USING TWO-DIMENSIONAL BOX PLOTS TO VISUALIZE THE VOWEL SPACE: A STUDY OF ROUNDED VOWEL ALLOPHONES IN TIGRINYA

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1. INTRODUCTION

The depiction of vowels in phonetic figures is traditionally with points plotted in a stylized 'vowel space' quadrilateral; these points represent the mean F1 and F2 for each vowel. While reversing the axes allows an intuitive representation of the height and backness of each vowel, the use of just the average values makes it difficult to assess the distribution of the data.

A conventional box plot displays the median, interquartile range, and total distribution of the data along one axis. For bivariate data like formant plots, two box plots could be superimposed at right angles, but as these are computed for F1 and F2 separately, this is not entirely accurate. Instead, a *bivariate highest density regions box plot* displays the same properties of the data set, but is calculated based on the density of the data points (Hyndman et al., 2010).

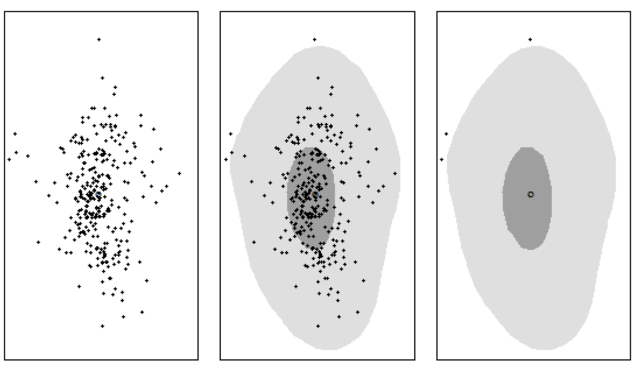

Figure 1. F1 vs. F2, as scatterplot and 2D box plot.

In the bivariate HDR box plot (henceforth 2D box plot) in Figure 1, the circle represents the median, and the darker area corresponds to the box of the conventional box plot. This visualization allows the distribution of the data to be seen clearly, and highlights any anomalies, as seen below. The use of these 2D box plots will be demonstrated through an investigation of rounded allophones in Tigrinya.

1.1. Rounding in Tigrinya

Tigrinya is an Ethio-Semitic language spoken in Eritrea and northern Ethiopia. It has received very little attention from a phonetic standpoint; as such, descriptions of two rounding processes in the language have only received an impressionistic description to date. In both of these processes, the vowels /ə/ and /ɨ/ are described as becoming *o* and *u* respectively (Ullendorff, 1955). I use vowels in italics here because it is not clear what the rounded vowels' identities actually are.

One process, Labiovelar Rounding (LVR), causes these changes when /ə/ or /ɨ/ is found after a labialized dorsal—/kʷ, gʷ, k'ʷ/ in Tigrinya. This change is deeply-ingrained in the language, and the orthographic characters for e.g. /kʷə/ and /ko/ are considered equivalent; many orthographic alternations occur between plain and labialized velars. LVR may also regressively affect a preceding /ə/ or /ɨ/ although orthographic substitution of *o* and *u* for these is less common (Kane, 2000).

The second process is Vowel Harmony (VH), which also rounds /ə/ and /ɨ/ when these segments are followed by an /o/ or /u/ respectively in the next syllable. Harmony usually occurs between central and back vowels of the same height, but its application is less consistent, seeming to vary sometimes between utterances, and appearing more saliently in some words than others; isolated reports also find occasional cross-height harmony (Ullendorff, 1955).

These two processes leave us with two questions about vowel rounding in Tigrinya. First, do /ɨ/ and /ə/ change to [u] and [o], or to other allophones (e.g. [ʉ, ʊ]; [ɵ, ɔ])? Second, do both processes round these vowels in the same way (i.e. to the same allophones)?

2. METHODS

A word list was prepared based on dictionary searches, comprising target words which would display VH or LVR. Sentences were devised to carry the target words, some composed by the author, others by the experimental participant. A decision was made not to use a consistent carrier phrase, so as to make the reading task more natural for the participant, and also obtain a wider range of vowels. Data were collected from a middle-aged male native Tigrinya speaker of the Akkele Guzay dialect; following discussion of the words, the participant was asked to read through the list of sentences twice, repeating each sentence twice (total of four utterances each). Any words that the participant was unfamiliar with were excluded. The vowels' phonological environments were kept as consistent as possible.

The vowels in the recordings were annotated in Praat (Boersma & Weenink, 2011), and average FFT formant values for all vowels were extracted using a custom script. While values for F1, F2, and F3 were collected, no significant patterns were found in F3, so this data is excluded from the results below.

The formant values were then analysed using R and the *hdrcde* package to generate the 2D boxplots seen below (R Development Core Team, 2011; Hyndman et al., 2010).

3. RESULTS

Rounded allophones in VH environments were found to have F2 values between the plain phonemic vowel and the trigger. Figure 2 summarizes these findings; means are also indicated by the vowel labels.

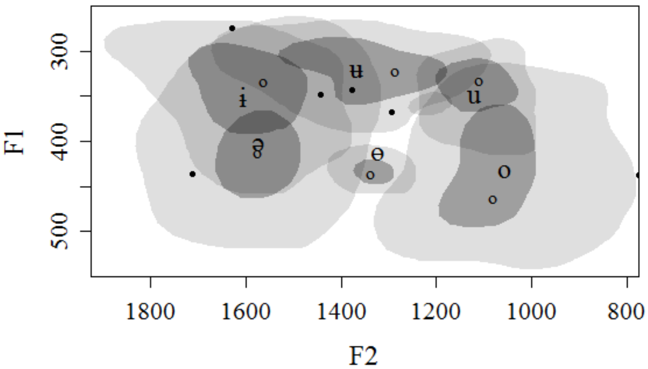

Figure 2. Vowel harmony allophones.

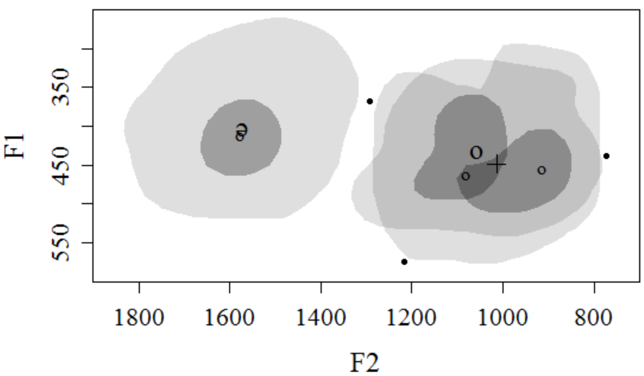

Figure 3. Mid progressive LVR (P-LVR) allophone.

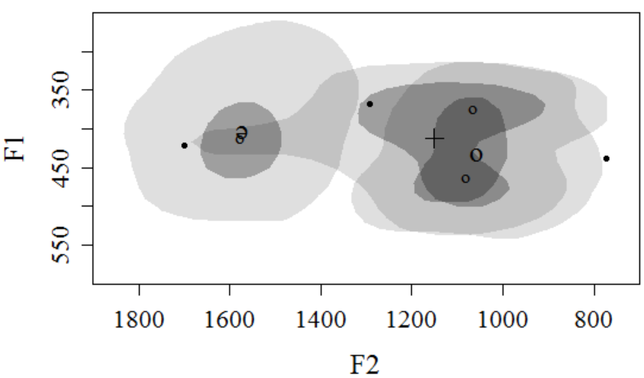

Figure 4. Mid regressive LVR (R-LVR) allophone.

Rounded allophones in LVR environments were found largely to overlap with /o/. Figures 3 and 4 summarize these findings for progressive and regressive LVR; '+' indicates the mean of the rounded allophone. F2 values for the P-LVR allophone were lower because of an over-representation of labial codas in the data; the odd "tail" of the R-LVR allophone is due to one word where none of the tokens displayed rounding.

4. DISCUSSION AND CONCLUSIONS

Although traditional descriptions of Tigrinya describe both VH and LVR as involving changes from /ə/ → *o* and from /ɨ/ → *u*, these are in fact clearly different processes with different outcomes.

VH operates solely in a regressive direction, between central and back vowels in adjacent syllables, whereby /ə/ and /ɨ/ are rounded to intermediate allophones [ɵ] and [ʉ] when followed by /o/, /u/, or other rounded allophones. Harmony is height-restricted, and seemingly variable in strength.

LVR rounds vowels adjacent to labiovelars, primarily in the progressive direction, but also potentially affecting preceding vowels or both preceding and following vowels. LVR causes a full shift from /ə/ → [o] and /ɨ/ → [u].

The use of 2D box plots for this kind of research highlights anomalies in the data that would not be visible from just the mean values. One such anomaly is seen in Figure 4, where one of the words elicitated failed to exhibit R-LVR.

This could also be used to demonstrate that vowels in a particular language are only contrastive along one dimension: for instance, in Eastern Arrernte, only the vowels /a/ and /ə/ are phonemic, meaning the only distinction between the vowels is that of height. Consequently, the vowels vary a great deal in backness, even though their mean F2 is still central (Ladefoged & Maddieson, 1996). By displaying only the mean value, important information about the distribution of the vowels is lost. Ladefoged & Maddieson avoid this by providing a scatterplot, but 2D box plots can display the full range of the data, the centre two quartiles, the median, and the mean if desired, while remaining easier to read than a scatterplot.

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