A MEASURE OF VARIABLE PLANAR LOCATIONS ANCHORED ON THE CENTROID OF THE VOWEL SPACE: A SOCIOPHONETIC RESEARCH TOOL

Dominic Watt[a] *& Anne H. Fabricius*[b]

[a]University of York, UK; [b]Roskilde University, Denmark
dominic.watt@york.ac.uk; fabri@ruc.dk

ABSTRACT

This paper presents part of an ongoing research program which aims to apply mathematical and geometrical analytic methods to vowel formant data to enable the quantification of parameters of variation of interest to sociophoneticians. We open with an overview of recent research working towards a set of desiderata for choice of normalization algorithm(s) based on replicable procedures. We then present the principles of centroid-based normalization and account for its performance in recent road tests. In sections 4 and 5 we introduce a method that utilizes the centroid of the speaker's vowel space as an anchor point or vertex for calculation of planar locations on formant plots, permitting quantification of the distribution of vowel tokens within the space. This information, along with details such as Euclidean distances, can then be used to precisely pinpoint the trajectories of diachronic change, for instance over a set of speakers in different age groups within a defined speech community. This has the advantage of mathematical reproducibility, and reduces the level of subjectivity in visual analyses of formant plots used in investigations of vowel variability and change in progress.

Keywords: sociophonetics, graphical methods, formant plots, vowels, normalization

1. INTRODUCTION

An account of a recently-developed '*S*-centroid anchor' method of calculating planar locations in the F1-F2 space is presented in this paper. Sections 2 and 3 discuss centroid-based normalization. Sections 4 and 5 introduce and exemplify the *S*-centroid anchor method.

2. CENTROID-BASED NORMALIZATION

The *S*-centroid vowel normalization procedure known as *Watt & Fabricius* (henceforth *W&F*), originally presented in [6, 21], was developed to offer a normalization method tailored specifically to sociophonetic research. It seeks as far as possible to optimize comparisons of the vowel systems of different speakers without making prior assumptions about configurational similarities between their systems, in contrast with other normalization methods such as [16] (Nordström's method), which is based on scaling women's and children's vowel spaces to men's vowel spaces.

The speaker-intrinsic, vowel-extrinsic, formant-intrinsic *W&F S*-centroid method has recently been employed in studies of variation in vowels in British Received Pronunciation (RP) [4, 5], the English of London [11], Nottingham [7, 8], South Africa [14], and (in modified form) Illinois [1]; Dutch [9]; Vietnamese [22]; and in laterals in Catalan and Spanish [19]. It normalizes a speaker's formant data by expressing each value as a proportion of the respective formant centroid value, where the centroid is derived using F1 and F2 maxima and minima for that individual's vowel space. Its original formula is given at (1), where formant n (F_n) for the centroid S is defined as the average of three formant values for the corner vowels [i a u']. The last of these is a hypothetical extreme vowel point derived from the coordinates of [i], such that [u']'s F1 and F2 are both set to equal [i]'s F1.

(1) $$S(F_n) = \frac{[\text{i}]F_n + [\text{a}]F_n + [\text{u'}]F_n}{3}$$

In contrast with other methods such as *Lobanov* [13], *W&F* requires only identification of the (mean) corner points of the vowel space, not a sampling of the entire vowel space. Its most successful version to date is known as *modified* or *mW&F*, presented in [6] and available in the NORM sociophonetics research toolkit [20].

3. ROAD-TESTING THE ALGORITHM

Fabricius, Watt and Johnson [6] employed a series of metrics to gauge a normalization algorithm's performance on a set of geometric parameters crucial for sociophonetic purposes:

- The degree of equalization of vowel space areas, estimated as the reduction of variance between the areas of speakers' spaces;
- The degree of overlap of spaces, defined as the ratio of the intersection and union (each speaker's space vs. all others in the sample);
- The two-dimensional angular relationships between mean vowel points compared with mean Hz data.

Figure 1: Peterson & Barney data, group means, Hz.

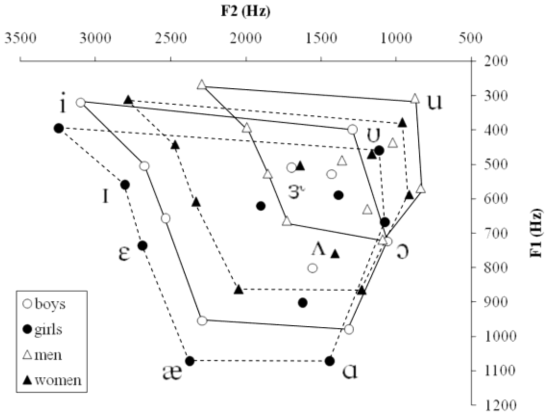
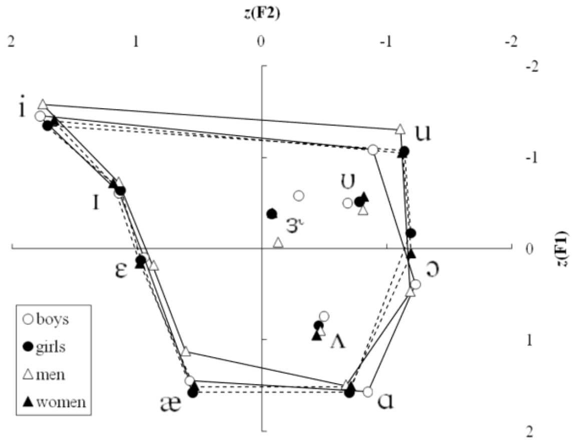


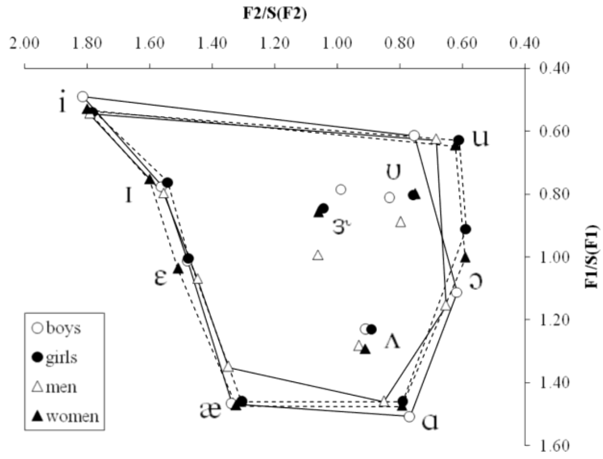
Figure 2: Peterson & Barney data, group means, *Lobanov*-normalized.



Applying these tests to a set of data from RP and Aberdeen English, [6] revealed that, of the three methods (*Lobanov*, *W&F* in two versions, and *Nearey's* $CLIH_{i4}$), the *W&F* algorithms consistently outperformed *Nearey*, while *Lobanov* tended to perform better than the other methods.

In more recent work, however, Flynn [7] presents a comparison of 24 algorithms applied to data from Nottingham English, tested using similar parameters to those in [6]. This study concludes that *W&F* and its derivatives outperform *Lobanov* in the tests applied to these data. See also [2, 8 , 9] for other normalization comparisons that include *W&F*. Figures 1, 2 and 3 illustrate the efficacy of *mW&F* and *Lobanov* in normalizing Peterson and Barney's American English vowel data [17].

Figure 3: Peterson & Barney data, group means, *mW&F*-normalized.



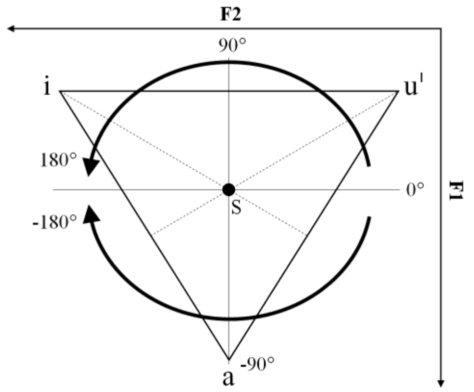
We contend that, for sociophonetic data, the *W&F* algorithms offer a competitive choice over earlier alternatives. This paper now presents an additional advantage of *W&F*: the fact that the centroid of the vowel system can provide an anchor point for geometrical comparisons of locations on the F1-F2 plane.

4. THE *S*-CENTROID ANCHOR METHOD

Given the efficacy of the *S*-centroid method, its utility for sociophonetic research is worth exploiting further. Previous work [4, 5] has explored the possibilities of quantifying planar locations between points in vowel space. These initial studies sought to plot vowel positions relative to each other and to examine how these configurational patterns, specifically the juxtaposition of TRAP and STRUT, and of LOT in relation to FOOT, changed in succeeding generations of RP speakers.

The new departure we present in this paper is to anchor the calculation of the angle not on one of the vowel tokens as in [4, 5] but on the centroid *S* (coordinates (1,1) under *W&F*). In keeping with mathematical convention, angle measures are standardized as shown in Figure 4, ranging from 0° to 180° degrees above the centroid, and from 0° to -180° degrees below it.

Figure 4: *S*-centroid anchor and angle values in 360 ° space.



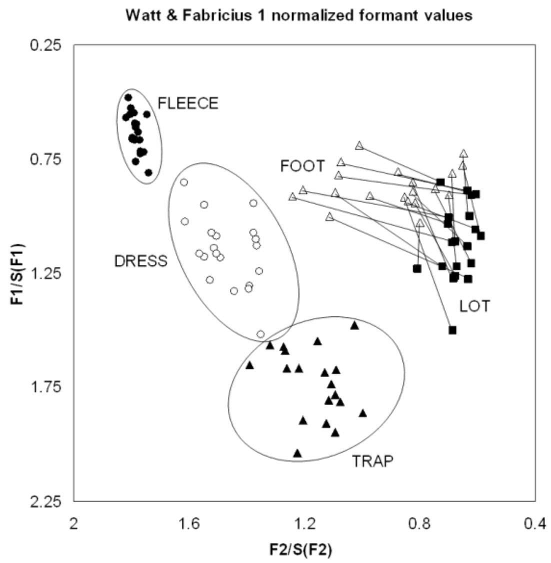
It should be noted that we make no claims here about the centroid's perceptual significance, although the concept does feature in some perception/normalization research, e.g. [3]. The centroid is used simply to investigate and illustrate properties of vowel distributions in F1~F2 space. The advantage of using *S* is that measurements are made relative to a stable point rather than a potentially mobile one, as in the metric technique introduced in [4, 5]. Both techniques of course also have advantages over unquantified 'eyeballed' descriptive observations of vowel plots. The *S*-centroid anchor method can also be used in combination with Euclidean/Cartesian distances as in [4, 5, 18]. Moreover, the quantification of planar locations opens up statistical testing as a possibility for these kinds of analyses.

5. EXEMPLIFICATION IN RP DATA

We now briefly illustrate the potential of the *S*-centroid anchor method for calculating planar locations in the vowel space. The data presented below derive from two studies of RP speakers' vowels [10, 15], originally recorded in 2005 and 2006. The comparison here is made between an older age group (males/females, born 1928-36) and a younger one (males/females, born 1976-81). Figure 5 includes a selection of vowel means for all 20 speakers, with lines connecting each individual's LOT and FOOT averages.

Figure 5 reveals variability in LOT~FOOT configurations across the whole data set. The angles of the connecting lines range from near-vertical to more horizontal. It is well known that FOOT has fronted in younger generations of RP speakers [5], but there is also marked variability in LOT's position in these plots.

Figure 5: Formant data for 20 RP speakers, *mW&F*-normalized; lines join speakers' LOT and FOOT means.



The *S*-centroid anchor method enables us to decompose this variability by comparing angle values *vis-à-vis* a stable centroid point. Figures 6 and 7 are radar plots representing individual speakers arranged in groups: older speakers are in the right two quadrants, with younger ones on the left, and male and female groups alternate. The scale from the periphery to the centre shows the angle value in degrees. These plots thus represent a vowel category's variable angle configurations relative to the centroid, enabling the researcher to portray changing positions in vowel space as changing angles relative to the centroid. From this perspective we can see that variability in FOOT angles is present among the younger generation, but much less so in the older generation. Both younger and older generations have some variability in LOT juxtapositions in the range of -40 ° to +20 °. However, variation in LOT does not follow a simple generational pattern. Older women and most of the younger men are very similar to one another, whereas younger women and older men display comparable ranges of variability, albeit over slightly different angular values. More data, including figures from intermediate generations, would elucidate this further. Variation within both vowel categories over time will then need to be considered in a full account of the trajectories of these vowels over time in RP.

Figure 6: FOOT angles to centroid for 20 RP speakers.

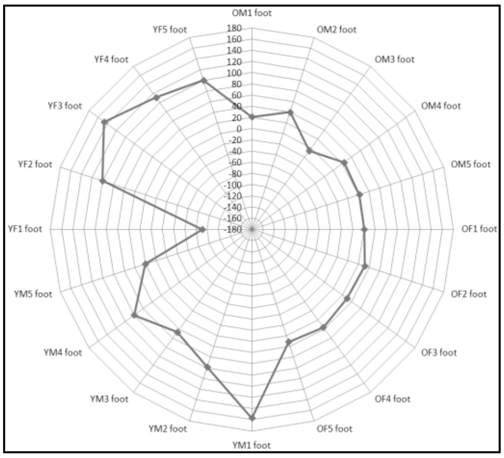
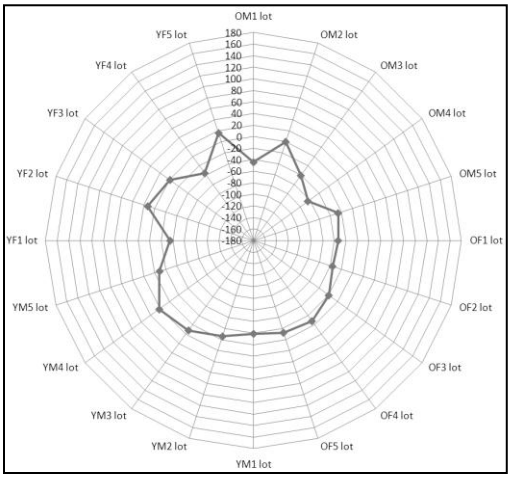


Figure 7: LOT angles to centroid for 20 RP speakers.



6. FUTURE DIRECTIONS

This research contributes a set of replicable parameters enabling a principled and data-led choice of normalization algorithm for sociophonetic data sets. The ways in which normalization algorithms affect planar locations in data can be readily measured using a tool such as the *S*-centroid anchor method. Gauging their relative effectiveness is the aim of future research efforts.

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