Some Acoustic Observations on the Distinction of Place of Articulation for Voiceless Nasals in Burmese

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ABSTRACT

Burmese has voiced-voiceless contrast of nasal sounds. The opposition between voiced and voiceless nasals stands in parallel with the one between aspirated and unaspirated consonants in regard to some grammatical function. The verb with a voiceless nasal initial is the "transitive," "active" or "causative" correlate of the verb with an ordinary voiced nasal initial. The present study describes the acoustic nature of voiceless nasals in Burmese based on the analysis of waveforms by a minicomputer using a linear prediction algorithm (LPC), and the discrimination of place of articulation by statistical study. Voiceless nasals consist of voiceless nasal friction portions and voiced nasal murmur portions. The intensity of the former is extremely weak and we could not find a significant difference according to the point of articulation. Therefore, we analyzed the voiced murmur portion of voiceless nasals and tried to find significant cues which can distinguish the point of articulation. As a result, we have been able to distinguish bilabial nasals, alveolar nasals and velar nasals by means of step-wise discriminant analysis of the values of nasal formant frequencies N1, N2 and N3, and bandwidths B1, B2 and B3. These results support the interpretation that voiced murmur portions of voiceless nasals in Burmese include significant cues which can distinguish points of articulation.

1. INTRODUCTION

It is not very rarely that languages in the world have voiced — voiceless contrast of nasal sounds. It is known that Burmese is one of such languages and the opposition between voiced and voiceless nasals stands in a parallel position with the one between aspirated and unaspirated consonants in regard to some grammatical function. We have formerly analyzed voiceless nasals in Burmese by making use of the sound spectrograph (Dantsuji, 1984), and confirmed that voiceless nasals in Burmese consist of voiceless portions and voiced portions. Figure 1–a and b show the waveform of voiceless nasal /ma/ in the linear scale (a) and in the sone scale (b). We

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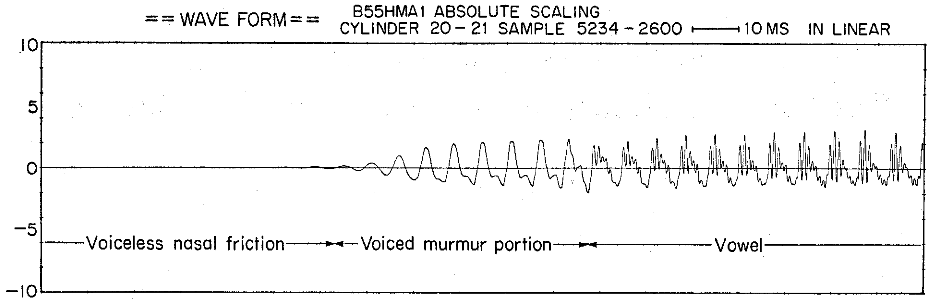

Figure 1-a.

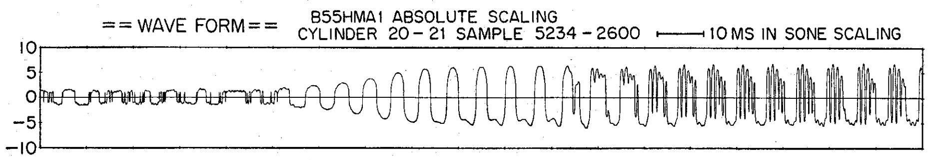

Figure 1-b.

Figure 1. The wave form of voiceless nasal in the linear scale (a) and in the sone scale (b). [m̥ma 4͡42]

find extremely low energy of the voiceless portion from the linear scale. When we transform it into the sone scale, we can find the hiss of the turbulence — narial turbulence in this portion. This means that this portion is a kind of nasal friction. However, we could not find significant cues available for the distinction of places of articulation by spectrum analysis of the voiceless nasal friction portion. Duration analysis suggests that there is a tendency for the duration of voiceless nasal friction portions of the alveolar voiceless nasals to be slightly shorter than that of the bilabial and velar voiceless nasals. This is, however, not statistically significant in a strict sense. In this respect, Ladefoged (1971) pointed out that "voicing began shortly before the closure was released and these sounds should be called partially voiced as opposed to fully voiced." Our data show that the voiced portion forms the latter 25~29% of voiceless nasals and it is quite shorter than that of murmur portions of ordinary voiced nasals in Burmese ($p<0.01$).

From the spectrum analysis of voiceless nasal friction portions of voiceless nasals, we have been able to find spectrum peaks around 0.5, 3 and 6 kHz but these are not significant for distinction of places of articulation. In this respect, Ohala (1975) pointed out that "the noise spectra of all voiceless nasals will be alike and will be perceptually undifferentiable. The voiced portions of the voiceless nasals may be necessary to maintain an audible difference between them." Therefore, we decided to try to find acoustic features in regard to the distinction of places of articulation by analyzing the voiced murmur portions of voiceless nasals in Burmese. The voiced portion of voiceless nasals is sub-segmented into the *onset*, *murmur* and *transition* (to the following vowel) portions. Hitherto, it has been said that the formant transition portion to the next vowel has the strongest cues in regard to the discrimination of places of articulation in the studies of ordinary voiced nasals in Japanese, English and some other languages. However, the murmur portion has also attracted attention recently (Recasens, 1983; Kurowski and Blumstein, 1984; Kitazawa and Doshita, 1984, etc.). It is considered that the voiced murmur portion includes information on both manner of articulation and place of articulation. The murmur portion has a longer duration, is more stable, and is less influenced by the following vowels than is the transition portion. From a preliminary experiment, it was found that the voiced murmur portion had useful cues for the perception of the place of articulation. Therefore, we decided to examine the voiced murmur portion of voiceless nasals in Burmese. Our main purpose is to see if we can find useful cues for distinguishing places of articulation, and ascribe them to some linguistically significant features.

2. EXPERIMENT

2–1. Informants and Materials

Informants were three adult male native speakers of standard Burmese. They came to Japan as research students on Japanese government scholarships and were at Osaka University of Foreign Studies for six months for Japanese language training. Recordings were made at the phonetic studio in Osaka University of Foreign Studies four months after they had arrived in Japan.

Informant A adult male (from Kyauk Pan Daung, 35 years.)
Informant B adult male (from Rangoon, 34 years.)
Informant C adult male (from Magwe, 35 years.)

Materials were mono-open syllables and included voiceless nasals at the word-initial position. The vowel following to the voiceless nasal is [–a]. In order to examine the influence of tones, three tones which occur in open syllables, i.e. the first tone (low plane [22]—[23]), the second tone (high plane [4$\widehat{42}$]) and the third tone (high falling [$\widehat{41}$]) were prepared[1]. For example,

hma	[m̥ma22]	([m̥ma23])	"in, at"
hma^2	[m̥ma4$\widehat{42}$]		"to miss"
hma^3	[m̥ma$\widehat{41}$]		"from"

Three different places of articulation were examined, i.e. bilabials, alveolars and velars. Each token was repeated six times. Therefore, 162 tokens in all (3 places of articulation × 3 tones × 6 times × 3 informants) were analyzed. The materials were written in Burmese script and presented to the informants.

2–2. Procedures

Analyses were made at Doshita Laboratory, Department of Information Science of Kyoto University. Speech waveforms were digitized from the output of the tape

1) There are several descriptions on tone systems in Burmese. We followed the system in Nishida (1972).

recorder. A JEIC 3118 low-pass filter with 70 dB/oct for anti-aliasing (the cut-off frequency was set to 8.9 kHz) and a DATEL DAS-250 16-channel 12-bit A/D converter of 4-microsecond sampling period were used for digitization. Through the A/D converter which was connected to a FACOM U-200 minicomputer at the common bus with direct access mode, speech data samples at every 54 microsecond (18.5 kHz sampling) were stored into a cartridge-disc of 2-megabyte in real-time for about 1 minutes continuously. Individual utterances were input from a digital magnetic tape to a minicomputer and the waveforms were drawn on an X-Y plotter. From the 3500 samples of data (190 msec), waveforms including murmur portions were sampled manually using a cursor. Each murmur portion was excised with four consecutive 27 msec Hamming windows for fast Fourier transform (FFT), and linear prediction analysis was applied to obtain a smoothed spectrum. The optimal prediction order was estimated in a preliminary experiment to be 26. These spectra were analyzed and displayed on the plotter. Formants corresponding to spectral peaks were computed from the solution of higher order polynomial equation by the Muller method. We adopted the lowest three prominent peaks of murmur spectra as the first nasal formant (N1), the second nasal formant (N2) and the third nasal formant (N3).

We examined whether these nasal formants and bandwidths were available for discrimination of articulation places of voiceless nasals. We also analyzed anti-formants by FFT. There are two main factors for anti-formants. One is owing to the nasalization and the other is owing to the voicing. However, it was difficult to differentiate anti-formants due to nasals from those due to voicing and therefore we did not make use of this cue in this work.

3. RESULTS AND DISCUSSION

It was difficult to distinguish places of articulation directly from waveform. Therefore, we examined the relationship between acoustic properties of voiced murmur portions of voiceless nasals and places of articulation by making use of values of nasal formants (Ns) and their bandwidths (Bs). The mean values and standard deviations (S.D.s) of nasal formants and band-widths of voiceless nasals of three informants in Burmese are shown in Table 1. Fujimura (1962), Recasens (1984), etc. state the properties of murmur of nasals as follows (>=higher frequency than):

N1 frequency values: [ŋ] > [ɲ] > [n] > [m]
N1 bandwidth values: [ŋ] > [ɲ], [n], [m]

"The differences in N1 values are presumably related to differences in the size of the coupling section at the velopharyngeal passage and of the pharyngonasal tract" (Recasens, 1983). Although these are characteristics of ordinary voiced nasals, our results of voiceless nasals also show the same tendency. The mean values of first nasal formant (N1) of bilabial voiceless nasals are 234, 214 and 231 Hz for informants A, B and C, respectively. Those of alveolar voiceless nasals are 307,

Table 1. Analysis frequency values (in Hz) for the murmur portion of voiceless nasals in Burmese (means and standard deviations).

Informant A	Bilabial /m̥/ Mean (S.D.)	Alveolar /n̥/ Mean (S.D.)	Velar /ŋ̊/ Mean (S.D.)
N1	234 (16)	307 (29)	298 (19)
N2	1060 (40)	1589 (137)	939 (81)
N3	2636 (105)	2556 (208)	2626 (169)
B1	74 (19)	98 (20)	130 (17)
B2	129 (53)	382 (165)	290 (134)
B3	195 (36)	252 (89)	234 (85)

Informant B	Bilabial /m̥/ Mean (S.D.)	Alveolar /n̥/ Mean (S.D.)	Velar /ŋ̊/ Mean (S.D.)
N1	214 (44)	225 (40)	274 (141)
N2	1142 (46)	1656 (90)	1109 (108)
N3	2536 (129)	2549 (206)	3027 (49)
B1	231 (110)	254 (99)	422 (104)
B2	171 (49)	284 (197)	380 (146)
B3	232 (95)	188 (88)	109 (51)

Informant C	Bilabial /m̥/ Mean (S.D.)	Alveolar /n̥/ Mean (S.D.)	Velar /ŋ̊/ Mean (S.D.)
N1	231 (37)	237 (53)	300 (89)
N2	1114 (37)	1463 (114)	1256 (84)
N3	2508 (74)	2544 (146)	2419 (55)
B1	271 (139)	258 (109)	313 (129)
B2	254 (54)	245 (115)	425 (153)
B3	247 (94)	301 (202)	330 (135)

225 and 237 Hz and those of velar voiceless nasals are 298, 274 and 300 Hz for informants A, B and C, respectively. It can be said that there is a tendency for N1 of bilabial voiceless nasals to be slightly lower than those of alveolar and velar voiceless nasals. In a strict sense, /m̥/</ŋ̊/ is statistically significant for informants A and C ($P<0.01$) but is not statistically significant for informant B ($p<0.1$). In this respect, /m̥/</n̥/ is significant for only informant A ($p<0.01$), and /n̥/</ŋ̊/ is significant only for informant C ($p<0.05$). Others are not statistically significant.

The mean values of the second nasal formant (N2) of alveolar voiceless nasals are 1589, 1656 and 1463 Hz for informants A, B and C, respectively. Those of bilabial voiceless nasals are 1060, 1142 and 1114 Hz, and those of velar voiceless nasals are 939, 1109 and 1256 Hz for informants A, B and C, respectively. As to N2, /n̥/>/m̥/, /ŋ̊/ is statistically significant ($p<0.01$) for all the informants. In this respect, when we search closely for spectrum peaks, we sometimes can find additional weaker peaks around 1500 Hz for bilabial and velar voiceless nasals and around 1000 Hz for alveolar voiceless nasals. However, these peaks are far weaker and unstable in comparison with adjacent peaks. Therefore, we did not adopt them as nasal formants.

In Chomsky and Halle (1968), distinctive features were described based on an articulatory point of view. On the other hand, in Jakobson, Fant and Halle (1952), distinctive features were also defined by acoustic aspects. In their framework, velar nasals have a "compact" feature and when the first formant "is higher (i.e. closer to the third and higher formants), the phoneme is more compact" (Jakobson et al., 1952). Although this refers to the case of the vowels, there exists a parallel between the compactness feature in vowels and consonants (Delattre, 1951; Jakobson et al., 1952). Alveolar nasals have an "acute" feature, and when the second formant "is closer to the third and higher formants it is acute." Therefore, we tried to distinguish alveolar voiceless nasals by means of the higher frequencies of second formants and separate velar voiceless nasals from bilabial voiceless nasals by means of their higher frequencies of first formants. We made a discriminant analysis[2) using the values of N1 and N2 as variables. Results are shown in Table 2–a.

Table 2-a. Classification matrix (Variables: N1, N2)

Informant A				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	18	0	0	100%
/n̥/	0	18	0	100%
/ŋ̊/	0	0	18	100%
TOTAL	18	18	18	100%
Informant B				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	15	0	3	83%
/n̥/	0	18	0	100%
/ŋ̊/	8	0	10	56%
TOTAL	23	18	13	80%
Informant C				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	18	0	0	100%
/n̥/	0	17	1	94%
/ŋ̊/	4	3	11	61%
TOTAL	22	20	12	85%

Table 2-b.

Informant B (Variables: (N3–N1), N2)				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	16	0	2	89%
/n̥/	0	18	0	100%
/ŋ̊/	1	0	17	94%
TOTAL	17	18	19	94%

2) "BMDP7M Stepwise Discriminant Analysis" on a HITAC 240 system was used for these analyses.

Table 2–a represents classification matrices of the group classifications and the percent of correct classifications of discrimination analysis. The left column represents source, and the uppermost row represents judged groups after analysis. The total percent of correct classifications are 100% for informant A, 80% for informant B and 85% for informant C. These results show tolerably high performance. However, the score is not so good for informant B, especially in the case of velar voiceless nasals. Therefore, we made use of the difference between third and first formants instead of first formants for informant B, according to the alternative acoustic description of feature "compact". Results are shown in Table 2–b. The percent of correct classification in total is 94% and that of velar voiceless nasals is also 94%. In this way we can obtain considerably better results than with the previous treatment for informant B.

In order to obtain better resolution, all the first, second and third formants and their bandwidths were used as variables for the step-wise discrimination analysis. Results are shown in Table 3 and Fig. 2. The percent of correct classification in total for informants A, B and C are 100, 100 and 98%, respectively. From the statistical points of view, only the first three formants are necessary information for informant A to obtain the 100% score. Fig. 2–a, b and c show the group means and distribution of all cases. The axes are the first two canonical variables. The individual representations of /m̥/, /n̥/ and /ŋ̊/ are indicated by the letters, M, N and G,

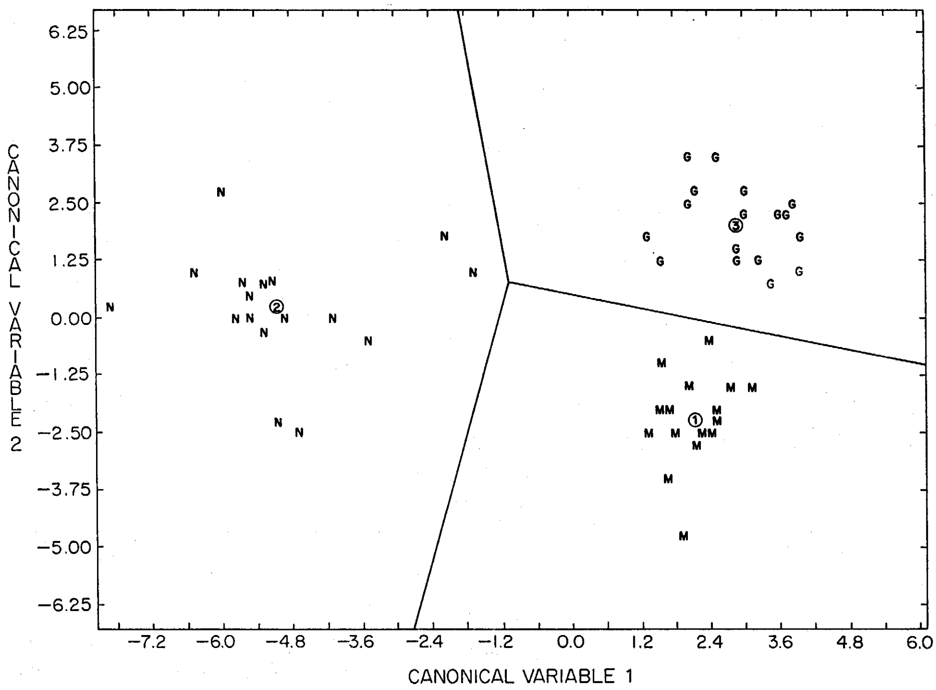

Figure 2-a.

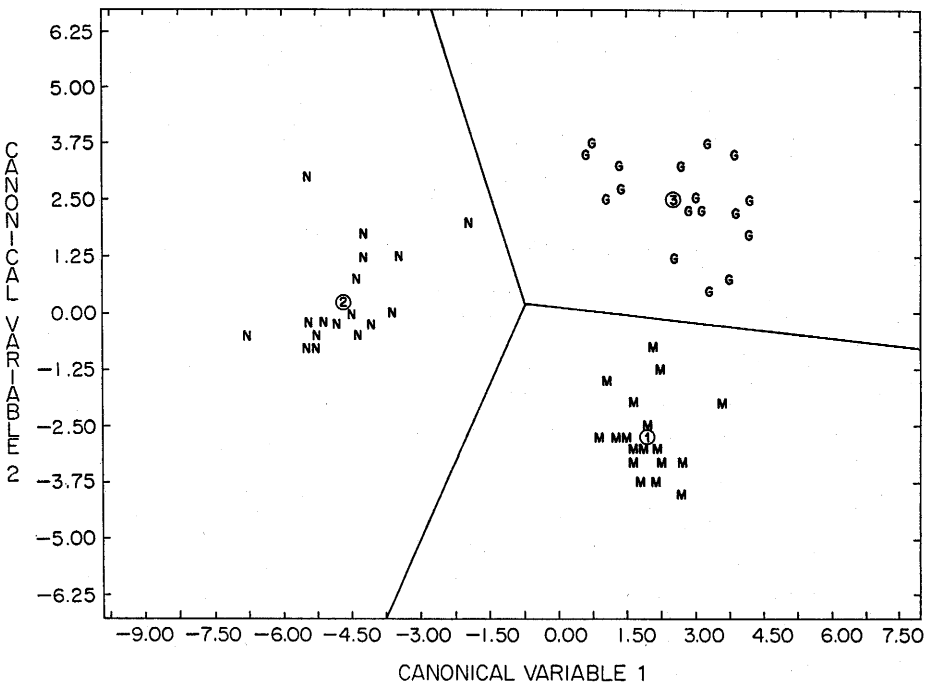

Figure 2-b.

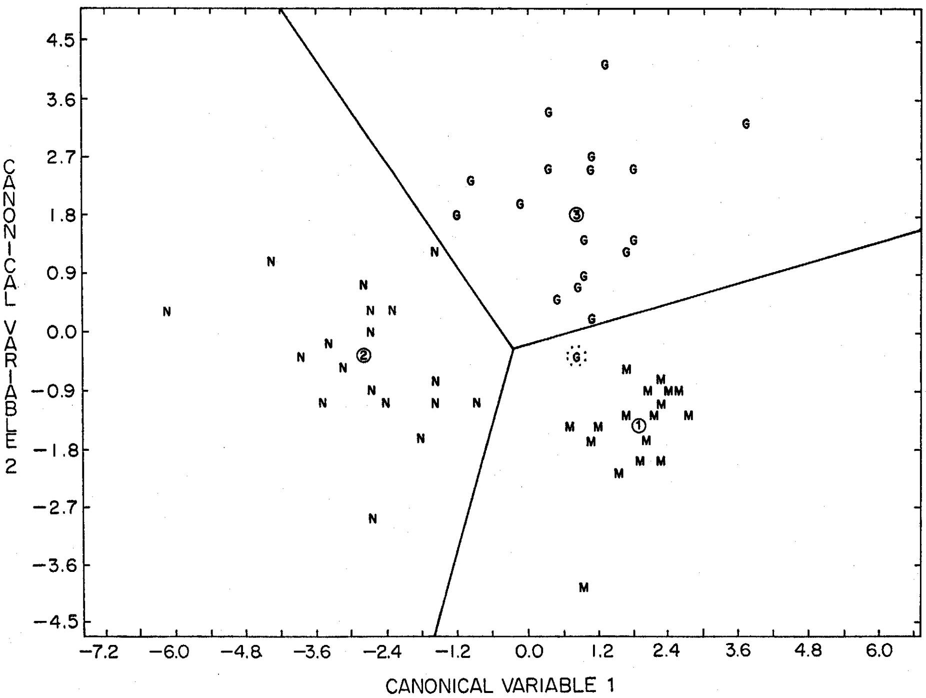

Figure 2-c.

Figure 2. Results of the discriminant analysis using N1, N2, N3, B1, B2 and B3 as variables. The axes are the first two canonical variables. The individual representations of bilabial, alveolar and velar voiceless nasals are indicated by the letters, M, N and G, respectively. The mean values of each group are marked by the figures, 1, 2, and 3.

Table 3. Classification matrix (Variables: N1, N2, N3, B1, B2, B3)

Informant A				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	18	0	0	100%
/n̥/	0	18	0	100%
/ŋ̊/	0	0	18	100%
TOTAL	18	18	18	100%
Informant B				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	18	0	0	100%
/n̥/	0	18	0	100%
/ŋ̊/	0	0	18	100%
TOTAL	18	18	18	100%
Informant C				
	/m̥/	/n̥/	/ŋ̊/	
/m̥/	18	0	0	100%
/n̥/	0	18	0	100%
/ŋ̊/	1	0	17	94%
TOTAL	19	18	17	98%

respectively and the mean values of each group are marked by the figures, 1, 2 and 3. The three solid lines indicate perpendicular bisectors of mean values of the distribution of each group—bilabial, alveolar and velar voiceless nasals. Fig. 2–a and b indicate that the distribution of each point of articulation is differentiated clearly by these three lines for informants A and B. We can find only one token that is classified incorrectly in Fig. 1–c. The misclassified token is circled by the dotted line. Fig. 1–c shows that the case classified incorrectly does not enter deep into the group but falls near the border line. These results show that each group of the place of articulation is effectively discriminated. With regard to the difference of tones, only one token for informant C resulted in the incorrect classification. For other tokens, we have been able to obtain correct classifications in spite of differences in tone. Therefore, it is plausible to say that the discrimination of places of articulation is seldom influenced by the difference of tones.

From these results, it is plausible to say that the murmur portion of voiceless nasals in Burmese includes the necessary information for discrimination of place of articulation, and these cues are stable and hardly influenced by differences of tone.

4. Summary and Conclusions

So far as our informants are concerned, the properties that can distinguish the place of articulation of voiceless nasals in Burmese have been clarified as follows. Voiceless nasals consist of voiceless nasal friction portions and voiced portions. The voiced portion is sub-segmented into the onset, murmur and transition portions. Bilabial voiceless nasals, alveolar voiceless nasals and velar voiceless nasals could be distinguished by means of a step-wise discriminant analysis utilizing the value of nasal formant frequencies N1, N2 and N3 and bandwidths B1, B2 and B3 of the murmur portion. The difference in tone seldom affected the result of distinction of the place of articulation. We also obtained good results using only the information of N1 and N2, or (N3–N1) and N2 in connection with features "compact" and "acute". From these results, it is confirmed that the murmur portion of voiceless nasals in Burmese includes acoustic cues which can distinguish the place of articulation.

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REFERENCES

Armstrong, L. E. and Pe Maung Tin (1925), *A Burmese Phonetic Reader*. University of London Press, London.

Bush, C. N. (1964), *Phonetic Variation and Acoustic Distinctive Features*. Mouton & Co, The Hague.

Catford, J. C. (1977), *Fundamental Problems in Phonetics*. Edinburgh University Press, Edinburgh.

Chomsky, N. and Halle, M. (1968), *The Sound Pattern of English*. Harper & Row, New York.

Cornyn, W. (1944), "Outline of Burmese Grammar," *Language*, Vol. 20, No. 4, Supplement.

Crothers, J. (1975), "Nasal Consonant Systems," in C. A. Ferguson, L. M. Hyman, and J. J. Hyman (eds.), *Nasalfest*. Stanford University, Stanford, 153–166.

Dantsuji, M. (1982), "An Acoustic Study on Glottalized Vowels in the Yi (Lolo) Language—A Preliminary Report—," *Studia Phonologica*, XVI, 1–11.

——— (1984), "A Study on Voiceless Nasals in Burmese," *Studia Phonologica*, XVIII, 1–14.

——— (1985), "Bion Forumanto ni yoru Biruma-go Musei-bion no Choonten no Benbetsu ni tsuite," (Discrimination of Articulation Points of Voiceless Nasals in Burmese, by Means of Nasal Formants) *Onsei-Gengo*, I, 62–74. (in Japanese).

——— "An Acoustic Study on the Distinction of Place of Articulation for Voiceless Nasals in Burmese," *Folia Linguistica*, XXI (forthcoming).

Fant, G. (1973), *Speech Sounds and Features*. M. I. T. Press, Cambridge, Mass.

Ferguson, C. A. (1963), "Assumptions about Nasals: A Sample Study in Phonological Universals," in J. H. Greenberg (ed.), *Universals of Language*. M.I.T. Press, Cambridge, Mass, 53–60.

Fujimura, O. (1962), "Analysis of Nasal Consonants," *J. Acoust. Soc. Am.*, Vol. 34, 1865–1875.

Jakobson, R., G. Fant and M. Halle (1952), "Preliminaries to Speech analysis," *Technical Report 13*. Acoustic Laboratory MIT.

Kitazawa, S. and Doshita, S. (1984), "Invariant and Variant Features of Nasal Consonants Observed in CV Syllables," *Transactions of the Committee on Speech Research*, The Acoustical Society of Japan, S84–7s, 565–572. (in Japanese).

Kurowski, K. and Blumstein, S. E. (1984), "Perceptual Integration of the Murmur and Formant Transitions for Place of Articulation in Nasal Consonants," *J. Acoust. Soc. Am.*, Vol. 76, 383–390.

Ladefoged, P. (1971), *Preliminaries to Linguistic Phonetics*. Univ. of Chicago Press, Chicago.

Maddieson, I. (1980), "A Survey of Liquids," *UCLA Working Papers in Phonetics*, Vol. 50, 93–112.

——— (1984a), "The Effects on F_0 of a Voicing Distinction in Sonorants and Their Implications for a Theory of Tonogenesis," *J. of Phonetics*, Vol. 12, 9–15.

——— (1984b), *Patterns of Sounds.* Cambridge University Press, Cambridge.

Maddieson, I. and Emmorey, K. (1984), "Is There a Valid Distinction between Voiceless Lateral Approximants and Fricatives?," *UCLA Working Papers in Phonetics*, Vol. 59, 77–84.

Mal'ecot, A. (1956), "Acoustic Cues for Nasal Consonants: An Experimental Study Involving A Tape-splicing Technique," *Language*, Vol. 32, 274–284.

McDavid, R. I. (1945), "Burmese Phonemics," *Studies in Linguistics*, Vol. 3, No. 1, 6–18.

Nishida, T. (1953), "Biruma-Go Onin-Taikei no Kozoteki-Bunseki" (A Structural Analysis of Phonological System of Burmese) *Tohogaku*, Vol. 7, 121–105. (in Japanese).

——— (1972), *Mentenkan-Yakugo no Kenkyu* (A Study of the Burmese-Chinese Vocabulary: Mien-Tien-Kuan I-Yu) Shokado, Kyoto. (in Japanese).

——— (1975), "On the Development of Tones in Tibetan" *Bulletin of the Oriental Study*, Vol. 25, 43–55.

Ohala, J. J. (1975), "Phonetic Explanations for Nasal Sound Patterns," in C. A. Ferguson, L. M. Hyman, and J. J. Hyman (eds.), *Nasalfest.* Stanford University, Stanford, 289–316.

Ohno, T. (1983), *Gendai Biruma-Go Nyumon* (A Basic Course in Modern Burmese) Tairyusha, Tokyo. (in Japanese).

Okell, J. (1969), *A Reference Grammar of Colloquial Burmese.* Oxford University Press, Oxford.

——— (1971), *A Guide to the Romanization of Burmese.* Luzac and Company Ltd, London.

Recasens, D. (1983), "Place Cues for Nasal Consonants with Special Reference to Catalan," *J. Acoust. Soc. Am.*, Vol. 73, 1346–1353.

Reenen, P. T. van (1981), *Phonetic Feature Definitions, Their Integration into Phonology and Their Relation to Speech, A Case Study of the Feature NASAL.* Foris Publications, Dordrecht.

Sprigg, R. K. (1965), "Prosodic Analysis and Burmese Syllable Initial Features," *Anthropological Linguistics*, Vol. 7, No. 6, 59–81.

Yabu, S. (1979), *Biruma-Go Nyumon* (A Burmese Primer, for the Burmese Language Training Course of Institute of Language and Culture of Asia and Africa (ILCAA)) Tokyo Gaikokugo Daigaku. (in Japanese).

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