‘Advanced Tongue Root’ in Lopit: Acoustic and ultrasound evidence

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Abstract

This paper presents the results of an acoustic and articulatory investigation of Advanced Tongue Root (ATR) in Lopit, an Eastern Nilotic language. As a phonological feature, ATR is widely attested in African vowel systems, and is held to correlate with tongue root advancement as a corollary of pharyngeal expansion. In the limited descriptive work on Lopit, there are different views on the presence and nature of such a contrast. Acoustic results indicate that Lopit has a 9-vowel system with an ATR-type contrast. Pilot ultrasound results suggest that the gestural correlate of the contrast is one of tongue root advancement.

Index Terms: Advanced Tongue Root, ultrasound, Nilotic

1. Introduction

Lopit is an Eastern Nilotic (Nilo-Saharan) language spoken in the Lopit Mountains of South Sudan, and by diaspora groups elsewhere in Africa and overseas. It is a minority language, and has received only limited descriptive attention. Existing phonological observations include proposals that in the vowel inventory of Lopit, the phonological feature ‘Advanced Tongue Root’ (ATR) is used to form contrasts between vowels, though there are different opinions on the number of monophthongs in Lopit, and presence and nature of such a contrast. The current study is part of a wider documentation project taking place with small community of Lopit speakers living in Melbourne, and presents selected results from an acoustic experiment and pilot ultrasound experiment investigating Lopit monophthongs.

1.1. Phonology of ATR, and observations for Lopit

ATR is viewed as a binary phonological feature distinguishing vowels of a similar height, backness, and rounding (see [1] for an overview). The feature is typically also used in vowel harmony processes, with vowels in a given word being either all [+ATR] or [-ATR]. ATR contrasts are widely attested in Niger-Congo and Nilo-Saharan languages, as well as some non-African languages. In languages with an ATR contrast, a 9-vowel system is most common, with a contrast among the close and mid vowels but only one open vowel. For most Eastern Nilotic languages, such as Maasai and Turkana, a 9-vowel system is usual [2] [3], but languages in the Bari sub-family have a 10-vowel system [4]. For Lopit, a 10-vowel system with an ATR contrast has been proposed by Vossen [5] and Turner [6], with both tentatively suggesting that the language has both a [+ATR] and a [-ATR] open vowel. Stirtz [7] instead proposes a 5-vowel system, with no ATR contrast. In the present research on Lopit, impressions are of a 9-vowel system with an ATR-type contrast and leftwards-spreading ATR harmony.

+ATR	/i/	/e/	/o/	/u/	
-ATR	/ɪ/	/ɛ/	/ɔ/	/ʊ/	/a/

1.2. Acoustic characteristics of ATR

Though ATR contrasts are widely attested, phonetic investigations remain limited, and have primarily focused on Niger-Congo languages. A very consistent finding is that vowels classed as [+ATR] tend to have a lower first formant frequency (F1) than their [-ATR] counterparts. Among Eastern Nilotic languages, this has been observed in the 9-vowel system of Maasai [2], and for the [+ATR] low vowel in in the 10-vowel system of Bari [8]. Differences in F2 values and duration between [+/-ATR] vowels have also been observed, but the pattern is less consistent across languages or pairs of vowels within languages (see [1]). There is also evidence that [+ATR] vowels may tend towards a more breathy voice quality [2] [9]. In general, then, a combination of cues may distinguish [+ATR] vowels from [-ATR] vowels, but lower F1 appears to be a crosslinguistically reliable correlate.

1.3. Articulatory characteristics of ATR

The phonological feature [+ATR] is held to correlate with advancement of the tongue root, as a corollary of pharyngeal expansion [10]. Tongue root movement has been observed in many early cineradiographic studies of Niger-Congo languages [11] as well as more recent ultrasound studies [12] [13] [14], and observations of pharyngeal expansion have been supported by evidence from magnetic resonance imaging (MRI) [15]. Few Nilo-Saharan languages have been the subject of articulatory investigations, but there are suggestions that the articulatory gesture may be less uniform than for Niger-Congo languages. In Western Nilotic DhoLuo, tongue height may be used instead or as well as tongue root advancement to produce [+ATR] vowels [16], and for Eastern Nilotic Ateso, tongue height is described as the main gesture [17]. Given that the acoustic consequences of tongue root advancement and tongue body raising are similar, both acoustic and articulatory investigations are required in order to identify the gestural correlate of ATR category.

2. Research aims

This paper seeks to establish the number of monophthongs in Lopit, and develop a description of the acoustic and articulatory nature of the contrast between proposed [+/-ATR] vowels. While there are a range of questions relating to the vowel inventory of Lopit, only results addressing the following questions will be presented in this paper: Is it possible to differentiate putative [+ATR] vowels /i, e, o, u/ from [-ATR] vowels /ɪ, ɛ, ɔ, ʊ/ on the basis of F1, F2, and/or F3, and on the basis of tongue root position and/or tongue body height? Is there acoustic or articulatory evidence that /a/ has a contrastive [+ATR] counterpart?

3. Method

3.1. Acoustic experiment

3.1.1. Participants

Participants for this acoustic phonetic experiment were four male speakers of the Dorik dialect of Lopit: AL, JL, DA, and VH, aged 52, 52, 35 and 28. They are part of the small Lopit community of Melbourne's south-eastern suburbs, and arrived in Australia between 2000-2009. Members of the community are all multilingual, as is the norm for many Lopit people both in South Sudan and in the diaspora, but Lopit is the main language used in daily life. Participant VH (chosen for his availability) took part in the pilot ultrasound experiment which followed.

3.1.2. Stimuli and procedures

The wordlist used included 10 examples of each [+ATR] vowel, plus 10 examples of each [-ATR] vowel occurring in a similar context, as well as 10 examples of /a/ in the environment of [-ATR] vowels and 10 examples of /a/ in the environment of [+ATR] vowels (where a [+ATR] low vowel would be expected to occur if it exists). Slides with prompts for these items (all nouns) embedded in the frame *ɛbak batak X tɛ rʊxʊlʊn* "the pig hit X purposefully" were shown to participants on a notebook computer. Prompts were written the Lopit working orthography (which does not indicate ATR quality or tone), with English glosses beaneath. Data were recorded over several sessions in the recording studio at the University of Melbourne, at a sampling rate of 16-bit/44.1kHz. For participant JL, it was only possible to record citation data. Analyses were based on three repetitions of the 100 words across four speakers, giving a total of 1200 vowel tokens.

3.1.3. Analyses

Data were labelled in Praat [18], then imported to the Emu Speech Database System [19] to extract acoustic data. In this paper, results for F1, F2, and F3 taken at vowel midpoints are presented. Data were queried in the R software environment [20] and tested with Linear Mixed Effects Models (LMM), as well as per-speaker Analyses of Variance (ANOVA).

3.2. Ultrasound experiment

3.2.1. Stimuli and procedures

A subset of the acoustic experiment wordlist was used for the ultrasound experiment, containing two words for each of the 10 vowels of interest (again including /a/ in the environment of [+ATR] vowels). Prompts were displayed to the participant on a computer screen, three times for each citation-form word, and the whole wordlist was repeated three times, to collect a total of 180+ tokens. Ultrasound Tongue Imaging (UTI) took place using the Mind Ray DP6600 ultrasound machine and a 65EC10EA microconvex transducer at 6.5MHz, with a probe depth of 10.8cm. VH wore a Probe Stabilisation Headset [21]. Ultrasound data were recorded at a variable frame rate of 24fps, and captured using the Articulate Assistant Advanced Software [22] with concurrent audio recording.

3.2.2. Analyses

Video files were de-interlaced to 50fps, and synchronisation of audio and video took place in Sony Vegas to repair any alignment issues. Audio data were labelled for vowel midpoints in Praat, and the corresponding video frame extracted in Anvil [23]. The 18 frames for each vowel type were then imported into EdgeTrak [24] for semi-automatic tracing of tongue contours. A total of 12 frames were traced for each vowel; for some frames, image quality was too poor for contour tracing to take place. Contours were then exported as a a series of XY coordinates, with 100 points for each contour, and a conversion from pixels to cm based on probe depth. The data were imported to R, and comparisons of curve shapes were undertaken using Smoothing Spline Analyses of Variance (SSANOVA) [25], using a modifed version of a script by Mielke [26].

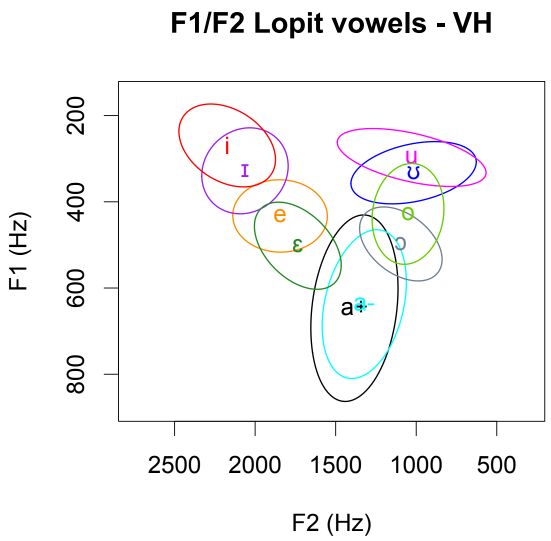

Figure 1: *Example vowel space for VH (95% CI).*

4. Acoustic results

4.1. F1

F1 values for the paired vowels /i, ɪ/, /e, ɛ/, /o, ɔ/, and /u, ʊ/ were compared using LMM, as well as for /a/ in the environment of [+ATR] vowels and [-ATR] vowels. For all pairs, [+ATR] vowels have significantly lower F1 values ($p<0.001$), but there are no significant differences between /a/ in the environment of [+ATR] compared to [-ATR] vowels ($p=0.5103$). For individual participants, ANOVA results show that F1 differences between [+ATR] vowels and their [-ATR] counterparts are significant ($p<0.001$) for all paired vowels and all participants, with the exception of /u/ and /ʊ/ ($p=0.1446$) for VH. No individual differences were apparent for /a/ in the two contexts. Figure 1 shows an example vowel space for VH, who also participated in the pilot ultrasound experiment.

4.2. F2

F2 values were compared for the same vowels, and LMM results show that there are significant differences for /i, ɪ/, /e, ɛ/, and /o, ɔ/, with F2 values being higher for the front vowels and lower for the back vowels ($p<0.001$). However, there are no significant F2 differences for /u, ʊ/ ($p=0.3551$), and as for F1 results, there are no significant differences between examples of /a/ in the [+ATR] compared to [-ATR] context ($p=0.1142$). Individual ANOVAs show some variation in F2 significance for different speakers and vowels, but no F2 differences between /a/ in the [+ATR] context and /a/ in the [-ATR] context.

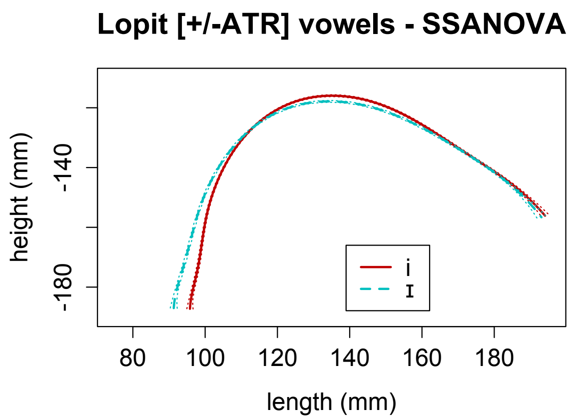

Figure 2: *SSANOVA results (mm) for traces of* [+ATR] /i/ *and* [-ATR] /ɪ/ *for participant VH. Tongue root is on the left.*

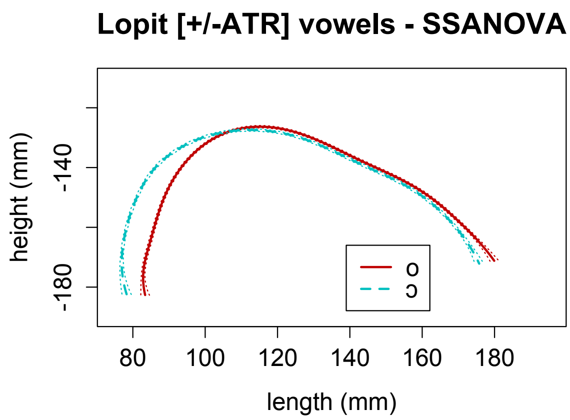

Figure 4: *SSANOVA results (mm) for traces of* [+ATR] /o/ *and* [-ATR] /ɔ/ *for participant VH. Tongue root is on the left.*

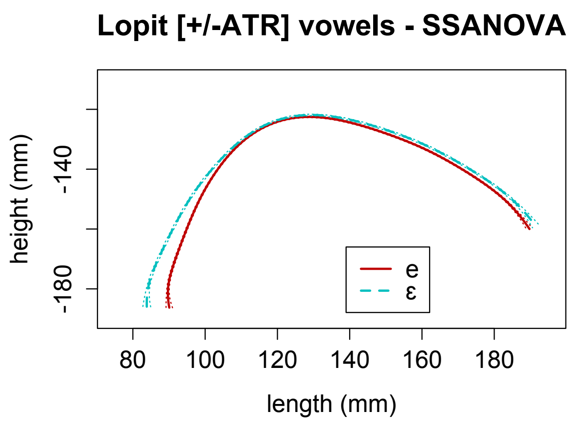

Figure 3: *SSANOVA results (mm) for traces of* [+ATR] /e/ *and* [-ATR] /ɛ/ *for participant VH. Tongue root is on the left.*

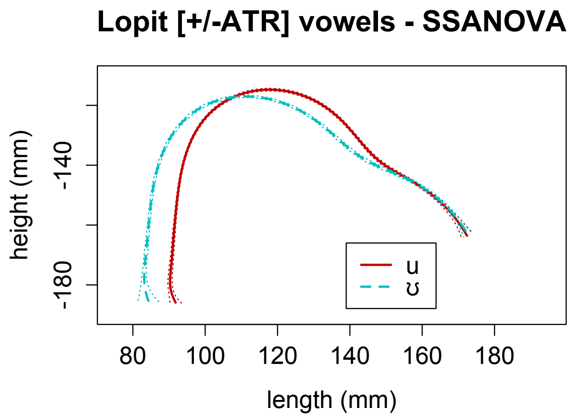

Figure 5: *SSANOVA results (mm) for traces of* [+ATR] /u/ *and* [-ATR] /ʊ/ *for participant VH. Tongue root is on the left.*

4.3. F3

While it was hypothesised that F3 may offer an additional cue to differences between back vowels /u, ʊ/, LMM results show that only /i, ɪ/ differ, with /i/ having significantly higher F3 values ($p<0.001$). Individual ANOVAs show that /o/ has significantly higher F3 values than /ɔ/ for participant JL ($p<0.01$), with a similar but non-significant pattern for VH ($p=0.0508$). Interestingly, DA shows significant F3 differences between /a/ in [+ATR] and [-ATR] contexts ($p<0.01$), for which no F1 or F2 differences were observed.

5. Ultrasound results

Figure 2 shows the SSANOVA results for the close-front vowels /i/ and /ɪ/ produced by participant VH. Differences in the curve shapes are considered to be significant in sections for which there is no overlap in the 95% confidence intervals (dotted lines) of each curve. For these vowels, differences in the position of the tongue root are apparent, with [+ATR] /i/ having a more anterior position. In additon, there are some differences in tongue body height, with /i/ having a slightly higher position. For the mid-front vowels/e/ and /ɛ/, shown in Figure 3, it is also the [+ATR] vowel, /e/, which has a more anterior positon. The pattern is similar among the back vowels; a large portion of the tongue root is significantly more anterior for [+ATR] /o/ than for /ɔ/ in Figure 4, and in Figure 5, again it is the [+ATR] vowel, /u/, which has a more anterior position. Some additional differences in tongue body height can be observed.

Figure 6 shows SSANOVA results for the low vowel /a/ in the context of [-ATR] vowels compared to [+ATR] vowels, where a [+ATR] counterpart would be expected if it were a contrastive vowel category in Lopit. In this comparison, there is clear overlap in the confidence intervals for each set of tokens at both the tongue root and the rest of the tongue body, indicating that at least for VH, there are not two distinct low vowels.

6. Discussion and conclusions

The acoustic and preliminary articulatory findings presented here provide strong evidence that the vowel inventory of the Dorik dialect of Lopit contains 9 monophthongs. Acoustic results suggest that the nature of the contrast between vowels is typical of ATR systems: there is a contrast between vowels of a similar height, backness, and rounding, and the contrast is primarily realised by differences in F1, with vowels categorised as [+ATR] having lower F1 values. This result also matches observations made for the closely-related Maasai [2]. The number of vowels is also typical of ATR-systems, and in particular, typical of other Eastern Nilotic languages in the Lotuxo-Maa sub-family of which Lopit is a member: there is evidence for 9 monophthongs, with an ATR-type contrast for the 4 pairs of vowels /i, ɪ/, /e, ɛ/, /o, ɔ/, and /u, ʊ/, but no convincing evidence for a [+ATR] counterpart to [-ATR] /a/.

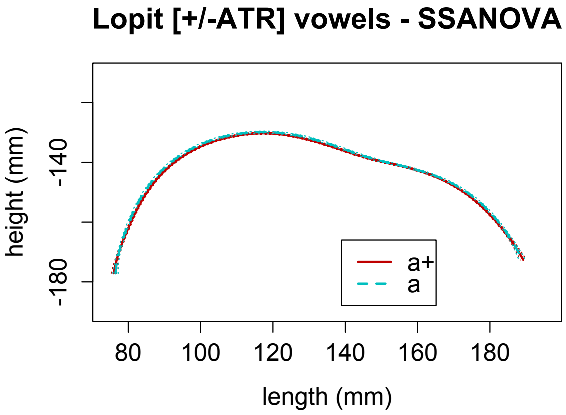

Figure 6: *SSANOVA results (mm) for traces of* /a/ *in the context of* [+ATR] *vowels and* /a/ *in the context of* [-ATR] *vowels for participant VH. Tongue root is on the left.*

Pilot ultrasound results provide supporting evidence for a 9-vowel analysis, with different tongue contours observed for the 4 pairs of vowels /i, ɪ/, /e, ɛ/, /o, ɔ/, and /u, ʊ/, but no sign that there is a [+ATR] counterpart to [-ATR] /a/ with a distinct tongue contour. Ultrasound results also indicate that the gestural correlate of [+ATR] vowels /i, e, o, u/ compared to [-ATR] vowels /ɪ, ɛ, ɔ, ʊ/ is one of tongue root advancement, rather than tongue body raising, for this participant. This is particularly interesting given that in earlier cineradiographic studies of Ateso, the only Eastern Nilotic language for which articulatory investigations of ATR have taken place, it was was proposed that the main gesture involved in producing [+ATR] vowels was tongue body raising [17]. However, it should also be noted that speaker-specific strategies for producing ATR distinctions have been found in various studies, and that these include options for utilising changes in either tongue height or tongue root, or both [16]. In further articulatory research on Lopit, then, it may well be the case that results differ across speakers.

Further articulatory and acoustic research would also benefit from the inclusion of speakers from a range of dialects. The present data were collected with speakers of the Dorik dialect of Lopit, one of the two northen-most dialects spoken in the Lopit Mountains. Observations of a 10-vowel system for Lopit were based on data collected mainly with speakers of southern and central dialects [5] [6], while the proposal for a 5-vowel system was based on data for the central Ngutira dialect [7]. Little is known about language variation and change in Lopit, but various systematic dialectal differences have been observed from the north to the south of the mountain range. While it would be unusual for the central area to lack an ATR contrast shared by the north and south, it is also the case that particular contrasts in ATR systems are susceptible to vowel merger processes. Further phonetic research is required to understand whether other Lopit vowel inventories are similar to the 9-vowel system, with ‘Advanced Tongue Root’ contrast, of Dorik Lopit.

7. Acknowledgements

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