Contextual Vowel Nasalization in Mongolian

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***Abstract*—This paper investigates contextual vowel nasalization in Mongolian. Percentages of nasalization of each vowel in each context were measured using Kay Nasometer II 6400, and formants of nasalized vowels were analyzed with Praat. The highest nasalance score for vowels appeared with nasal contexts, followed by fricative, lateral, stop and affricate contexts. We found that high vowels are more easily nasalized compared to low vowels.**

Keywords—Mongolian vowels, nasalization, formants

I. Introduction

A vowel can be nasalized in certain contexts, i.e., followed or preceded by certain consonants. Nasalization is caused by the gesture of lowering the velum. When pronouncing nasalized vowels, the airflow resonates in both the nasal and the oral cavity, and resonance in nasal cavity and oral cavity are coupled [1]. This coupling or anti-resonance effect makes the nasalized vowels differ significantly in acoustic characteristics from oral sounds. Vowel nasalization has been reported to affected by several factors, such as vowel type [2] and gender [3]. High vowels are nasalized more easily than low vowels, and female speakers exhibit higher nasalance score than male speakers.

Nasalance scores depend on particular dialect [3], so we are going to focus on standard Mongolian based on Chakhar dialect (a dialect considered as standard Mongolian) in this paper. Studies on Mongolian nasalance are relatively immature. The previous studies on the nasal sounds in standard Mongolian are mainly based on the traditional phonological theory instead of acoustic phonetics. Nasometer developed in the past ten years, and it is used to measure nasal sounds in the process of speech production. It is widely used to diagnose speech disorders, measure the degree of cleft palate and extract various parameters for the physiological research [4][5]. Therefore, Nasometer is an ideal device to study nasal sounds.

Nasal sounds and oral sounds differ clearly in terms of phonology, but nasalization is a complex feature from a phonetic perspective. The aim of this study is to examine contextual vowel nasalization in Standard Mongolian. To be specific, this paper explores how consonant contexts affect vowel nasalization and then describes the acoustic feature of the nasalized vowels.

II. Method

A. Subjects

One male and one female speaker were enrolled in the study, both of whom are the hosts of the Inner Mongolia Radio and Television Station. Their ages were between 40 to 45 years and both had clear voice, no history of hearing impairment or voice disease.

B. Speech Material

The speech materials were chosen considering all the possible permutations of vowels and consonants. According to the characteristics of Mongolian speech, we chose CV (consonant+vowel) and VC (vowel+consonant) syllables to provide the same context conditions for all vowels for the analysis. The vowels are /ɐ, ə, i, ɔ, ʊ , o, u, ɛ, œ/; the consonants are /n, m, ŋ, p, pʰ, x, k, l, s, ʃ, t, tʰ, tʃ, tʃʰ, j, ɾ/. Each vowel and each consonant can be combined to form a syllable (except for /ŋ/, which only appears after a vowel), and 249 words or syllables are designed in this experiment. To make sure that the speakers are able to recognize and speak these words and syllables smoothly , we transcribed them in Latin, International Phonetic Alphabet and traditional Mongolian. The list includes some nonsense words.

C. Instrumentation and Procedures

The test words were recorded in a professional recording studio with quiet environment using a Kay Nasometer II 6400. The speaker wears the device with a divider between the mouth and the nose to record oral sound and nasal sound separately. The microphone mounted on the upper side of the divider records nasal sound, and the microphone on the lower side records oral sound. During the recording, the Audio streams are encoded to two channels.

D. Data Analysis and Statistics

The Nasometer automatically measures the energy of oral and nasal sounds and calculates the nasalization. Nasalance is the degree of nasalization during speech pronunciation. The formula for calculating the value of nasalance score (N) is:

$$N = 100\% \times n / (n + o) \qquad (1)$$

In (1), n is the nasal acoustic energy and o is the oral acoustic energy. Nasalance represents the proportion of nasal energy in the total acoustic energy. The calculated value is between 0-100%, and a higher value means a stronger nasalization. The overall nasalance curve is formed by a sample of nasalization data displayed in a two-dimensional graph with nasalance as the vertical axis (with a scale between 0-100%) and time as the horizontal axis. Fig. 1 is a nasalance curve example showing the degree of nasalance of "nɐn" (meaningless word).

In Fig. 1, the curve at the starting point is very high, then gradually declines to the bottom, and gradually rises back, which reflects the change of nasalance score from consonant

2021 International Conference on Asian Language Processing (IALP) | 978-1-6654-8311-7/21/$31.00 ©2021 IEEE | DOI: 10.1109/IALP54817.2021.9675254

/n/ with high nasal energy to vowel /ɐ/ with low nasal energy and then to /n/ with high nasal energy again.

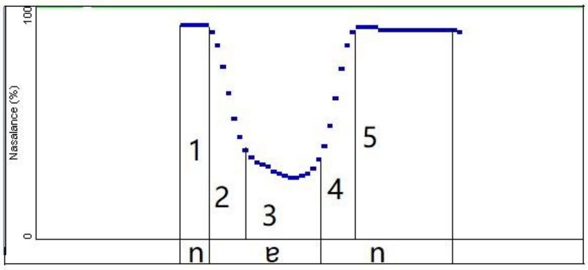

Fig. 1. Example of nasalance curve

We divide the syllable "nɐn" into five parts, "1" represents the syllable-initial nasal sound /n/; "2" and "3" for the vowel; "4" and "5" for the nasal sound /n/ at the end of the syllable. There is a transition "2" from the initial nasal sound /n/ to the vowel /ɐ/, and another transition "4" from the vowel /ɐ/ to the nasal sound /n/. Meanwhile, "3" indicates the stable part of the vowel; "5" indicates the stable part of the nasal. In natural speech, "1" and "5" may not appear as shown in Fig. 2. In this case, we call it nasal weakening.

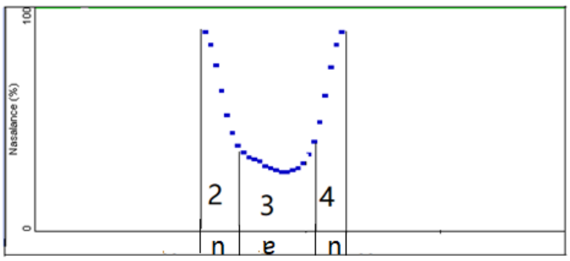

Fig. 2. Example of nasalance of nasal weakening curve

Nasalance score of vowels with different nasal contexts were compared using one-way analysis of variance (ANOVA), defining a p-value <0.05 as significant.

III. Results

A. Effect of Nasal Contexts

During the articulation of a vowel sound, the airflow mainly comes out of mouth, but a part of the airflow comes out of nostrils, which means a part of the nasalization comes with the vowels themselves.

There are 9 vowels in standard Mongolian, differentiated by position of tongue and roundness of lips. There are three nasal sounds /n, m, ŋ/ in Mongolian. We divide the analysis of nasalance of nasalized vowels into three groups: first, the nasalance of single vowels, represented as "V"; second, vowels before nasal consonants, represented as "VN"; third, vowels after nasal consonants, represented as "NV". Table 1 shows the vowel nasalance in nasal syllables, and the nasalance of the individual vowels.

One-way ANOVA was performed on the experimental data (see in Table 2). The results are as follows: first, among the five categories of "mV, nV, Vm, Vn, and Vŋ", there is a significant difference between the nasalance scores of vowels before nasals and after nasals ($p < 0.001$); second, after making a multiple testing, among the five categories "mV, nV, Vm, Vn and Vŋ", the result shows that the difference in vowel nasalance between "mV" and "nV" and between "Vm" and "Vn" is not obvious compared with other types.

TABLE I. Vowel Nasalance in Nasal Syllables (%)

	ɐ	*ɘ*	*i*	*ɔ*	*ʊ*	*o*	*u*	*ɛ*	*œ*
V	13	3	14	3	3	3	4	6	3
mV	28	20	52.5	13.5	17.5	11.5	28.5	19.5	10.5
nV	31.5	18.5	56.5	19.5	19	14.5	27	18	16.5
Vm	55.5	42	55	32.5	40.5	40.5	47	43	26.5
Vn	56.1	45.4	56.8	39.1	44.5	44.1	50.2	43.8	27.9
Vŋ	56.5	59.5	78.5	48.5	44	48	46	47	41

TABLE II. The Results of ANOVA

Multiple comparisons		
category	***type***	***significance***
mV	nV	0.913
	Vm	< 0.001
	Vn	< 0.001
	Vŋ	< 0.001
nV	Vm	< 0.001
	Vn	< 0.001
	Vŋ	< 0.001
Vm	Vn	0.346
	Vŋ	< 0.001
Vn	Vŋ	< 0.001
*. The significance level of the mean difference is 0.05.		

We can draw following conclusions from the nasalance data (see in Table 1) of vowels with different syllable types:

First, not all the airflow comes out of mouth during vowel articulation. In fact, a small part of the airflow comes out through the nasal cavity. Therefore, when articulating a single vowel, the vowel also has a nasalance value. The vowel /i/ has the highest value, followed by /ɐ/. Second, vowels following or preceding the nasal sounds /n, m, ŋ/ are affected by the nasal sounds with an increasing nasalance score. Meanwhile, the increasing tendency of nasalance is proportional to the nasalance value of a single vowel. The vowel /i/ has the mostly increased nasalance score, indicating that the high vowel /i/ is most easily nasalized. When preceded by a nasal, the nasalance scores of the vowels are ordered as: /i/>/ɐ/>/u/>/ɘ/. Third, with the influence of nasal sounds, tongue position is an important factor to the vowel nasalization. That's to say, higher vowels are more easily nasalized than the lower ones. Fourth, there's no obvious difference between the nasalance scores of vowels following /n/ and /m/. Fifth, the nasalance score of vowels preceding the nasal sound /-ŋ/ is significantly higher than the nasalance score of vowels preceding /-n/ and /-m/. Sixth, the nasalance scores are significantly higher when preceding nasals than following them.

B. Effect of Non-nasal Contexts

We divided the non-nasal consonants into stops, fricatives, affricates and laterals, and then extracted the nasalance scores of vowels when combined with different consonants to investigate the effect of non-nasal consonants on vowel nasalization.

1) Effect of Stop Contexts on Vowel Nasalization

The data of the nasalance scores of vowels preceded by stops /p, pʰ, tʰ,t, k/ are shown in Table 3.

TABLE III. VOWEL NASALANCE IN STOP SYLLABLES (%)

	ɘ	i	ɔ	ʊ	o	u	ɛ	æ
p	3	7.5	3	3	2.5	4	3.5	3
pʰ	3	6.5	4	2.5	2.5	3.5	4.5	5
k	3	6	4	3	3	3.5	4	3
tʰ	3.5	5.5	3.5	2.5	2.5	3.5	7.5	5
t	4	6	5	3	3	3.5	8	5
Average	3.3	6.3	3.9	2.8	2.7	3.6	5.5	4.2

It can be seen from Table 3 that the nasalance scores of vowels /ɐ/ and /i/ are relatively high; for the nasalance score of /ɐ/, stops with further back place of articulation induces higher nasalance; the nasalance scores of vowels following the stops range from 2.5% to 8%; the effect of the stops on the vowel nasalization is generally small.

2) Effect of Fricative Contexts on Vowel Nasalization

The data of the nasalance scores of vowel with fricatives /x, s, ʃ/ contexts are shown in Table 4.

TABLE IV. VOWEL NASALANCE IN FRICATIVE SYLLABLES (%)

	ɐ	ɘ	i	ɔ	ʊ	o	u	ɛ	æ
x	17.5	5.5	7	3.5	3	3	3.5	9.5	6
s	15.5	4	5	2.5	3	3	3.5	8	6
ʃ	11.5	3.5	5.5	4.5	3	3	3.5	4.5	3.5
Average	14.8	4.3	5.8	3.5	3	3	3.5	7.3	5.2

It can be seen from Table 4 that the nasalance scores of vowels /ɐ, ɛ/ are relatively higher; fricatives have a great influence on the following vowels especially on front vowels, and the scores range from 3% to 17.5%; meanwhile, the effect of the soft palate consonants /x/ on vowel nasalization is greater than other fricatives.

3) Effect of Affricate Contexts on Vowel Nasalization

The data of the nasalance scores of vowels preceded by affricates /tʃʰ, tʃ/ contexts are shown in Table 5.

TABLE V. VOWEL NASALANCE IN AFFRICATIVE SYLLABLES (%)

	ɐ	ɘ	i	ɔ	ʊ	o	u	ɛ	æ
tʃʰ	6	3	5	3.5	2.5	3	3.5	4	3
tʃ	11	3.5	6	3.5	3	3	3.5	3.5	3
Average	8.5	3.3	5.5	3.5	2.8	3	3.5	3.8	3

What can be inferred from Table 5 is that /ɐ, i/ have relatively low nasalance scores; the nasalance scores of vowels with the non-aspirated affricate context are higher than those with aspirated context. The overall scores range from 2.5% to 11%.

4) Effect of Approximants on Vowel nasalization

The data of the nasalance scores of the vowels following /l, ɾ, j, w/ are shown in Table 6. It can be inferred from Table 6 that the nasalance scores of vowels /ɐ/ and /i/ are relatively high; the overall nasalance scores of vowels preceded by approximants are low, ranging from 2% to 12%. Approximants lower the nasalance scores of single vowels.

TABLE VI. VOWEL NASALANCE IN LATERAL SYLLABLES (%)

	ɐ	ɘ	i	ɔ	ʊ	o	u	ɛ	æ
l	14	4.5	7	5	3	2.5	4.5	7	5.5
ɾ	11.5	3	5.5	5	3	2.5	4.5	5.5	3.5
j	10.5	3.5	8	3.5	3	3	3.5	5.5	3
w	11.5	4	4	6	3	3.5	5.5	6	5
Average	11.9	3.8	6.1	4.9	3	2.9	4.5	6	4.3

Therefore, the influence of non-nasal consonants on vowels (from largest to smallest) is ranked as: fricative > approximant > stop > affricate.

Above all, the average nasalance scores of the vowels following the stops, fricatives, affricates and approximants show that, compared with the single vowel, consonants lower the nasalance score of vowels except for the vowel /ɐ/ preceded by fricatives and approximants. Among them, the vowels preceded by fricative have the highest nasalance scores, and the second highest are the vowels with stop contexts, the vowels with affricates contexts have the lowest scores. Overall, the nasalance scores of the vowels with consonant contexts are relatively low, ranging from 2% to 15%. Moreover, aspiration sound tends to reduce the nasalance of the vowel.

IV. VOWEL NASALANCE AND TONGUE POSITION

Some vowels tend to be nasalized easily, and some don't. This is due to the different tongue position of each vowel, which is investigated through the data of the nasalance scores and tongue positions of the vowels. Fig. 3 shows the nasalance scores of vowels with nasal /m, n/ contexts, and Fig. 4 is the acoustic space area of the standard Mongolian vowels [6].

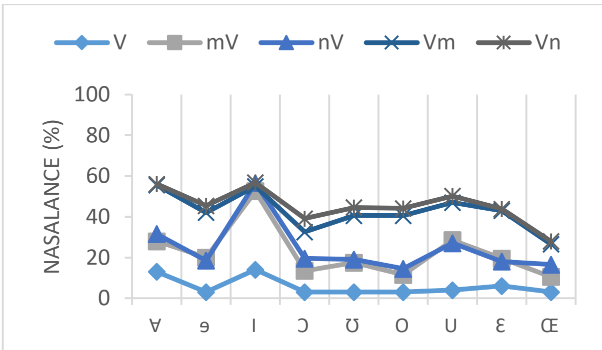

Fig. 3. Nasalance of the vowels with nasals /n,m/ as contexts (%)

It can be seen from Fig. 3 that the nasalance values of vowels preceded by nasal sound are greater than the ones followed by nasal sound. That is, the effect of the nasal endings are greater than that of initial nasals. When influenced by nasals, the nasalance scores of /i, ɐ, u/ are relatively larger than the other vowels.

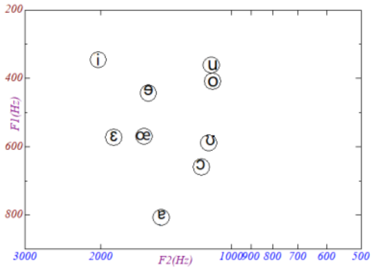

Fig. 4. Vowel acoustic space area of Mongolian

The relationship between Mongolian vowel nasalance and tongue position is summarized as follows: first, the high vowels /i, u/ and low vowel /ɐ/ have a greater degree of nasalization. There is significant difference between the degree of dropping of soft palate between high and low vowels, but no significant difference between high vowels [7].

When pronouncing high vowels, both uvula and velum dropped greatly, making the area of the posterior chamber larger, so much more airflow goes through the nasal cavity leading to a higher nasalance. As for the low vowels, the height of the velum is lower than that of the high vowels, so low vowels themselves have high degree of nasalance. Therefore, the height of tongue is the important factor to the vowel nasalance instead of the frontness of tongue.

V. Nasalized Vowel Formants

The coupling introduces several zeros and supplementary peaks in the speech spectra [1]. which are represented in the sound spectrogram as three formants: the oral formant, nasal-formants, and anti-formants. In addition, sounds with a strong nasalization will cause a large decline of energy above the first formant. It's difficult to accurately represent the oral formant and the nasal formant and calculate the zero parameters.

The formants data of the vowels preceded by /n, m/ and followed by /ŋ/ are shown in Table 7

TABLE VII. The Formants of the Vowels Following Nasals

	n-		m-		-ŋ	
	F1	F2	F1	F2	F1	F2
ɐ	643	1022	684	1024	662	1015
ɘ	534	662	527	732	497	633
i	377	925	385	1035	392	968
ɔ	663	869	692	909	655	895
ʊ	538	782	513	737	503	766
o	511	768	534	839	500	807
u	438	724	414	635	429	566
ɛ	667	838	625	811	635	877
œ	591	753	595	738	527	751

We analyzed the formant frequencies of vowels with the initial nasal sounds /n, m/ and ending /ŋ/. By comparing the data of F1 and F2, it can be seen that there's a decline in the vowels of F1 and F2 following the nasal sounds, especially the front and central vowels have a larger declined amplitude. And F2 of all vowels does not exceed 1100 Hz. This is the energy attenuation after the nasalization of vowel, which is affected by the nasal sounds. Energy attenuation of the vowel formants is an important acoustic parameter of vowel nasalization.

There's no consistency in energy attenuation of the vowels with different nasal contexts, especially the vowel /i, ɐ, u /with high nasalization. In the dimension of height of tongue position, high vowels lower the tongue position and the low vowels move up the position; in the dimension of frontness of tongue, all the vowels move backwards.

The spectrograms of CV and VC syllables consist of vowels /ɐ, ɘ, i, ɔ, ʊ, o, u, ɛ, œ/ with nasals /n-, m-, -ŋ/ contexts and stop /p/ contexts are shown in Fig. 5, Fig. 6, Fig. 7, and Fig. 8.

It can be seen from the figures that the vowel formants followed by stop sound are smooth, and the energy of the first three formants F1, F2 and F3 are strong. However, the vowel formants followed by the nasal sounds /n, m, ŋ/ are not smooth, especially those above F2 have particularly weak energy.

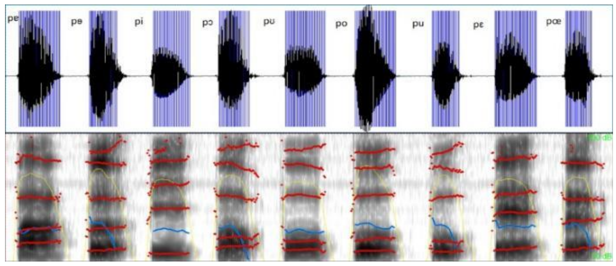

Fig. 5. Stop /p/ preceding vowels

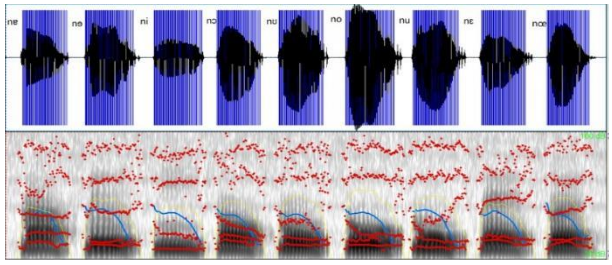

Fig. 6. Nasal /n/ preceding vowels

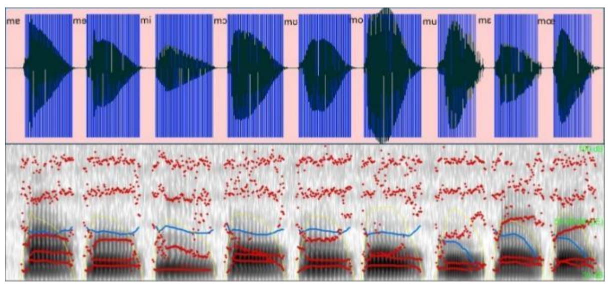

Fig. 7. Nasal /m/ preceding vowels

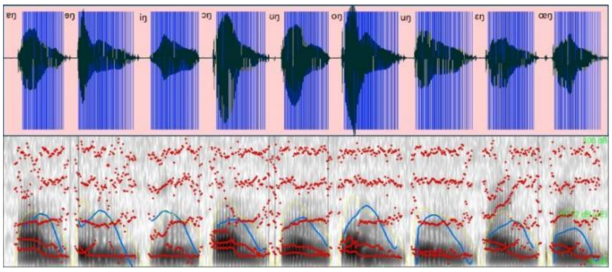

Fig. 8. Nasal /ŋ/ following vowels

VI. Conclusions

The purpose of this paper is to analyze the vowel nasalance of standard Mongolian from the experimental point of view using Kay Nasometer II 6400 and Praat, including discussion on the acoustic characteristics of vowel nasalization, the parameters of vowel nasalance, the relationship between vowel nasalization and tongue position, and the formant analysis of the nasalized vowels.

The conclusions are as follows: first, the high vowels /i/ and the low vowel /ɐ/ have higher nasalance scores than other vowels; second, the high vowels are nasalized easily; third, the height of tongue is closely related to the degree of vowel nasalization; fourth, the influence of nasal sounds on the nasalance of vowels is ranked as (from high to low): ŋ > n > m; fifth, the influence of non-nasal consonants on the nasalance of vowels is ranked as: fricative > lateral > stop > affricative; sixth, the formants of nasalized vowels are neither smooth nor stable with a weaker energy of F2 and F3. Compared to pure vowels, F1 of the nasalized high vowel declines, and F1 of the nasalized low vowel increases.

The result of this paper is based on the corpus of two speakers. In the future study, much more corpus should be collected to get the normative nasalance scores for Mongolian.

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