Acoustic distribution of vowels in differently sized inventories – hot spots or adaptive dispersion?

Peder Livijn
Department of Linguistics, Stockholm University

Abstract

Twenty-eight differently sized vowel inventories were searched for evidence of acoustically favoured regions ('hot spots') or size-dependent adaptive dispersion patterns. The data did not provide evidence either for an effect of inventory size on the acoustic distance between point vowels or a clustering of vowels into hot spots. The implications of these data for modelling of vowel systems are discussed

Introduction

The Quantal Theory of speech (QT; Stevens, 1972, 1989) and the Theory of Adaptive Dispersion (TAD; Liljencrants and Lindblom 1972; Lindblom, 1986) make different and partly conflicting predictions as to the effect of inventory size on the acoustic distribution of elements of vowel systems.

On the assumption that the relationship between articulatory movements and their acoustic results is non-linear, QT essentially predicts that languages will select their basic vowel elements at stable regions of the acoustic space ('hot spots'). The distribution of these 'quantal' vowels would thus be independent of inventory size.

In contrast, TAD claims that the demand for sufficient contrast between elements in a vowel inventory will lead to an 'adaptive dispersion' of these elements; in particular, large inventories would tend to expand the acoustic (e.g., F1/F2) vowel space such that the distance between the point vowels would be greater in large than in small systems.

The results of previous studies (Engstrand and Krull 1991) have been inconclusive with respect to these competing hypotheses. In this study, data from several language with differently sized vowel inventories have been obtained in order to shed further light on this problem.

Method

For this study, 28 languages with vowel inventories of different sizes were selected from the IRIS database (Engstrand and Cunningham-Andersson, 1988). Constraints on language selection were that a) the languages were to be as genetically and typologically varied as possible, b) there had to be a recording with a male speaker, and c) the speech material had to include a word list with all the long vowels of the inventory appearing in a C_C frame in stressed position. Diphthongs or nasal vowels were not used.

Measurements of F0-F4 were made using wide band spectrograms, and the ESPS formant-tracking algorithm. In cases where a formant (usually F4) was hard to locate on the spectrogram, an additional LPC-analysis was used. Measurement points were selected, in order of priority, on the basis of a steady-stated portion of F2, a turning point (maximum or minimum) in F2, or at the middle of the vowel segment. Formant frequencies were subsequently converted into Bark units, using a formula in Traunmüller (1990).

Results

Figure 1 shows the sum of the Euclidean distances in Bark (based on F1 and F2) between the point vowels /i/, /a/ and /u/ plotted as a function of inventory size. While it can be seen that distances in 4 - 8 vowel inventories do not display any tendency to grow with inventory size, the largest systems (11 vowels or more) tend to expand the acoustic vowel space to some extent. However, the latter tendency is fairly weak and due to three languages only. Thus, the present data do not provide convincing evidence of a size-related effect.

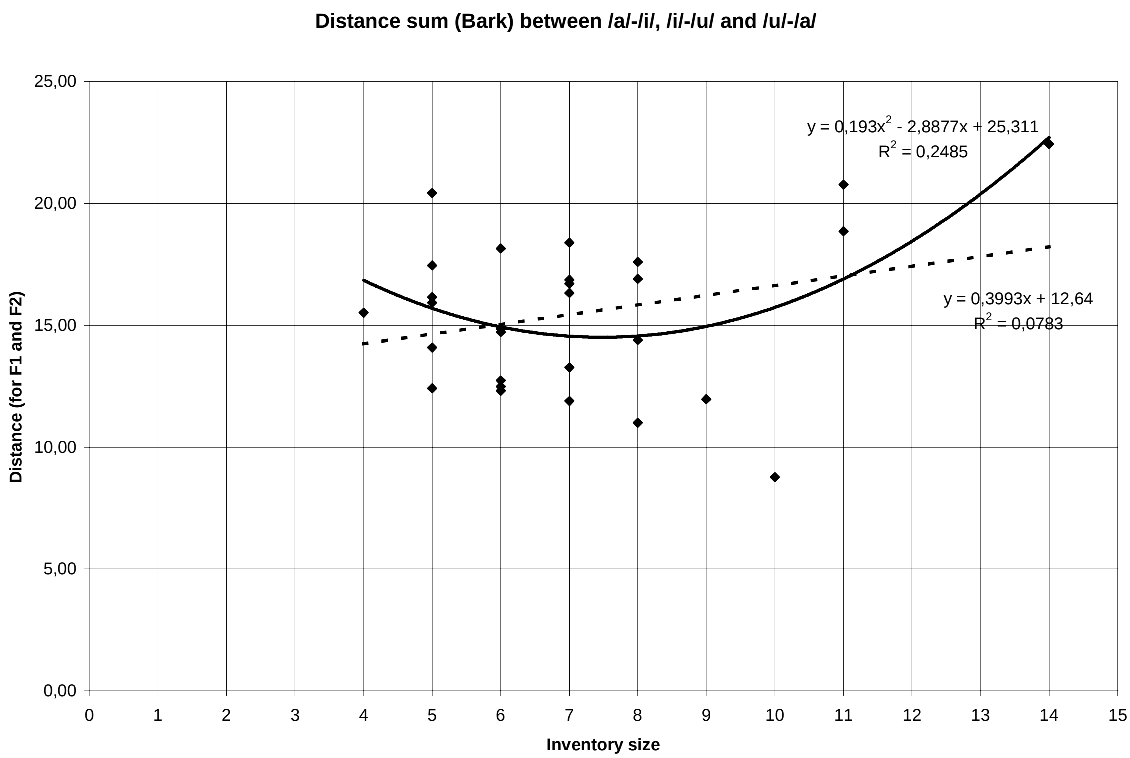

Figure 1. The sum of the distances between /i/, /a/ and /u/ in Bark as a function of inventory size for all 28 vowel systems.

Figure 2 presents the total vowel distribution in the F1/F2 space (again converted to Bark units) as found in all 28 languages. It is apparent that the distribution is quite random. In particular, a closer analysis shows that the location of point vowels is highly variable even in languages with similar inventory sizes. Thus, there is not much evidence for ‘hot spots’ in these data. In fact, it is even hard to discern larger regions that seem to be more densely populated than others. It should be noted, however, that vowels seem to be particularly sparse in a high and a mid central region.

This effect thus seems to be independent of inventory size and might reflect a general, perhaps perceptually motivated preference for front and back rather than central vowels.

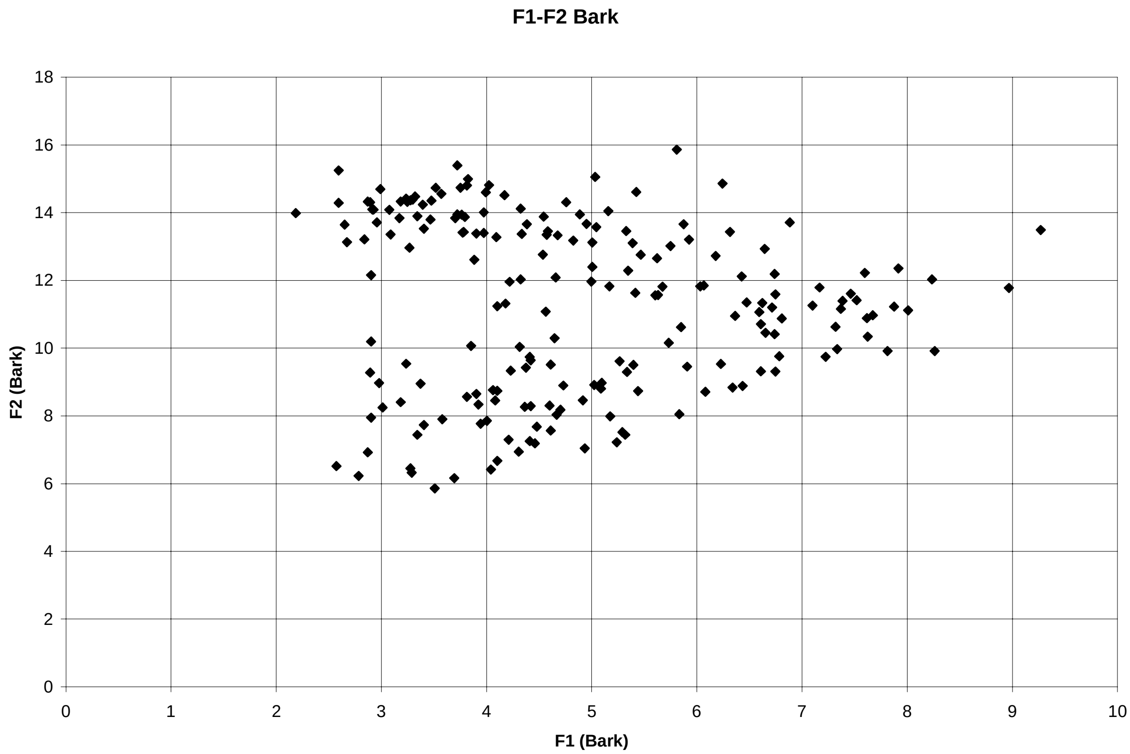

Figure 2. F1 – F2 plot of all vowels of the 28 languages in this survey (Bark) Note the lack of vowels in the high and mid central areas

Summary and conclusions

To summarise, the present measurements have not provided clear evidence either for an effect of inventory size on the acoustic distance between point vowels as predicted by TAD or a QT type clustering of vowels into hot spots. However, the tendency to increased distances in the largest systems deserves to be further explored using an extended database.

The largely negative result could be interpreted such that languages use additional means for accommodating elements in crowded vowel spaces. It has been shown for consonants (Lindblom and Maddieson, 1988) that large systems tend to be based on recruitment of new articulatory dimensions rather than squeezing more units into few dimensions. It is likely that the construction of large vowel systems is based on mechanisms partly analogous to this 'size principle' using dimensions such as nasality, diphthongisation or voice quality.

However, the exact relationship between inventory size and utilisation of more elaborated vowel types remains to be explored.

References

Engstrand O, Krull D (1991) Effects of inventory size on the distribution of vowels in the formant space: preliminary data for seven languages. PERILUS 13. pp 15-18

Engstrand O, Cunningham-Andersson U (1988) IRIS – a data base for cross-linguistic phonetic research. Unpublished manuscript, Department of linguistics, Uppsala Universitet.

Liljencrants J, Lindblom B (1972) Numerical simulation of vowel quality systems: The role of perceptual contrast. Language 48: 839-862

Lindblom B (1986) Phonetic universals in vowel systems. In: Ohala JJ, Jeager JJ (eds) Experimental Phonology. Orlando, FL: Academic Press, pp. 13-44

Lindblom, B. & Maddieson, I (1988) Phonetic universals in consonant systems. In L.M. Hyman and C.N. Li (eds.), Language, speech and mind. Studies in honour of Victoria A. Fromkin. pp. 62-78. London: Routledge

Maddieson I (1984) Patterns of sound. Cambridge: Cambridge University Press

Maddieson I, Precoda K (1989) Updating UPSID. JASA, suppl 1, vol. 86, s19, 1989

Stevens KN (1972) The Quantal nature of speech: Evidence from articulatory-acoustic data. In: David EE, Denes PB (eds) Human communication: A unified view. New York: McGraw-Hill, pp. 51-66

Stevens KN (1989) On the Quantal nature of speech. J Phonetics 17: 3-45

Traunmüller H (1990) Analytical expressions for the tonotopical sensory scale, JASA, suppl 1, vol. 88, pp 97-100, 1990