Measuring the Optimization of Vowel-Spaces: A Method for Cross-Linguistic Analysis

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Recently, a number of studies looking at the emergence and evolution of phonological systems have shown that, given sufficient time, organizations of the articulatory space emerge in which phonemes are maximally distinctive perceptually (e.g. Steels, 1997; de Boer, 2000; Oudeyer, 2005; de Boer & Zuidema, 2010). However, there has been little investigation into the typological description of articulatory optimization in the world's languages. It is not known, for example, how optimized natural vowel-spaces actually are, or whether the vowels of, for example, English are more or less distinctive than those of, for example, Swahili. Peterson and Barney (1952) showed that it is possible to 'see' the spacial relationships between vowels by plotting their first and second formant frequencies in a plot with reversed logarithmic axes. This provides a useful means to visualize the space used by the tongue to produce vowels of differing qualities. By converting the formant frequencies to a linear psychoacoustical scale (e.g. the bark, mel, or ERB-rate scales), it is possible to calculate the perceptual distances between vowels, and obtain a measure of the degree to which a particular organization of vowels is optimized.

In this poster I introduce such a methodology, which (to my knowledge) has not been attempted previously. This is achieved in three steps: first, we measure the formant frequencies of the basic set of monophthongs in a given language; second, we plot these vowels in a perceptual space; third, we compare this vowel-space to 100,000 randomly simulated vowel-spaces. Since an optimized distribution of vowels should deviate greatly from distributions generated stochastically, this method provides a robust measure of the nonrandomness (i.e. optimization) of a vowel-space. I call this measure the vowel optimization quotient (VOQ).

Using recordings from the UCLA Phonetics Lab Archive (2007), this method has been applied to 100 languages. The results suggest that there is a high level of variation in the extent to which vowel-spaces are optimized. The Kamba language, for example, uses a set of vowels that are highly distinctive from one another (fig. 1a), while the Amharic language uses a set of vowels that are not so perceptually distinctive (fig. 1b). This could have potential applications in phonology and linguistic typology, and, given its reliance on a number of visual methods, such as multidimensional vowel plots, spectrograms, and diagrams of the vocal tract, it also highlights the important role visual methods play in modern Linguistics.

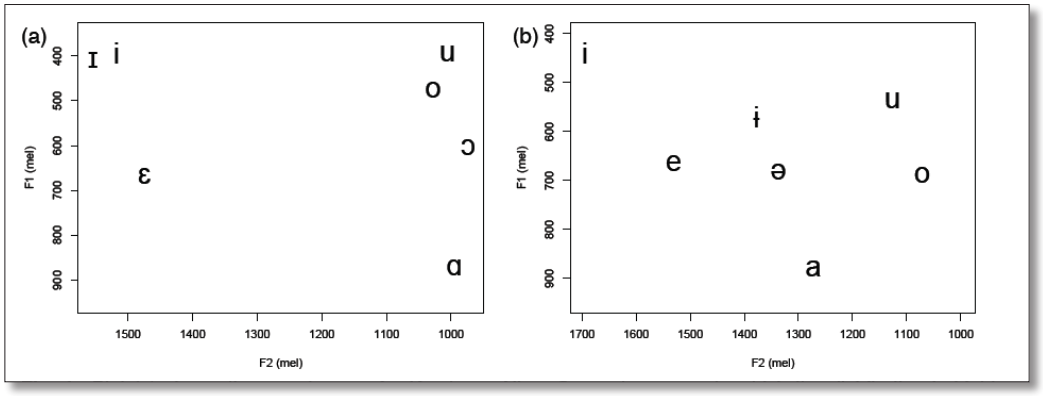

Figure 1. Plot (a) shows the vowel-space for Kamba, a Niger-Congo language, in which the distribution is highly optimized (VOQ = 3.8). Plot (b) shows the vowel-space for Amharic, an Afro-Asiatic language, in which the distribution is relatively unoptimized (VOQ = 1.6).

References:

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