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An exploration of the acoustic space of rhotics and laterals in Ruruuli

Margaret Zellers[1], *Alena Witzlack-Makarevich*[2], *Lilja Saeboe*[3], *Saudah Namyalo*[4]

[1]Kiel University, Kiel, Germany
[2]Hebrew University of Jerusalem, Jerusalem, Israel
[3]Oxford University, Oxford, UK
[4]Makerere University, Kampala, Uganda

mzellers@isfas.uni-kiel.de, awitzlack@mail.huji.ac.il, lilja.saeboe@ling-phil.ox.ac.uk, snamyalo@chuss.mak.ac.ug

Abstract

Liquid consonants—rhotics and laterals—have been shown to demonstrate unique distributional patterns cross-linguistically. It is also claimed that rhotics are more difficult to distinguish from one another phonetically than laterals, and that rhotics are less flexible than laterals when it comes to participation in consonant clusters and coarticulatory patterns. We investigate the phonetic realization of the rhotic and lateral phonemes in a Bantu language, Ruruuli. The acoustic space used for rhotics and laterals in this language is extremely similar, although the density peaks in terms of formant values are different. Formant values as well as formant ratios can be reliably used to distinguish between rhotics and laterals. In common with many other languages, an asymmetry between laterals and rhotics is found in Ruruuli, with laterals being more positionally constrained than rhotics. The overlap in acoustic space between rhotics and laterals may cast doubt on the status or stability of the phonological contrast between rhotics and laterals in this language.

Index Terms: liquid consonants, laterals, rhotics, acoustic phonetics, Bantu

1. Introduction

The goal of the current study is to address the phonetic features underlying an attested phonological contrast between /r/ and /l/ in the Bantu language Ruruuli-Lunyala (ISO 639-3: ruc), spoken in the Nakasongola and Kayunga districts of central Uganda. Such a contrast is typologically unusual in languages in the region and requires further investigation.

According to our current analysis [1], /l/ and /r/ are two distinct phonemes and a number of segmentally minimal pairs were identified, e.g. *alaalya* /alaːlja/ 'to spread out' vs. *araalya* /araːlja/ 'to scatter', *ibala* /iβala/ 'stain, spot' vs. *ibara* /iβara/ 'name', *rubogo* /ruβogo/ 'brownish bull or he-goat' vs. *lubogo* /luβogo/ 'bark cloth', *kinyolo* /kiɲolo/ 'door bolt' vs. *Kinyoro* /kiɲoro/ 'the Kinyoro way'. Numerous speakers we worked with are consistent in preserving the contrast between rhotics and laterals. Specifically, the contrast is preserved word-initially and after the vowels /a/, /o/, and /u/, while it is neutralized after the front vowels /i/ and /e/. The underlying /l/ is realized as a rhotic after /i/ and /e/, and this positional restriction is reflected in the orthography. On the other hand, there seems to be substantial dialectal and idiolectal variation in the realization of liquids. Their representation in the practical orthography was one of the most challenging topics during its development.

1.1. Rhotics and laterals cross-linguistically

Rhotics and laterals comprise the class of liquid consonants. Laterals are articulatorily classified on the basis that airflow is blocked by the tongue in the middle of the mouth, but can still proceed over the sides of the tongue. Rhotics have proven more difficult to describe as a natural class from a phonetic point of view. [2] argued that rhotics should be classified based on a cluster of acoustic features, while more recent work has argued that rhotics have a common articulatory feature, a secondary pharyngeal constriction [3, 4]. The liquid class is reported to be characterized cross-linguistically by a high degree of interchangeability between the two subclasses of rhotics and laterals; however, when the behavior of rhotics and laterals are compared, laterals tend to pattern more with obstruents, while rhotics tend to pattern more with vocoids [5].

[6] reports on relationships between rhotics and laterals across a variety of languages, finding that it is very infrequent for a language to have more than one rhotic consonant, while systems involving multiple laterals are more frequent. In phonological systems with multiple liquids, the most common configuration is one lateral and one rhotic; allophonic alternations between rhotics and laterals are also common.

A substantial amount of evidence suggests that the rhotic consonants are cross-linguistically more difficult to distinguish from one another than the lateral consonants. [7] found that Swedish listeners performed mostly at chance level when attempting to distinguish between alveolar and uvular rhotics, and were strongly influenced by whether they themselves tended to use the alveolar or the uvular variant. [8] reports that listeners had more difficulty distinguishing among unfamiliar rhotics than unfamiliar laterals, nasals, fricatives, or plosives, and that the acoustic space covered by the rhotics was relatively smaller than for other classes, though similar in size to that of laterals. [9] reports on the high degree of phonetic variability available for rhotics in Israeli Hebrew, where rhotics can be produced as (canonical) dorsal approximants, "dirty vowels" (i.e. approximants with some frication), fricatives, taps, trills, and even plosives. Non-approximant productions of rhotics were particularly typical in word-initial position. [10] report comparable types of variability in constriction in the production of Greek rhotics, with place and degree of constriction being conditioned by segmental and prosodic context, in addition to individual speaker differences. The high degree of variability in these production studies is consistent with the reports about difficulty of distinguishing among rhotics.

Contrasts in rhotics are reported to be relatively more susceptible to collapse than contrasts in other types of consonants, including laterals. [11] reports that in Russian, while alveolar

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and palatalized laterals are consistently distinguishable in terms of their acoustic and articulatory characteristics, alveolar and palatalized rhotics are much less distinguishable. Furthermore, palatalized rhotics may not arise in all positions, and the palatalization of the rhotic does not lead to coarticulatory palatalization on adjacent consonants. [12] point out that many languages prohibit /r/ from arising adjacent to the approximant /j/ and similarly located high front vowel /i/; they argue that this is due to conflicting articulatory needs and inflexibility in terms of coarticulation. [5], on the other hand, suggests that the asymmetry between rhotics and laterals arises on the basis of articulatory differences: namely in the configuration and stability of the dorsal aperture, and in the degree of stiffness of the tongue tip.

1.2. Rhotics and laterals in Bantu languages

Many Bantu languages have only one contrastive liquid [13], though inventories with two liquids have been reported (e.g. for Chaga [14]). For the Bantu languages of Uganda it has also been claimed that only one liquid phoneme exists [15]. However, the realization of this phoneme varies and this variation is often captured in practical orthographies. Luganda illustrates a typical situation: the alveolar liquid consonant phoneme /l/ has different realizations depending on the preceding vowel. According to [16, p. 4], the liquid takes the form of an "alveolar rolled" (alveolar trill, [r]) only after a front vowel, and elsewhere it is realized as an "alveolar lateral frictionless" (lateral approximant [l]) (see also [17]). This pattern is reflected in the standard orthography of Luganda in the convention of writing $<$ r $>$ after front vowels and $<$ l $>$ elsewhere. Similar positional restrictions on the distribution of rhotics are reported for many Bantu languages, see e.g. [18] on Lunyole and [19] on Jita. Thus the Bantu languages appear to differ from other languages in terms of the respective degree of constraints on laterals and rhotics (cf. Section 1.1).

Among phoneticians and transcribers, there are discrepancies as to the actual realization of this phoneme in Bantu languages. Thus, according to [15, p. 41] the phonetic realization of the liquid in Luganda is "usually somewhere between **r** and **l**, and is not as predictable as the convention would indicate" (see also [20, p. 261–263] and the overview in [21]). [21] summarizes earlier accounts by stating that though Luganda scholars agree that the liquid is realized as a rhotic after a front vowel, they do not agree as to whether this rhotic is a tap or a trill, or whether it varies between the two. Similarly, accounts of the realization of the liquid in Luganda after non-front vowels vary between [l], [ɾ], [ɹ], and [ɺ].

1.3. Research questions

The current study aims to address two questions: (a) How do the acoustic spaces of rhotics and laterals in Ruruuli compare with each other in terms of size and degree of overlap?, and (b) To what extent do the acoustic features support a phonological distinction between rhotics and laterals in Ruruuli, as suggested by the orthography, versus a single liquid phoneme, in common with most other Bantu languages in the area?

2. Methodology

2.1. Data: selection, segmentation, annotation

The data used in the current study come from recordings made to accompany a dictionary of the Ruruuli-Lunyala language [1]. The recordings were carried out in the summer of 2019 in Nakasongola, Uganda. All tokens were produced by a single speaker (female, age 43 at the time of recording). The speaker was selected to carry out the dictionary recordings as she was considered by the community to be a representative and clear speaker of the Ruruuli language. Thus, although the current study may be considered as somewhat limited since it only investigates a single speaker, it is reasonable to assume that this speaker produced all relevant contrasts as well as producing coarticulations in an appropriate and standard manner for Ruruuli.

The recordings were carried out as lists of single words, with each word repeated three times; in order to keep prosodic features consistent, the third production of the word was always the token selected for the collection. The recording was made using a Zoom H4n recorder, with the speaker wearing a headset microphone, which helped to minimize inevitable background noise while recording in the field.

For the current study, a set of /l/ (n = 141) and /r/ (n = 155) tokens were selected semi-randomly from the data. The phonological classification of the token as lateral or rhotic arose from the orthography assigned to the word by the speakers' community and attested in [1]. A phonetic segmentation of the lateral or rhotic, plus the preceding and following vowels, was carried out by hand. Impressionistic phonetic labels were also assigned to the rhotics and laterals; /r/ was realized primarily as [ɹ] or [ɾ], and /l/ was realized primarily as [l] or [ɺ]. Identification of lateral boundaries proceeded based on the sudden change in position of formants in the spectrogram and, when visible, indications of the movement of the tongue in the spectrogram. Identification of rhotic boundaries was based on the sudden drop and following reappearance of the third formant (F3). If a clear boundary could not be identified, the boundary was placed in the middle of the formant transition. Two annotators carried out the segmentations; ambiguous cases were resolved through discussion. Liquid duration was measured automatically from the boundaries of the annotated segments.

2.2. Formant extraction

Following many of the studies cited in Section 1.1, we investigated the distribution of formants in the liquid tokens. For each token, the first three formants (hereafter F1, F2, and F3) were automatically extracted from the center of the liquid consonant using Praat's [22] default calculation of a Formant Object. Since F3 tends to drop in the middle of rhotics, merging with F2, the F3 reported by Praat is likely to actually be the fourth formant; this is borne out by the fact that the measured F3 was significantly higher in rhotic tokens (according to the phonological classification) than in lateral tokens (Mean F3 for rhotics = 2661 Hz; mean F3 for laterals = 2559 Hz; $t(280.08) = -3.32$, $p < .01$). However, we have retained the label F3 since the measured formant was the third one available for automatic measurement. Since all of the tokens came from one speaker, values were left in Hertz rather than normalizing using a logarithmic adjustment. The automatic formant measurements were hand-checked and two errors were manually corrected.

3. Analysis and results

3.1. Liquid duration

Tokens with the phonological label /r/ were longer than those with the phonological label /l/ (mean duration /r/ = 0.436 sec, mean duration /l/ = 0.379 sec, $t(261.34) = -2.94$, $p < .01$). Tokens labelled as /r/ were relatively shorter following the vowel /u/ than other liquids ($t(274.3) = 3.774$, $p < .01$), but otherwise

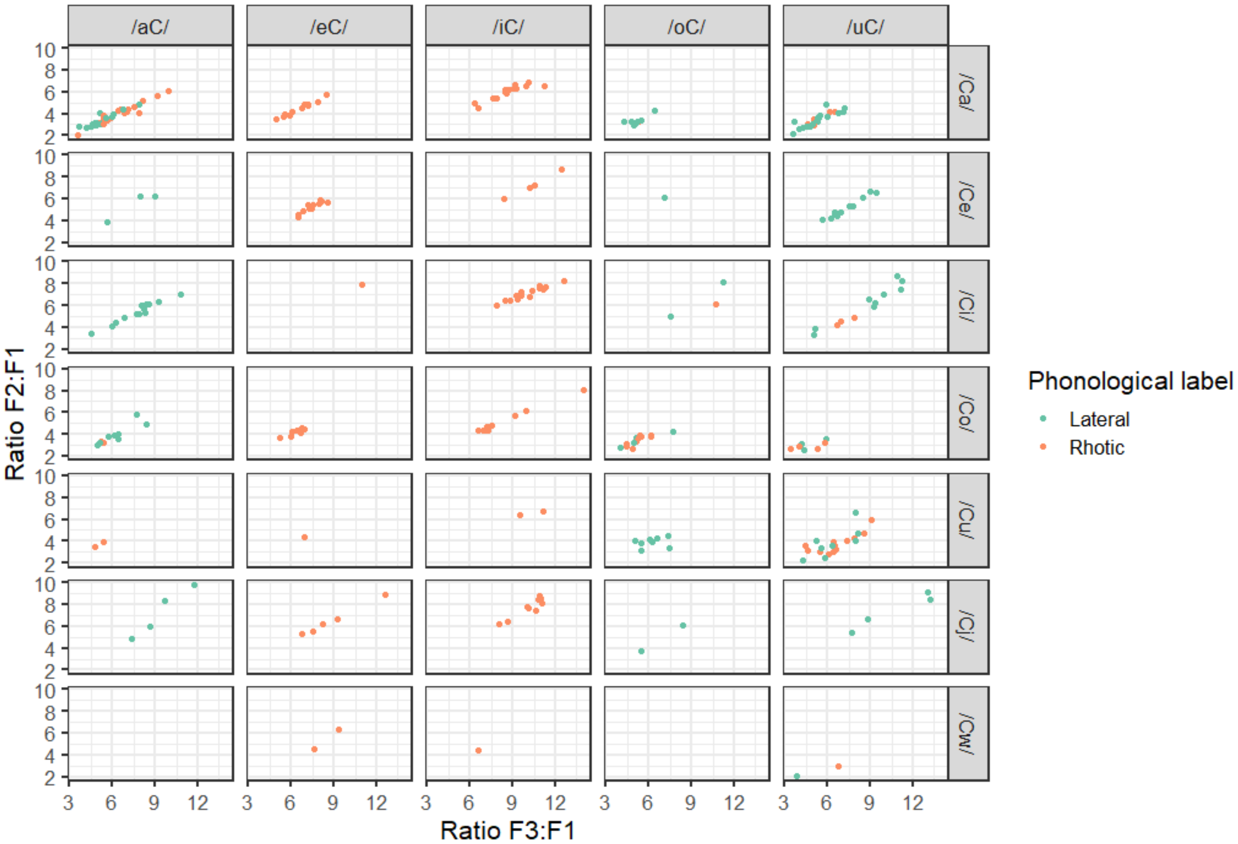

Figure 1: *Scatterplot of formant ratios in /r/ and /l/ tokens in different vocalic contexts. C refers to the location of the liquid consonant, with its preceding or following vowel.*

no significant effects of vocalic context on liquid duration were found. This contrasts with e.g. [21]'s report for Luganda, where liquids following front vowels were found to be shorter than those following non-front vowels.

3.2. Formant structure

Tokens which were phonologically classified as rhotics or laterals could be distinguished from one another statistically using the formant values. A logistic regression calculated using package `lme4` [23] in R [24] showed that the interactions F1*F2, F2*F3, and F1*F3 all contributed significantly to the distinction between phonological rhotics and phonological laterals ($\chi^2(2,9) = 41.22$, $p<.01$ when compared to a null model).

Since the interactions between the formants attained statistical significance, we decided to further investigate the role which the ratio between the formants plays in terms of distinguishing laterals and rhotics in Ruruuli. Figure 1 shows the distribution of two ratios, F2 compared to F1 and F3 compared to F1. (The ratio F3 to F2 was not significantly different between /r/ and /l/, even though the F3*F2 interaction achieved significance in the logistic regression). Figure 1 additionally shows the distribution of rhotics and laterals in the different intervocalic contexts which are possible in Ruruuli. Although Ruruuli has phonologically long and short vowels, for the sake of simplicity we have collapsed long and short vowels into five vowel-quality categories, /a/, /e/, /i/, /o/, and /u/. The post-liquid context has two additional possibilities, the glides /j/ and /w/; while post-liquid /j/ is common, /w/ is relatively infrequent, occurring in only 5 tokens in the current study.

A visual inspection of Figure 1 shows that most vowel contexts do not make use of the whole acoustic range, either for rhotics or for laterals. In contexts adjacent to /o/ and /u/ the tendency is for the lower range of both formant ratios to be used (that is, F2 and F3 are relatively closer to F1), while in contexts adjacent to /i/, there is more tendency for the higher range of the ratios to be used (that is, F2 and F3 are relatively farther away from F1). This is consistent with coarticulatory effects related to the vowel, since F2 should be higher in /i/ than in /o/ or /u/.

For most intervocalic contexts where both /r/ and /l/ are possible, /l/ has a relatively larger variability than /r/. The only contexts where this is not the case are /aCa/, /oCu/, and /uCu/ (where C represents the liquid consonant). A series of independent t-tests with Bonferroni corrections showed that only in the /aCa/ case are the rhotics and liquids reliably distinguished either by the raw formant values or the ratio values (F2:F1 ratio: $t(25.23) = -2.797$, adjusted $p<.05$; F3:F1 ratio: $t(24.34) = -3.260$, adjusted $p<.01$).

As can be seen in Figure 1, laterals do not arise following the front vowels /i/ and /e/ in Ruruuli, although they may themselves be followed by a front vowel or form a syllable-initial cluster with the approximant /j/.

Figure 2 shows the overall distribution of /r/ and /l/ in terms of the F1 and F2 values measured for them. From this image it is clear that the overall formant space occupied by rhotics and laterals is extremely similar. Laterals may have slightly

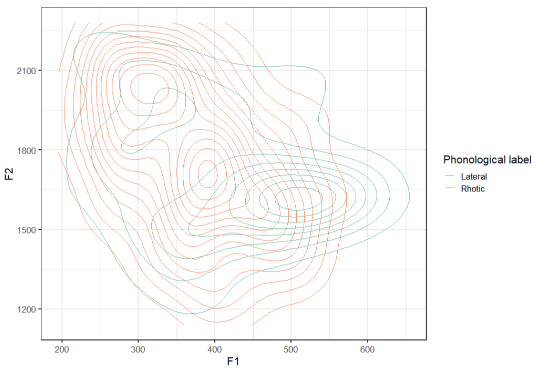

Figure 2: *Density plot of F1 and F2 in /r/ and /l/.*

higher F1 values, while rhotics appear to achieve both higher and lower F2 values than laterals. The clearest difference in the visualization is in the locations of density peaks. Each density distribution appears to have two peaks. This is consistent with the results of our impressionistic phonetic labelling (cf. Section 2.1), where there were two main realizations of /r/ and /l/ respectively. However, since our labelling is still preliminary, we have not yet carried out an analysis directly linking the formant distributions to the impressionistic labels.

4. Discussion

The current study finds a high degree of overlap in the acoustic features, specifically the formant characteristics and durations, of laterals and rhotics in Ruruuli. Despite the overlap, laterals and rhotics can be distinguished using the first three formant values. A closer inspection of the data suggests that in many contexts, no acoustic distinction is necessary, since only one category or the other arises. In cases where both categories are possible, however, there is also not always a clear distinction between the formant ratios associated with laterals and rhotics.

4.1. Acoustic overlap and status of phonological contrast

It is not unusual for rhotics and laterals to share a substantial amount of acoustic space [8], as was found in the current study. In contrast to other languages, where the acoustic space for rhotics is found to be smaller than that of laterals (cf. Section 1.1), here the size of the two acoustic spaces is similar. However, the linguistic context of Ruruuli also raises some possible considerations with regard to language change and language contact. The dominant language in the region of Uganda where Ruruuli is spoken is the related Bantu language Luganda. Luganda has no phonological contrast between /r/ and /l/, the various realizations are instead found in complementary distribution depending on the segmental context [20, 21]; most other Bantu languages in the area also have a single liquid phoneme (cf. Section 1.2). Although the orthography of Ruruuli/Lunyala, developed by the speakers, suggests a distinction between /r/ and /l/ in contrastive contexts (cf. Section 1), it is still unclear to what extent this phonological distinction exists for all speakers.

Since the current study only used data from one speaker, it is necessary to be cautious about extending assumptions about the phonological structure to all speakers. The selection of the current data set was based partly on convenience, since the lexical tokens were already labelled. The current study will serve as a foundation for future work on the Ruruuli liquid consonants. We plan to extend the analysis to include data taken from spontaneous interactions (interviews and conversations). Additionally, a perceptual study will investigate the degree to which speakers of Ruruuli are able to auditorily distinguish tokens of /r/ and /l/, providing further information as to the status of the phonological contrast.

4.2. Other acoustic features

The studies reported in Section 1.1, to the extent that they investigate acoustic (rather than articulatory) data, focus their attention heavily on formant values as a crucial acoustic indicator for rhotics and laterals. While the formant values and formant ratios indeed provide a way of distinguishing rhotics from laterals in a statistical sense, the overlap of the formant space is still substantial. Although the peaks of the distributions in Ruruuli are different, as discussed in Section 3, there are still many cases in which the formant values and distributions of /r/ and /l/ fall in similar spaces. Additionally, the influence of coarticulation on both /r/ and /l/ appears to behave similarly, although a further, more detailed analysis would be necessary to confirm this impressionistic observation. The finding that rhotics and laterals in Ruruuli appear to have different average durations might support their identification as separate phonological categories, since in Luganda, where they are allophones of one liquid phoneme, duration variations matched with the expected allophonic representation in a specific vocalic context [21].

It is likely that acoustic features other than the formant values could support the contrast between /r/ and /l/ in perception. [21], for example, additionally investigates harmonic-to-noise ratios and intensities of liquid consonants. These, as well as differences in speed of transitions, or other features such as frication accompanying tokens of one liquid but not the other, might be potential phonetic cues to this contrast in Ruruuli.

5. Conclusions

The current study found evidence that the acoustic space for rhotics and laterals in Ruruuli overlaps substantially, although the two are still statistically distinguishable and have different density peaks in terms of their formant distributions. While in contexts following high vowels, confusion is avoided by the prohibition against laterals, in other contexts it is not possible on the basis of the formants to fully distinguish between /r/ and /l/. These findings contribute to the description of Ruruuli as well as its contextualization among other Bantu languages. They also provide additional information helping to characterize cross-linguistic asymmetries between laterals and rhotics. While investigations of other acoustic parameters as well as perceptual studies are still needed in order to more clearly classify these sounds, the current work provides a foundation on which to build other research on the liquid consonants in Ruruuli.

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