Vowel characterisation by centroids

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Abstract

The present report is about a new methodological approach for the description and categorization of vowels in different languages. In this report we will concentrate on American English and Greek. Our methodology is based on determining vowel centers and measuring their locations for the corner vowels. Vowel centers were determined by comparative computation of the linear average values and the centroid values for the first two formants and plotting these results. The results of our methodology indicate the following: 1) centroid measurements give precise depiction of vowel characteristics, 2) centroid measurements appear constant and these values are not subject to variability, 3) the overall shape of the vowel space maintains a constant shape, regardless of the formant frequency values of the respective languages.

Key words: Vowel space, formant, vowel centroid, frequency values, cross-linguistics

Introduction

This paper is about a methodology and categorization and the mapping of vowels in two languages: American English and Greek. Two main questions are addressed: 1) what are the vowel spaces defined by the corner vowels, and 2) what is the vowel center of the corner vowels. A comparison of the vowel centers and the corner vowels of the two languages will be shown.

Peterson and Barney's (1952) foundational research with 76 speakers discusses vowel variability and overlap, and they identified an English vowel space, in a log-log plot in which formant one (F1) is plotted against formant two (F2). Liljencrants and Lindblom (1972) further investigated the phonetic structure of vowel systems and showed vowel F2 versus F1 spaces depicting linear plots, in their prediction model of the locations of vowels. Fourakis, Botinis, and Katsaiti (1999) found that vowel system of Greek, as seen in the F1 and F2 frequency plots define a larger vowel space in comparison to Italian vowel spaces. Bradlow (1995) examined the vowel spaces of Spanish and English comparing acoustic vowel categories and she discussed dispersion theory as an explanation of size and configuration differences. Goertz and Anderson (2020) investigated formant computations and found that application of experimental mathematics improves the overall efficacy of vowel representation. In view of this previous research and the state of the art, we are moving towards new methodologies and vowel descriptions.

In the present report we aim to show new light on the description and distribution of vowels as a function of their dispersion with reference to a centroid vowel space location. In addition, we will present cross-linguistic vowel data in two relatively well-studied languages.

Methods and materials

In accordance with the questions in the introduction and related methodology, speech data was acquired from Greek native speakers with key words containing the vowels/i, e, a, o, u/ in carrier phrases. The key words were /pis/ "say", /pas/ "go", and /tus/ "them" and the carrier phrases was "ˈeleje ___ arˈɣa" (s/he was saying ___ slowly). Formant values were determined using PRAAT and the F1 and F2 values were measured at the approximate mid-point of the vowel. In addition to our Greek data , used metadata for both Greek and English from published materials.

Our methodological approach is based on the centroid concept. Centroids are the mathematical weighted averages and the exact centers of the triangular area formed by formant data. Centroids were computed using several algorithms run in Matlab 2022a, including the Matlab CentroidPolygon.mlx file. These programs use formant data to compute: the centroid F1-F2 coordinates, shape of the vowel space, and area of the vowel space.

Results

In accordance with the questions from the introduction and the methods we described, the results are as presented in plots. Only for female speakers are included and no statistics are reported as this study is a qualitative description.

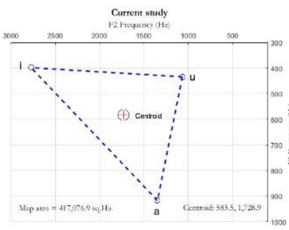
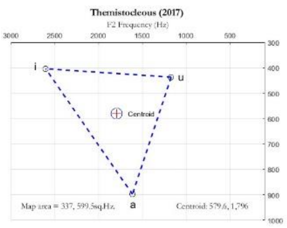


Figure 1.1



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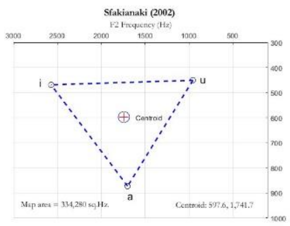

Figure 1.3

Figure 1. Greek corner vowel distributions: 1.1 Vowel space of five female Greek speakers (the present study); 1.2 Metadata from Themistocleous (2017), 45 female speakers; 1.3 Metadata from Sfakianaki (2002), 10 female speakers.

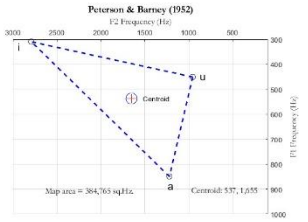

Figure 2.1

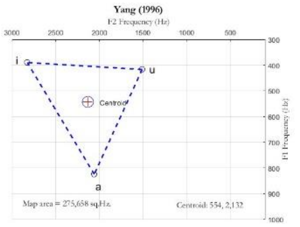

Figure 2.2

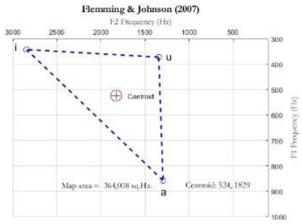

Figure 2.3

Figure 2. English corner vowel distributions: 2.1 Metadata from Peterson, Barney (1952), 28 female speakers; 2.2 Metadata from Yang (1996), 30 female speakers; 2.3 Metadata from Flemming, Johnson, (2007), 9 female speakers.

Figure 1 shows that the three Greek vowels/i, a, u/ show minor differences among the studies and have basically the same triangular acoustic structure, which is evident in different studies with various objectives (e.g. Botinis 1981, Lengeris 2016). On the other hand, the three corner vowels appear to be the most distinct among the five vowels in Greek (Nicolaidis 2003).

Figure 2 shows that the three vowel triangles in American English tend not to form equal sides in comparison to Greek.

The high American English vowels are higher than the Greek high vowels among all studies, whereas the low vowel /ɑ/ in American English is fairly close to Greek /a/. On the other hand, the high vowel /u/ in American English is more fronted than the respective Greek vowel /u/ in two studies (Yang 1996, Flemming, Johnson 2007).

It seems that the larger vowel space of American English is due more to its high expansion, rather than the low expansion. On the other hand, American English does not experience any noticeable back expansion.

In all English figures, /i/ is higher than /u/. English /u/is lower than Greek /u/ contrary to expectations. The Greek vowel /u/ is contrary to the maximum dispersion theory prediction (Liljencrants & Lindblom 1972), as well as being contrary to the expectation that more crowed vowel systems would have more extreme corner vowels.

In this study, Greek centroids generally cluster around the F1-F2 values of 579/1796 Hz. and English centroids generally cluster around F1-F2 values of 538/1829 Hz. It appears that the vowel spaces, as indicated by the r values (the measure of dispersion) of the centroids for both languages show differences in the vowel areas. The r value for Greek vowels was 11.9, compared to the r value for English vowels of 113.7, indicating that English vowel locations are more dispersed, especially in F2.

Vowels position around the centroid in various orientations and distances, suggesting that the designation front or back, for example, should be indicated by the relation to the vowel space centroid.

Discussion and outlook

It looks like physical-oriented theories, such as the principle of maximal contrast (Liljencrants & Lindblom 1972) or vowel dispersion theory (Trudgill 2009) may partly represent vowel acoustic reality. We would argue that given some basic anatomical and physiological restrictions, the acoustic structure of each language is overwhelmingly language-conditioned rather than physically-conditioned.

Our centroid calculation method depicts the entire vowel space in a straightforward way. On the other hand, this method is a stable mathematical representation of corner vowel and vowel space characteristics, being at the same time more accurate and reliable than the traditional average methods.

Under the assumption that the centroid method of measurement is reliable and precise, (1) we are planning experiments with similar speech samples to map vowel distributions in several languages, and (2) centroid measurements of vowel spaces will be evaluated further to measure speaker individuality and vowel variation. In contrast to traditional analysis, we believe that this method can show a more accurate map of vowel spaces.

References

Botinis, A. 1981. The Greek vowels. Working Papers 21, 29-36. Department of Linguistics and Phonetics, Lund University.

Bradlow, A.R. 1995. A comparative acoustic study of English and Spanish vowels. The Journal of the Acoustical Society of America, 97(3), 1916-1924.

Flemming, E., Johnson, S. 2007. Rosa's roses: reduced vowels in American English. Journal of the International Phonetic Association 37(1), 83-96.

Fourakis, M., Botinis, A., Katsaiti, M.. 1998. Acoustic characteristics of Greek vowels. Phonetica 56: 28-43.

Goertz, G., Anderson, T. 2020. Sound dimensions and formants. ExLing 2020: 11th International Conference of Experimental Linguistics, 93-96. Athens, Greece.

Lengeris, A. 2016. Comparison of perception-production vowel spaces for speakers of Standard Modern Greek and two regional dialects. The Journal of the Acoustical Society of America, 140(4), EL314-EL319.

Liljencrants, J., Lindblom, B. 1972. Numerical simulation of vowel quality systems: the role of perceptual contrast. Language 48(4), 839-862.

Nicolaidis, K. 2003. Acoustic variability of vowels in Greek spontaneous speech. Proc. 15th International Congress od Phonetic Sciences, 3221-3224. Barcelona, Spain

Peterson, G., Barney, H. 1952. Control methods used in a study of the vowels. The Journal of the Acoustical Society of America 24(2). 175-184.

Sfakianaki, A. 2002. Acoustic characteristics of Greek vowels produced by adults and children. Selected papers on theoretical and applied linguistics 14, 383-394.

The Math Works, Inc. 2022. MATLAB (Version 2022b). [Computer software].

Themistocleous, C. 2017. The nature of phonetic gradience across a dialect continuum: evidence from modern Greek vowels. Phonetica 74(3), 157-172.

Yang, B. 1996. A comparative study of American English and Korean vowels produced by male and female speakers. Journal of phonetics, 24(2), 245-261.