ACOUSTIC SEPARATION OF HIGH-CENTRAL VOWELS IN BODO, RABHA AND KOREAN

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This paper presents acoustic data from five different vowel systems – Bodo, Rabha, and three dialects of Korean language (Seoul, Chungcheongdo, and Jeollabukdo) – and investigates the status of the high-central vowel in each system. Most of the previous work on Bodo and Rabha is limited to impressionistic accounts of a vowel located in the high-central region, while studies on Korean are clear only in the establishment of the corner vowels. Considering constraints on the acoustic space for maintaining contrast, we investigate the following questions: (1) how is the high vowel space negotiated under different inventory sizes and structures; and (2) what effect does this negotiation have on the overall distribution of vowels in each of these systems. The current work is an analysis of vowel data collected from 5 speakers of Seoul Korean, 6 speakers of Chungcheongdo Korean, 5 speakers of Jeollabukdo Korean, 10 speakers of Bodo, and 10 speakers of Rabha. Mel-transformed F1, F2, and F3 values were normalized for speaker effects and acoustic separation between each pair of vowels was calculated using Euclidean distance. The three varieties of Korean (Seoul, Chungcheongdo and Jeollabukdo) discussed in this work have a seven-vowel system, /i □ u e o □ a/, while Bodo and Rabha each have a six-vowel system, /i □ u e o a/. Peripheral distance between vowel categories was not found to increase absolutely with increases in inventory size comparing the Bodo/Rabha systems to the Korean systems. However, the relative acoustic spacing of the high-central vowel within the F1-F2 plane was comparable between Bodo, Seoul Korean, and Chungcheongdo Korean. The status of the high-central vowel in Rabha and Jeollabukdo Korean is less clear, as distance measures demonstrate asymmetric spacing in these two systems. We observed two distinct patterns in this study: a) incorporation of F3 and expanding vowel space to three dimensions is a relevant factor in the acoustic separation of contrastive categories in certain languages;b) the prediction that languages with larger vowel inventories make greater use of the vowel space, in absolute terms, may indeed be viable along certain dimensions, though not necessarily for the vowel space as a whole.

1. Introduction

This study is conducted on high-central vowels in three languages: Bodo, Rabha and Korean. Bodo and Rabha are Bodo-Garo languages of the Tibeto-Burman family, spoken in the Assam province of India (Joseph and Burling, 2001). Korean is geographically and genetically far apart from Bodo and Rabha, however, it is of interest in the current study as Korean has a high-central vowel [□] likeBodo and Garo do (Umeda, 1995; Yang, 1996; Sohn, 2001). While Sohn (2001) calls this vowel a high, back, unrounded vowel, Umeda (1995) and Yang (1996) claim that the [□] in Korean, written as 으, is high, central, and unrounded. Studies on Korean remain divided over the general characterization of the vowel space, with acoustic data only clear in the establishment of the corner vowels (Kim, 1968; Yang, 1992).

In case of Bodo and Rabha, it is not clear whether the third high vowel, apart from [i] and [u], is a high, back, unrounded or a high, central, unrounded vowel. Bhattacharya (1977) reports that the third high vowel in Bodo is [ō], i.e. unrounded and can occur with half-close to close and central to back tongue positions. Heclaims that it can be represented with the IPA [□]. Basumatary (2005) lists the third high vowel in Bodo as [w] - high, back, unrounded. Burling (2013) reports that it is a central vowel but with the IPA [□]. Sarmah et al. (2013) claim that the third high vowel in Bodo is a high, central, unrounded [□]. In case of Rabha, Burling (2013) is of the opinion that the third high vowel in Rabha, [□], is clearly a high, back, unrounded vowel and also tense.

Bodo and Rabha each have a six-vowel system, /i□ u e □ a/ while Korean varieties (Seoul, Chungcheongdo, and Jeollabukdo) have a seven-vowel system, /i□ u e o □ a/. The National Institute of Korean Language, in its publications list 10 Korean vowels /a, i, □, u, e, □, □, o, wi, we/, the last two of them, clearly, are diphthongs. Sohn (2001) claims the presence of ten vowels in Korean, namely, /i, y, e, □, ø, □, u, ə, o, a/. However, Umeda (1995) reports that in the synchronic variety of Seoul Korean the distinction between '애' [e] and '애' [□] is not preserved and [ə] does not appear as a separate phoneme in Korean. Igeta and Arai (2011) also report Korean as having a seven-vowel inventory and overlapping of [e]-[□] and [a]-[o] vowels.

The vowel inventory size and vowel quality of the languages under present analysis prompted the following questions: (a) how is the high vowel space negotiated under different inventory sizes and structures; (b) what effect does this negotiation have on distribution of vowels in these systems?

In what has come to be known as Adaptive Dispersion theory, Liljencrants and Lindblom (1972) predict that vowel system size and relative spacing between peripheral vowels should be directly related. As the number of vowels in a system increases the separation of vowels in that space should be optimized. However, Livjin (2000) demonstrates that unless the number of vowels in the system is greater than eight, the distance between peripheral vowels need not increase. Liljencrants and Lindblom (1972) use the principle of maximal separation to predict that a six-vowel system should contain three high vowels, /i□ u/ and a seven-vowel system should contain four high vowels, /i y □ u/. However, when investigated for typological evidence this prediction did not generally hold true, as the most common six and seven vowel systems in Schwartz et al.'s (1997) cross-linguistic study were /i□ e o u □/ and /i□ e o u □ a/, respectively.

In the current work we analyze vowel data collected from 5 speakers of Seoul Korean, 6 speakers of Chungcheongdo Korean, 5 speakers of Jeollabukdo Korean, 10 speakers of Bodo, and 10 speakers of Rabha. Mel-transformed F1, F2, and F3 values were normalized for speaker effects using Lobanov's (1971) z-score method and acoustic separation between each pair of vowels was calculated using Euclidean distance as applied in Liljencrants and Lindblom (1972).

2. Methods

Speakers of Bodo, Rabha, and three varieties of Korean (Seoul, Chungcheongdo, and Jeollabukdo) were recorded producing mono- and disyllabic words in frame sentences of the type "I said *X*," where the target word *X* in each case was uttered sentence-medially. Bodo recordings were conducted in and around Udalguri town in Assam. Rabha recordings were done at the Indian Institute of Technology Guwahati in a quiet room. Korean recordings were done in Seoul city, South Chungcheong province and in North Jeolla province of South Korea. All recording were done with an Audio-Technica AT2020 USB microphone connected directly to a laptop computer running Mac OS.

Acoustic analysis was done in Praat 5.3 (Boersma&Weenick, 2013), where the first three formants (F1-F3) were calculated at vowel midpoint using the Burg algorithm, and transformed from Hertz to Mel as in (1). All Mel-transformed formants were then normalized for speaker effects using the z-score method introduced in Lobanov (1971).

$$F_{Mel} = 500 \times ln\left(1 + \frac{F_{Hz}}{550}\right) \quad (1)$$

In order to test whether Liljencrants and Lindblom's (1972) predictions of optimal peripheral vowel separation obtain in Bodo, Rabha, and Korean, distance between vowel categories was measured as the vector magnitude between vowel formant medians in two- and three-dimensional acoustic space. If the organization of the vowel space is purely a function of perceptual constraints (i.e. maximal acoustic separation ensures minimal likelihood of confusing contrastive categories), then we expect similar spacing of peripheral vowels along the corner axes[1]. If, however, there are additional relevant parameters in the distribution of vowel phonemes along dimensions of F1, F2 (and F3), then we would expect the high vowels to behave differently from the front vowels which may further pattern differently from the back vowels. The metric we use to evaluate *relative spacing* in the context of F1, F2, and F3 is the ratio of distances between adjacent vowels on a particular axis; i.e. the medians of the peripheral, non-corner vowels ([□], [e], [o]) are measured from the medians of the vowels at their respective axis endpoints ([i u] in the case of [□], [i a] for [e], and [u a] for [o]), and these two distance measures are compared in a ratio[2]where a value of 1 would represent maximally even spacing, and greater values indicate greater asymmetry in the system.

A robust test of the hypothesis that the high-vowel space in languages like Bodo, Rabha, and Korean is negotiated differently than front or back vowel space – or alternatively, that maintenance of acoustic distance is characteristically different between F2 and F1 dimensions – would require pairwise comparisons of speaker-intrinsic distance ratios in order to obtain large enough *n* for statistical evaluation (minimally 10 if non-parametric methods are used). As vowel productions by individual speakers in the present sample are not large enough to allow robust speaker-intrinsic calculations we only report vowel distance ratios for the generalized system in a given language variety.

3. Results

Prior to calculating relative vowel spacing in each system, vowel plots of category means and standard deviation ellipses were produced in F1-F2 space[3]. All plotting was done in NORM; however, Lobanov normalization was computed manually prior to input to NORM (Thomas & Kendall, 2007). The six- and seven-vowel inventories in Bodo/Rabha and Korean, respectively, exhibit noticeably different negotiation of F1-F2 acoustic space. The Bodo system (Figure 1), for example, represents close to canonical patterning, with zero overlap in vowel regions demarcated at one standard deviation from the mean. Rabha (Figure 2) on the other hand shows considerable overlap between the high-central vowel (represented in the figures below as /W/) and the other two front vowels /i e/.

The three varieties of Korean (Seoul, Chungcheongdo, and Jeollabukdo) appear substantially different despite possessing the same phoneme inventory. The F1-F2 space occupied by /u/ and /o/ in Seoul (SK) and Chungcheongdo Korean (CK), for example, are almost the reverse of each other, while Jeollabukdo Korean (JK) generally follows CK's organization of the back vowels. Regarding the positioning of the high-central vowel relative to the other high vowels /i/ and /u/, the three varieties of Korean present three different general patterns. SK exhibits generally even spacing of /□/ between /i/ and /u/, whereas CK shows a close affinity between /i/ and /□/, and JK shows the opposite (/□/ closely overlapping with /u/).

Quantifying the degree of separation between vowel categories – and testing the assumption from Liljencrants and Lindblom (1972) that languages maximize the acoustic separation of vowels as part of a system driven by the need for perceptual contrast – is a matter of relating the Euclidean distance from a particular vowel to the relevant adjacent vowels in a ratio where 1 represents maximally even spacing along a given axis. This measure captures *relative* spacing, which is now deemed a more adequate organizational principle for vowel systems (Livjin, 2000); however the initial prediction in Liljencrants and Lindblom (1972) was that vowel separation would increase absolutely as inventory size increases.

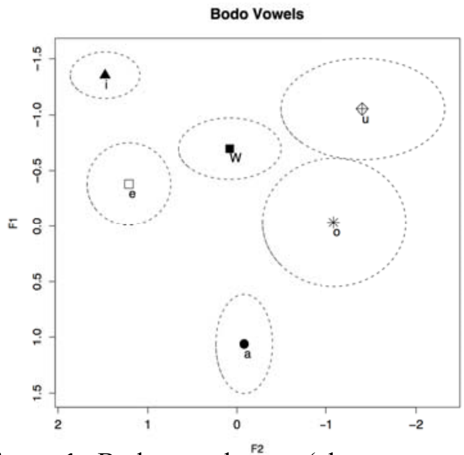

Figure 1. Bodo vowel space (ellipses represent +/- 1σ)

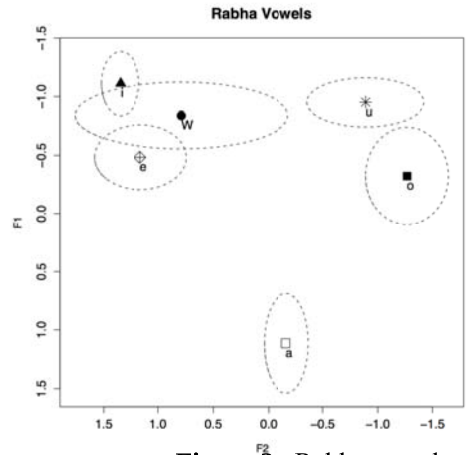

Figure 2. Rabha vowel space (ellipses represent +/- 1σ)

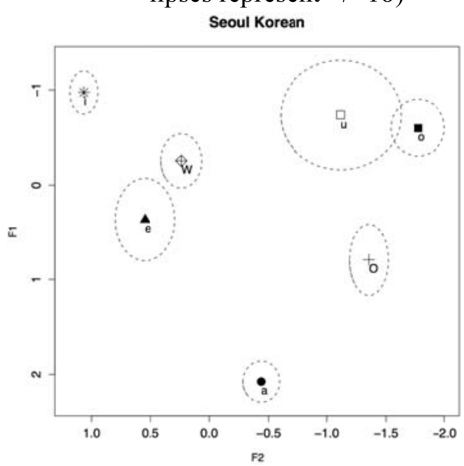

Figure 3. Seoul Korean vowel space (ellipses represent +/- 1σ)

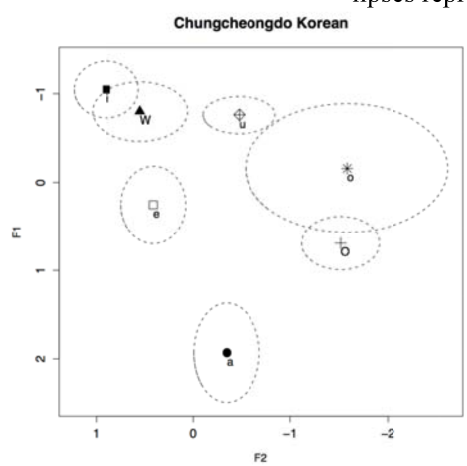

Figure 4. Chungcheongdo Korean vowel space (ellipses represent +/- 1σ)

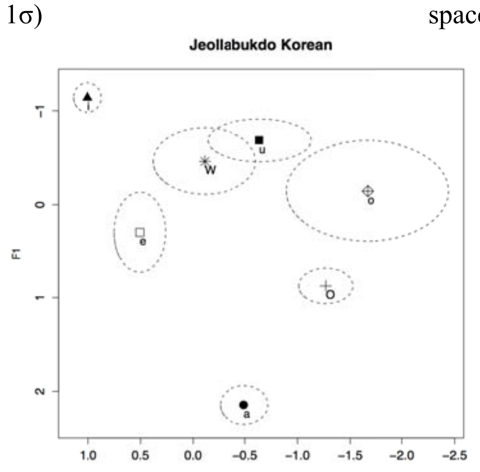

Figure 5. Jeollabukdo Korean vowel space (ellipses represent +/- 1σ)

In the F1-F2 plane this prediction can be simply evaluated as the domain (F2) and range (F1) covered by vowel productions in languages of different inventories. Bodo and Rabha, each with a six-vowel inventory, exhibit F2 spreads (post-normalization) of 3.077 and 2.668, respectively, and F1 spreads of 2.51 and 2.286. In the case of Korean, a language with a seven-vowel inventory, F2 spreads for Seoul, Chungcheongdo, and Jeollabukdo, respectively are 2.783, 2.692, and 2.748. The ranges in F1 for the three varieties of Korean are 3.066, 3.003, and 3.266, respectively.

As noted in the previous section, whether or not these differences are statistically significant is not a question that can be answered in the present study; however, from a cursory inspection there does not appear to be a clear separation in the absolute F1 and F2 ranges covered by vowels in six- versus seven-vowel systems. A relation that has been shown to be far more robust cross-linguistically is relative spacing within the formant space of vowel categories in a given language. In Table 1 and Table 2 we present Euclidean (vector) distances between peripheral vowels in two (F1-F2) and three (F1-F2-F3) dimensions. These values are then used in calculation of distance ratios for the non-corner peripheral vowels in the five languages studied (Table 3 and Table 4).

Table 1. Two-dimensional Euclidean distances between vowel medians (F1-F2)

	Bodo	**Rabha**	**S. Korean**	**C. Korean**	**J. Korean**
<i>-< >	1.653	0.358	1.120	1.002	1.378
< >-<u>	1.605	2.124	1.436	0.753	0.579
<i>-<e>	1.034	0.685	1.409	1.403	1.630
<e>-<a>	2.016	2.155	2.036	1.855	1.997
<u>-<o>	1.260	0.694	0.600	1.288	1.088
<o>-< >	--	--	1.399	0.978	1.178
<o>-<a>	1.504	1.863	--	--	--

Table 2. Three-dimensional Euclidean distances between vowel medians (F1-F2-F3*)*

	Bodo	**Rabha**	**S. Korean**	**C. Korean**	**J. Korean**
<i>-< >	2.158	1.038	1.644	1.561	2.240
< >-<u>	1.609	2.197	1.748	0.835	0.895
<i>-<e>	1.146	0.876	1.709	1.735	2.082
<e>-<a>	2.059	2.246	2.184	1.898	1.997
<u>-<o>	1.386	0.754	1.261	1.343	2.181
<o>-< >	--	--	1.436	1.014	1.262
<o>-<a>	1.504	1.864	--	--	--

Table 3. Peripheral vowel distance ratios (2-D)

	Bodo	**Rabha**	**S. Korean**	**C. Korean**	**J. Korean**
<i>-< >-<u>	1.03	5.925	1.282	1.331	2.380
<i>-<e>-<a>	1.95	3.145	1.445	1.322	1.225
<u>-<o>-< >	--	--	2.334	1.318	1.083
<u>-<o>-<a>	1.194	2.683	--	--	--

Table 4. Peripheral vowel distance ratios (3-D)

	Bodo	**Rabha**	**S. Korean**	**C. Korean**	**J. Korean**
<i>-< >-<u>	1.341	2.116	1.063	1.869	2.501
<i>-<e>-<a>	1.796	2.564	1.277	1.094	1.042
<u>-<o>-< >	--	--	1.139	1.325	1.729
<u>-<o>-<a>	1.086	2.471	--	--	--

No comprehensive pattern emerges in the comparison of F2-axis peripheral vowel spacing (<i>-<□>-<u>) with F1-axis spacing (<i>-<e>-<a>; <u>-<o>-<□>; <u>-<o>-<a>). In two-dimensional acoustic space, Bodo and Seoul Korean exhibit their most even peripheral spacing among the high vowels; however, in three-dimensions the back vowel axis becomes the most evenly spaced in Bodo, while the Rabha high vowels exhibit a nearly three-fold reduction in distance ratio when F3 is incorporated, suggesting that F3 may be a relevant parameter in maintaining contrast between /i/ and /□/ in that system.

Chungcheongdo Korean appears relatively even in distance ratios between high-, front-, and back-vowel regions (<0.013 between highest and lowest ratios), but expanding to three dimensions with the incorporation of F3 yields a more asymmetric spacing. Finally, Jeollabukdo Korean exhibits most even spacing in the back vowels in the F1-F2 plane, while the front vowels become more evenly distributed in F1-F2-F3 space.

4. Discussion

Two patterns emerge from the vowel plots and phoneme distance calculations on acoustic data from Bodo, Rabha, and Korean. First, the incorporation of F3 and expansion of the vowel space to three dimensions is a relevant factor in the acoustic separation of contrastive categories in certain languages (notably in the high vowel space of Rabha and the back vowel space of Bodo and Seoul Korean). Second, the prediction from Liljencrants and Lindblom (1972) that languages with larger vowel inventories make greater use of the vowel space, in absolute terms, may indeed be viable along certain dimensions, though not necessarily for the vowel space as a whole. All three varieties of Korean, for example exhibit a greater range of F1 values than either Bodo or Rabha (the smallest of the three, Chungcheong-do Korean, being 3.003 as compared with Bodo at 2.51). Given that Korean has a denser back vowel space than Bodo and Rabha, and that back vowel distinctions are primarily manifest in F1, this greater span along the F1 dimension could be a consequence of inventory differences between Korean and Bodo/Rabha. What this and the relative spacing differences along F1, F2, and F3 dimensions lead to is a more basic question with regard to the theory of Adaptive Dispersion; namely, do requirements for the maintenance of perceptual contrast in F1-F2 space behave differently along primarily horizontal (F2) versus vertical (F1) axes. Future studies using pairwise comparisons of individual speakers' vowel spaces will allow statistical verification of the more general trends we have demonstrated in this paper.

REFERENCES

[1] U.V. Joseph and R. Burling, 2001. Tone correspondences in Bodo-Garo languages, *Linguistics of Tibeto-Burman Area*, **24** (2), 41-55.

[2] H. Umeda, 1995. Age differentiation of the vowel system in the Seoul Korean: Acoustic measurements, *Journal of Asian and African Studies* 48-49, 443-453.

[3] B. Yang, 1996. A comparative study of American English and Korean vowels produced by male and female speakers, *Journal of Phonetics*, **24**, 245-261.

[4] H-M. Sohn., 2001. *The Korean Language,* Cambridge University Press.

[5] C-W. Kim, 1968.The vowel system of Korean, *Language*, **44** (3), 516-527.

[6] B. Yang, 1992. An acoustical study of Korean monophthongs produced by male and female speakers, *Journal of the Acoustical Society of America*, **91**, 2280–2283.

[7] P. C. Bhattacharya, 1977. *A Descriptive Analysis of the Bodo Language*, Gauhati University.

[8] P. Basumatary, 2005. *An Introduction to the Boro Language,* Mittal Publication, New Delhi.

[9] R. Burling, 2013. The 'sixth' vowel in the Boro-Garo languages, *North East Indian Linguistics,* Cambridge University Press India, **5**.

[10] P. Sarmah, D. Choudhury, L. Dihingia, 2013. A Study of Bodo vowels, 19th Himalayan Languages Symposium, Canberra, September 6-8, 2013.

[11] T. Igeta and T. Arai, 2011, A case study on comparison of male and female vowel formants by native speakers of Korean, ICPhS XVII, 934-937, Hong Kong.

[12] J. Liljencrants and B. Lindblom, 1972. Numeral simulation of vowel quality contrasts: the role of perceptual contrast. *Language,* **48** (4), 839-862.

[13] P. Livjin, 2000. Acoustic Distribution of Vowels in Differently Sized Inventories – Hot Spots or Adaptive Dispersion? XIIIth Swedish Phonetics Conference Proceedings, 93-96. Skövde, Sweden.

[14] J-L. Schwartz, L-J.Boë, N. Vallée, C. Abry, 1997. The Dispersion-Focalization Theory of vowel systems, *Journal of Phonetics*, **25** (3), 255-286.

[15] B. M. Lobanov, 1971. Classification of Russian vowels spoken by different listeners.*Journal of the Acoustical Society of America* 49, 606-08.

[16] P. Boersma and D. Weenink, 2013. Praat: doing phonetics by computer [Computer program]. Version 5.3.56, retrieved 15 September 2013 from http://www.praat.org/

[17] E. P. Thomas and T. Kendall, 2007. NORM: The vowel normalization and plotting suite. [Online Resource: http://ncslaap.lib.ncsu.edu/tools/norm/]

[1]By *corner axes* we mean the lines formed between any two corner vowels, the corner vowels being /a i u/ in Bodo and Rabha, and /a i u □/ in Korean

[2]By convention the larger of the two distances is always placed in the numerator, so that vowel distance ratios are always greater than or equal to 1

[3]Three-dimensional plots were not produced because of complications in presentation/interpretation