Acoustic Study of Mongolian Unaspirated and Aspirated Consonants

Axu Hu, Menghuan Wang* and Tana Gegen
Department of Key Laboratory of China's Ethnic Languages and Information Technology of Ministry of Education, Northwest Minzu University, Lanzhou, Gansu, China
*Corresponding author

Abstract—For the difference between aspiration and non-aspiration of consonants in Mongolian, it is generally considered that the airflow of unaspirated such as [p], [k], [t] is weak. The airflow of the aspirated like [pʰ], [tʰ], [kʰ] is strong. This paper has further analyzed this based on experimental phonetics. For aspirating and non-aspirating of stop and affricate in the Mongolian, the glottal pressure and airflow were extracted and compared. The difference between Mongolian unaspirated and aspirated consonants is obtained: not only the intensity of the airflow but mainly the difference in the length of the consonant burst section.

Keywords—Mongolian; consonant; air pressure; airflow

I. INTRODUCTION

Today's research on Mongolian phonetics is mainly based on traditional research methods. In recent years, physiological and acoustic methods have gradually been introduced into modern phonetics. As a part of multimodal speech research [1], speech acoustics research based on airflow pressure signal mainly uses the theory of speech aerodynamics to observe the changes of human airflow during speech from the perspective of physiological phonetics. Based on this method, this paper explores the distinguishing characteristics of the Mongolian aspirating and non-aspirating consonant.

In foreign countries, acoustic research on the distinguishing characteristics of consonant aspiration and non-aspiration has started early. There are three main points of view today. (1) Voiceless aspirated sound after blast, the glottis is open as usual, and after a period of breath, the vocal cord vibrates to emit a vowel. (2) The difference between non-aspiration and aspiration is the difference between the mouth tuning and the throat tuning time. (3) The air pressure and airflow on the glottis of the unaspirated and aspirated sounds are corresponding to the obstruction-closure-burst process is different [2].

In Mongolian, some consonants have the same place of articulation, but they have the differences of unaspirated and aspirated, they form two opposite phonemes, which has discriminating functions. Such as stop [p] / [pʰ], [t] / [tʰ], [k] and [kʰ], affricate [dz] / [ts], [dzʰ] / [tsʰ], [dz] / [ts], [dzʰ] / [tsʰ], among them, [kʰ], [dz] / [ts], [dzʰ] / [tsʰ] are loanwords, and [pʰ] generally appears in loanwords and onomatopoeia. For the phenomenon of aspiration and non-aspiration in Mongolian, Mongolian linguists have a similar view. Qing Geerhai believes that the consonant overall airflow is strong during the vocalization process, but there are still have differences inside [3]. Mr. Sun Zhu believes that the aspiration and non-aspiration of the Mongolian consonants are mainly reflected in the difference in the intensity of the airflow from the release obstruction section [4].

II. INSTRUMENTS AND METHODS OF RESEARCH

A. Pronunciation Partner and Material

The pronunciation partner is a man and a woman. Female speaker, 24 years old, Mongolian. Male speaker, 26 years old, Mongolian, both are from Wulanchabu City and master's degree in Mongolian Linguistics. The pronunciation material is three pairs of stop sounds in standard Mongolian [p] / [pʰ], [t] / [tʰ], [k] / [kʰ] and affricate [dz] / [ts], [dzʰ] / [tsʰ], [dz] / [ts], followed by vowels [a], [o], [u], each sample read twice, a total of 144 sounds.

B. Acquisition Equipment

American KAY company 6600 Phonatory Aerodynamic System. The hardware have a mask with dual handles, a pressure sensor, a gas flow test tube, a pressure test tube and a microphone. There is a set of software equipment matched with the hardware equipment, displaying pitch, sound pressure, air pressure and airflow signals through the form of waveforms.

III. AIR PRESSURE SIGNAL ANALYSIS

The study of phonetics based on the airflow pressure signal is mainly to study the changes of the airflow pressure corresponding to the human body when performing different pronunciation actions. Taking the female speaker's stop sound [p] / [pʰ] and squeaking [dz] / [ts] as examples, we analyze the pronunciation process and find out the correspondence between the pronunciation action and the change of the airflow pressure signal, and Consonant burst position and vowel start position.

A. Airflow Pressure Analysis of the Stop

Figure 1 shows the airflow and pressure signal of Mongolian stop sound. the place of air pressure begins indicates form obstructions. This is because when the vocal organs begin to form obstructions, the airflow gathers in the mouth to form a certain amount of air pressure. When the air pressure is maximum, the highest point of the air pressure...
peak indicates the burst position, because when the air pressure in the mouth reaches a maximum value, a large air pressure difference is formed inside and outside the mouth, and the stop sound starts to blast. The place where the airflow starts to be gentle after the highest peak of the airflow (line) indicates the position where the vowel starts. This is because the airflow does not become obstructed when the vowel is emitted, the airflow overflows completely, the air pressure cannot be formed in the oral cavity, and the airflow tends to smooth. After finding the position of the burst and the starting position of the vowel, it is not difficult to see that the highest peak of the air pressure to the beginning of the vowel is the consonant burst section.

In Fig. 1, to compare the distance from the start position of the vowel and highest peak of the air pressure of unaspirated and aspirated. The distance from the highest air pressure peak of the unaspirated sound to the start position of the vowel in the A1 and B1 lines is very short. This shows that burst duration of unaspirated sound is short, and the vowel is directly followed in a short time. In the A2 and B2 lines, the distance from the highest air pressure peak of aspirated sound to the start of the vowel is relatively long, which means that aspirated sound of Mongolian has a longer burst duration. The vowel connected after a long time.

**FIGURE I. (FEMALE) STOP SOUND [P] AND [PH] AIRFLOW PRESSURE (A IS THE SUPRAGLOTTIC AIRFLOW, B IS THE PRESSURE ON THE GLOTTIS)**

**FIGURE II. (FEMALE) AFFRICATE [ʣ] AND [ʦ] AIRFLOW PRESSURE (A IS THE SUPRAGLOTTIC AIRFLOW, B IS THE PRESSURE ON THE GLOTTIS)**

It can be seen from the lines A1 and B1 of Fig. 2 that the distance from the highest peak of the air pressure to the start position of the vowel is very short, which indicates that burst duration of non-aspirated affricate is short. In lines A2 and B2, the second line indicates the position at which the vowel starts after the affricate is burst completely. And it can be seen that there is a distance from the peak of the air pressure to the starting position of the vowel, which means that burst duration of non-aspirated affricate is long and the vowel is connected after long time.

IV. EXPERIMENTAL DATA ANALYSIS

In the analysis of the air flow and pressure signal, we extracted the airflow, the air pressure value, and the duration of the burst section of the consonant burst position of the male and female voices. The following conclusions were obtained.
A. Analysis of Airflow and Air Pressure Data Used in Stop and Affricate.

**TABLE I. AIRFLOW, AIR PRESSURE AND THEIR RESPECTIVE AVERAGE VALUES (FEMALE, MALE) USED IN STOP AND AFFRICATE BURST IN THE MONGOLIAN.**

| consonant | vowel | airflow | air pressure | airflow | air pressure |
|-----------|-------|---------|--------------|---------|--------------|
| p         | a     | 0.21    | 0.97         | 0.22    | 0.83         |
|           | ə     | 0.34    | 1.84         | 0.34    | 0.37         |
|           | u     | 0.41    | 1.90         | 0.11    | 0.48         |
| t         | a     | 0.04    | 0.14         | 0.64    | 0.68         |
|           | ə     | 0.28    | 1.70         | 0.64    | 0.60         |
|           | u     | 0.19    | 0.63         | 0.46    | 0.63         |
| k         | a     | 0.10    | 0.01         | 0.42    | 0.36         |
|           | ə     | 0.32    | 0.01         | 0.46    | 0.35         |
|           | u     | 0.20    | 0.27         | 0.18    | 0.44         |
|           | average | 0.23  | 0.83         | 0.39    | 0.56         |

| stop       | female |        |          | male    |        |
|------------|--------|--------|----------|---------|--------|
| p          |        | 0.86   | 0.34     | 1.39    | 0.54   |
|            | ə      | 1.87   | 0.65     | 1.05    | 0.48   |
|            | u      | 0.91   | 1.06     | 0.72    | 0.41   |
| t          |        | 0.79   | 0.51     | 1.60    | 0.30   |
|            | ə      | 1.56   | 0.71     | 1.53    | 0.90   |
|            | u      | 0.90   | 0.81     | 0.62    | 0.37   |
| k          |        | 1.35   | 0.17     | 2.14    | 0.47   |
|            | ə      | 1.20   | 0.19     | 1.94    | 0.57   |
|            | u      | 0.77   | 0.26     | 0.90    | 0.47   |
|           | average | 1.02  | 0.52     | 1.32    | 0.50   |

| affricate  | female |        |          | male    |        |
|------------|--------|--------|----------|---------|--------|
| dz         |        | 0.28   | 1.42     | 0.62    | 0.72   |
|            | ə      | 0.44   | 1.69     | 0.90    | 0.58   |
|            | u      | 0.29   | 1.20     | 1.01    | 0.53   |
| dẑ        |        | 0.31   | 2.98     | 0.85    | 0.11   |
|            | ə      | 0.44   | 2.80     | 0.67    | 0.09   |
|            | u      | 0.21   | 3.11     | 0.46    | 0.22   |
| dz̃        |        | 0.35   | 3.95     | 0.46    | 0.14   |
|            | ə      | 0.49   | 4.20     | 0.37    | 0.02   |
|            | u      | 0.25   | 2.16     | 0.34    | 0.29   |
|           | average | 0.34  | 2.61     | 0.63    | 0.3    |

| ts         |        | 0.91   | 1.01     | 0.86    | 0.82   |

|            | ə      | 1.31   | 1.68     | 0.82    | 0.52   |

**Note:** In order to ensure the relative accuracy of the data, the data in Table 1 is the average of the two passes, the air flow is in liters per second, and the air pressure is in cm mercury.

**TABLE II. AIRFLOW AND AIR PRESSURE (INTEGRAL AVERAGE) USED IN STOP AND AFFRICATE BURST IN THE MONGOLIAN.**

| non-aspirated | aspirated | non-aspirated | aspirated |
|---------------|-----------|---------------|-----------|
| stop          | airflow   | airflow       | airflow   |
|               | 0.31      | 1.17          | 0.48      | 1.02     |
| air pressure  | 0.68      | 0.51          | 1.45      | 1.21     |

In Table 1, the airflow and air pressure value are gained when non-aspirated/aspirated stop and affricate are connected the vowel sound [a], [u], and [ə] of the male and female speakers. Comparing the airflow and the air pressure value parameters, the comparison of the maximum airflow used in the Mongolian when the consonant is burst is: aspirated stop > aspirated affricate > non-aspirated affricate > non-aspirated stop. The contrast relationship between the maximum air pressure formed when the consonant is burst is: non-aspirated stop > aspirated stop, non-aspirated affricate > aspirated affricate. Moreover, the female speaker uses less airflow than the male in the process of the burst, and the formed air pressure is greater than that of the male.

In Table 2, the airflow and air pressure values used for the burst of the male and female are averaged. The air flow rate obtained by the non-aspirating/aspirating stop and the non-aspirating/aspirating affricate are 0.31 liter/sec, 1.17 liter/sec, 0.48 liter/sec, 1.02 liter/sec, respectively. This shows that in Mongolian, the air flow of aspirated is about 4 times that of non-aspirated stop, and the air flow of aspirated affricate is about 2.5 times that of non-aspirated affricate. The air pressure generated by the consonant burst is 0.69 cm Hg, 0.51 cm Hg, 1.45 cm Hg, and 1.21 cm Hg. And the magnitude relationship of the obtained air flow and air pressure is consistent with the results of Table 1.
### b. The Data Analysis of the Burst Duration of the Stop and Affricate

#### TABLE III. THE DURATION OF THE STOP AND THE AFFRICATE AND THE AVERAGE VALUE (FEMALE, MALE)

| consonant | vowel | male | female |
|-----------|-------|------|--------|
| p         | a     | 0.08 | 0.09   |
|           | ə     | 0.09 | 0.10   |
|           | u     | 0.10 | 0.10   |
| t         | a     | 0.08 | 0.08   |
|           | ə     | 0.10 | 0.15   |
|           | u     | 0.10 | 0.11   |
| k         | a     | 0.13 | 0.19   |
|           | ə     | 0.16 | 0.18   |
|           | u     | 0.13 | 0.14   |
| average   |       | 0.11 | 0.22   |
| pʰ        | a     | 0.64 | 0.69   |
|           | ə     | 0.67 | 0.72   |
|           | u     | 0.88 | 0.98   |
| tʰ        | a     | 0.62 | 0.72   |
|           | ə     | 1.01 | 1.12   |
|           | u     | 1.21 | 1.26   |
| kʰ        | a     | 0.98 | 1.20   |
|           | ə     | 0.72 | 0.83   |
|           | u     | 0.65 | 0.73   |
| average   |       | 0.82 | 0.92   |

#### TABLE IV. THE DURATION BURST OF THE STOP AND THE AFFRICATE SOUNDS (THE AVERAGE OF MEN AND WOMEN)

| consonant | non-aspirated stop | aspirated stop | non-aspirated affricate | aspirated affricate |
|-----------|--------------------|----------------|-------------------------|--------------------|
| duration  | 0.14               | 0.87           | 0.09                    | 1.26               |

Note: In order to ensure the relative accuracy of the data, the data in Table 1 is the average of the two passes, and the unit of duration burst is the second.

In Table 3, the burst duration and average are gained when non-aspirated/aspirated stop and affricate are connected the vowel sound [a], [u], and [ə]of the male and female speakers. After comparing and analyzing the data, it is concluded that the male and female are consistent in the distribution of the length of the burst: aspirated affricate>aspirated stop>non-aspirated stop>non-aspirated affricate, and the female is slightly shorter than the male.

In Table 4, the average length of the men's and women's burst duration is averaged, and the lengths of the non-aspirating/aspirating stop and affricate are 0.14 seconds, 0.87 seconds, 0.09 seconds, and 1.26 seconds, respectively. This shows that in Mongolian, the length of burst of aspirated is about 6 times that of the unaspirated. The unaspirated affricate has no consonant burst section, and aspirated affricate has the longest consonant burst section, about 1.5 times that of the aspirated stop. This is basically consistent with our conclusions in the analysis of airflow and air pressure signals.

### c. Relationship Between Airflow, Air Pressure and Duration of the Burst Section

Based on the above data, the airflow and air pressure values, as well as the length of burst, has a positive and negative proportional relationship in the Mongolian consonants. The airflow rate used for aspirated stop is about 4 times that of unaspirated stop, and the airflow used for aspirated affricate is about 2.5 times that of the unaspirated affricate. The air pressure formed by unaspirated affricate is larger than that of aspirated affricate. After the obstacle is removed, the length of the unblocking section of aspirated stop is about 6 times that of unaspirated stop, and the air pressure formed by unaspirated affricate is larger than that of aspirated affricate. After the obstacle is removed, the length of the unblocking section of aspirated stop is about 6 times that of unaspirated stop, the burst duration of unaspirated affricate is the shortest, and aspirated affricate has the longest consonant burst section, which is about 1.5 times that of unaspirated stop. At the same time, it can be obtained that in Mongolian, the airflow required for the consonant sound is proportional to the length of the burst section, and inversely proportional to air pressure. Generally, when the airflow required for sounding is increased, the length of burst section will increase accordingly, and the air pressure will decrease.
V. CONCLUSION

This paper analyzes the distinguishing characteristics of the consonant non-aspirating/aspirating in Mongolian from the perspective of air pressure and airflow, and obtains the distinguishing characteristics of the aspirating/non-aspirating characteristics in Mongolian. It is necessary to consider three factors, namely, the maximum airflow value that is emitted when the sound is emitted, the maximum pressure value formed by the consonant resistance, and the length of obstruction is removed. The changes of these three influence the judgment of the difference characteristics of consonant non-aspirate/aspiration. So why in Mongolian, the difference between aspiration and non-aspiration has always been considered to be only the strength of the airflow? This is because in the process of human auditory feedback, the listening is integral, the strong and short sounds sounds less, but not the strong and long sounds make people feel that it is louder. Therefore, because the noise part of aspirated sound is relatively long, people will think it is stronger. In addition to the difference in airflow and air pressure intensity, the lasting time of airflow also the main reason. For example, there is no difference in the meaning of aspiration or non-aspiration in the mother tongue. When the voice is sent, although it is already strong enough, it sounds very unnatural. This is because they did not send the consonants to a certain length and began to emit vowels. As Mr. Zhao Yuanren wrote in his early years to teach foreigners to learn to send aspirated, "they always send not enough air when they send aspirated" [4]. This is basically consistent with the conclusions we analyzed in the experiment.

ACKNOWLEDGEMENTS

Project supported by the National Social Science Fund (Grant No. 15CYY042) Business funds of Central Universities (Grant No. 31920170140) Supported by Program for Young Talent of SEAC.

REFERENCES

[1] Kong Jiangping, "Voice Multimodal Research and Diversified Phonetics Research", Chinese Journal of Speech [A], 2008 (1)
[2] Wu Zongji, Lin Maocan, "Summary of Experimental Phonetics" [M], Higher Education Press, 1987
[3] Qing Getai, "Mongolian Grammar" [M], Hohhot, Inner Mongolia People's Publishing House, 1992
[4] Sun Zhu, "Mongolian Language Collection" [A], Qinghai People's Publishing House, Xining, 1985
[5] Wu Zongji, "Wu Zongji's Collection of Linguistics" [A], The Commercial Press, Beijing, 2004