [u] are compared, and the maximum airflow rate and average airflow rate of [u] are the largest, while [i] is the smallest, for vocal power, [u] is the minimum and [i] is the largest, for the glottal resistance, [u] is maximum and [i] is the smallest, for the vocal efficiency is the maximum of [i], the smallest of [u]. The overall relationship is: for the airflow rate [u] > [a] > [e] > [i], on the sound power [i] > [e] > [a] > [u], on glottal resistance [u] > [a] > [e] > [i], the sound efficiency

is[i] > [e] > [ə] > [u]. Therefore, the change of each parameter and the tongue position are also related. The airflow rate and glottal resistance increase with the back and elevation of the tongue position, while the vocal power and vocal efficiency are decreasing follow by the back and rise of tongue, which is completely different from the tight vowel. Combined with the conclusions drawn from the analysis of Fig. 2 and Fig. 3, it can be concluded that the main difference between the loose vowel and the tense vowel is in addition to the tension of the pronunciation part, and also the the tongue position influence on each parameter.

IV. CONCLUSION

In this paper, we use the speech aerodynamic method to explore the relationship between the elastic, length, tongue position and aerodynamic parameters of the standard Mongolian vowels, and obtain conclusions: the aerodynamic parameters of the elastic vowels, the size relationship between the vowels, as well as the influence of the vowel tongue changes on the aerodynamic parameters in Mongolian based on a large number of data. Generally, in tight short vowels, the airflow rate and vocalization efficiency decrease with the posterior shift and elevation of the tongue position, while the vocal power and glottal resistance increase with the posterior shift and elevation of the tongue position. The airflow rate and glottal resistance of the lax vowels increase with the backward movement and elevation of the tongue position, and the vocal power and vocalization efficiency decrease with the backward movement and elevation of the tongue position. It can be seen that the tightness of the vowels and the height of the tongue have an important influence on the changes of speech aerodynamic parameters, while the length of the vowels has little effect on them. Feedback to the physiological, it can be said that in the elastic vowel, not only the vocal cords must maintain a certain tension or slack, but also the tongue position must maintain a certain position, two conditions are indispensable. The same type of long and short vowels have little change in the vocal cord tightness and tongue position changes, and the length of the vocalization will only affect the partial tightness. This study explores the elasticity of vowels from the dynamics of speech production. This is a new attempt in the study of speech and voice, and there are many problems to be solved, (1) Automatically mark the spectrogram and PAS signal, and convert the existing NSP format recording into WAV format to realize batch processing from the program. (2) Eliminate the influence of the nasal resonance formant on the extraction of vowels by the method of the formant. (3) Improve the theory of speech aerodynamics, and explain many problems from the perspective of speech production, which need to be solved in future work.

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