# Vocalic tongue shape contours in Zande

*Julia Eichholz[1], Michelle Meier[1], Reinhold Greisbach[1], Helma Pasch[2], Germain Landi[2], Tamás Gábor Csapó[3,4], Alexandra Markó[3,5], Andrea Deme[3,5]*

[1]IfLPhonetik & [2]Afrikanistik, University of Cologne, [3]MTA–ELTE "Lendület" Lingual Articulation Research Group, [4]Dept. of Telecommunications and Media Informatics, Budapest University of Technology and Economics, [5]Dept. of Phonetics, Eötvös Loránd University Budapest

jule.biese@gmail.com, mmeier@smail.uni-koeln.de, reinhold.greisbach@uni-koeln.de, helma.pasch@online.de, landi.germain@ymail.com, csapot@tmit.bme.hu, marko.alexandra.elte@gmail.com, andrea_deme@hotmail.com

## Abstract

*In Zande, a Niger-Congo language, there is a phonological process of vowel harmony that resembles to the process of vowel harmony found in many languages of West Africa. In these languages this phonological process is controlled by the feature Advanced Tongue Root (±ATR). The present study examines, whether the feature Advanced Tongue Root controls vowel harmony in Zande as well. One native speaker of Zande was examined using UTI (ultrasound tongue imaging) while he produced the vowels of Zande in isolation. The tongue contours were compared pairwise to detect areas of significant deviation using functional t-tests. The results show that the tongue contours deviate regularly in the area of the tongue dorsum and only occasionally in the area of the tongue root. This might be interpreted in a way that vowel harmony in Zande is not controlled by the feature ATR but by the feature Tongue Height.*

## Introduction

The phonetic manifestations of phonological features are still poorly investigated in many languages outside of Europe. The phonological feature Advanced Tongue Root (±ATR) is a common feature in the vowel systems of many languages in West Africa. In these languages vowels may occur pairwise with +ATR and -ATR contrast (Ladefoged & Maddieson 1996). Based on its definition, ±ATR reflects a forward versus backward movement of the tongue root. However, the actual articulatory realization of this feature, be it a difference in the position of the tongue root, a difference in tongue body height or a combination of both, is disputed and may vary from language to language (Dalton 2011, Hudu 2014).

In the present investigation we focus on the vowel system of the African language Zande (classification: Niger-Congo, Atlantic-Congo, Volta-Congo, North, Adamawa-Ubangi, Ubangi, Zande) spoken in the tri-border area Central African Republic, the Democratic Republic of Congo and South Sudan.

Phonological analyses of Zande led to different solutions regarding its vowel system, claiming that either eight or ten non-nasal vowel phonemes exist in it (Tucker & Hackett 1959, Kumbatulu 1982, Boyd 1997). These analyses are mainly influenced by morphonological reasoning, because Zande exhibits a rather complex vowel harmony, stretching over the whole word or even a whole utterance. Rather undisputed is the fact, that on the phonetic level there are five pairs of vowels which commute under the vowel harmony resulting in ten phonetically distinguishable vowels, even from proponents of the eight vowel solution (Tucker & Hackett 1959, p. 39).

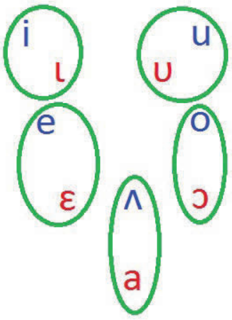

*Figure 1. Due to vowel harmony, either only vowels from class 1 (blue; assumed +ATR) or vowels from class 2 (red; assumed -ATR) are found in a word or an utterance.*

If arranged in a vowel triangle the phonetic vowel inventory of Zande would look like Fig. 1, where there is a clearly visible height difference between class 1 (closed: blue) and class 2 (open: red) vowels. On the other hand descriptions of the vowel quality of the class 1 vowels as being “cavernous” as compared to the class 2 vowels being “hard” (Tucker & Hackett 1959) may also lead to the impression that the distinguishing (phonological) feature could be ±ATR (and not tongue height), as it is in many West African languages. So the aim of this investigation is to shed some light on the phonetic realization of this distinctive vowel feature of Zande, i.e. whether class 1 vowels are produced with advanced tongue root (+ATR) and class 2 vowels are produced with retracted tongue root (-ATR).

## Methods

For the investigation of the articulatory manifestation of the assumed ±ATR feature in Zande we used ultrasound tongue imaging (UTI). UTI is a noninvasive method which offers the possibility to observe the midsagittal tongue contour shape and position as a whole. It might be argued, that due to the shadow of the hyoid bone, the critical region of the tongue root is not completely visible in ultrasound images, but e.g. Hudu (2014) could observe a clear ±ATR tongue root distinction in all of his 5 speakers of Dagbani (a language of Ghana) in his UTI investigation.

We recorded the tongue shape of one male native speaker of Zande in 10 vowels with 3 tones uttered 6 times in isolation, that is, we recorded 18 tokens for every vowel and 180 tokens altogether.

We used a 'Micro' ultrasound system (Articulate Instruments Ltd.) which allows for fixing the transducer beneath the jaw of the speaker with an ultrasound stabilization headset. This headset fixes the transducer, so that its distance to the rear pharyngeal wall and the hard palate remains constant during one complete recording session. Despite the fixed position of the transducer, opening of the jaw is still possible and it will push the transducer slightly inside tissues of the chin. We used a 2-4 MHz / 64 element 20 mm radius convex ultrasound transducer with 92° field of view at 82 fps. The midsagittal tongue contours were traced manually in the center of each vowel - as deduced from the simultaneously recorded audio signal - using APIL’s web app for tongue tracing in UTI images (http://apil.parsertongue.com/).

For the inferential statistical analysis of the tongue contours we used Functional Data Analysis (FDA) (see e.g. Ramsey et al. 2009). Instead of comparing the position of specific points on the tongue contour (e.g. “the highest point in the midsagittal arc” or “the lowest angle at which the tongue root was visible for all tokens of a vowel pair” (Hudu 2014, p.42)) FDA allows to evaluate the tongue shape as a whole, and to determine the areas where the tongue contour pairs differ.

To be comparable in the framework of FDA the continuous tongue contours have to be “digitized”, i.e. evaluated at certain points resulting in a vector pair of x- and y-coordinates. For this digitalisation a polar beam grid was applied. The origin of the beam grid, which was the same for all of the vowels, was placed inside the tongue and the angular distance between two beams was set to 4 degrees (Fig. 2).

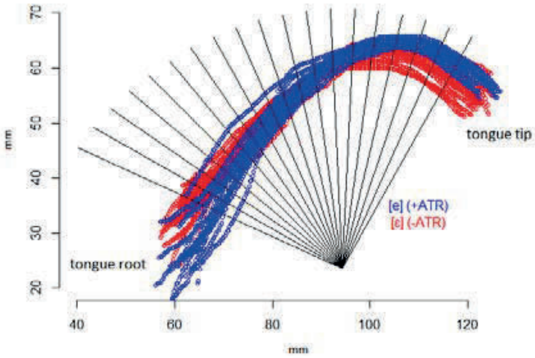

*Figure 2. Tongue contours of /e/ (blue) and /ɛ/ (red), with polar beam grid.*

The evaluation of the contours was restricted to an angular arc, where there was a value for every token of the vowel pair in question (Fig. 3).

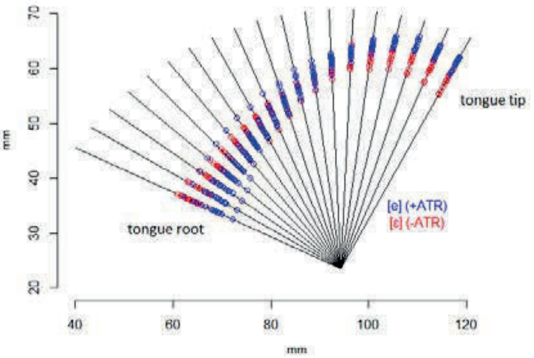

*Figure 3. Digitized tongue contours of /e/ (blue dots on the beams) and /ɛ/ (red dots on the beams).*

The visible area of the tongue contours differs from vowel pair to vowel pair, since the tongue tip is protruded e.g. in the case of the a/ʌ-vowel pair, or the hyoid bone is high as e.g. in the u/ʊ-vowel pair (see Fig. 7).

Using this angular beam arrangement, the tongue contours were “digitized” (Fig. 3). In this way average tongue contours of the vowels can be calculated by averaging the distance from the origin for every angle of the coordinate system (Fig. 4) and expressed in “distance form origin” (y-axis) as a function of angle (x-axis), i.e. in polar coordinates (Fig. 5).

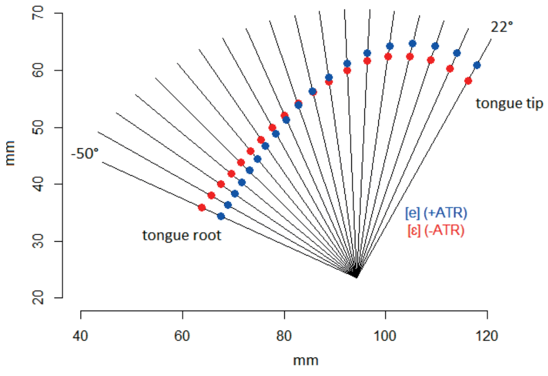

*Figure 4. Averaged tongue contours of the vowels /e/ (blue) and /ɛ/ (red).*

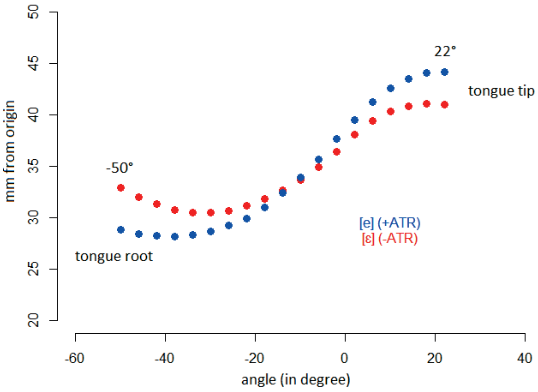

*Figure 5. Transformation of the averaged tongue contours of the vowels /e/ and /ɛ/ into polar coordinates (x-axis = angle; y-axis = distance from origin).*

Each vowel pair was compared statistically using the functional *t*-test as described in Ramsey et al. 2009. The test statistic of this test is the maximum value of the multivariate *t*-test at each point. The critical value for this test statistic is generated by a permutation test.

For the analysis we used the FDA-package for R, where this test is implemented (Ramsey et al. 2017). The plot in Fig. 6 is automatically produced by the functional *t*-test routine of the FDA package. We chose the preset value of p=0.05 as critical value (Fig. 6). All regions of the contour pairs were judged to be significantly different, where the observed statistic curve is above the maximum 0.05 critical value line.

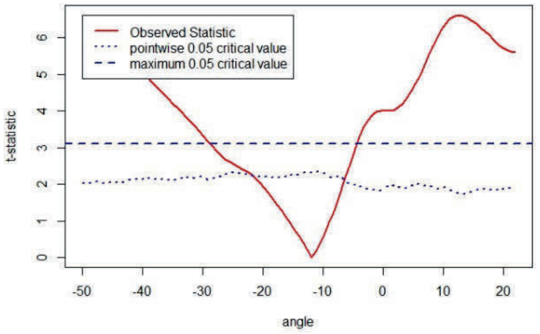

*Figure 6. Result of the functional t-test for the opposition /e/ versus /ɛ/ based on 18 tongue contours each. We take the zones of the tongue contours to be significantly different, for which the observed statistic is above the maximum 0.05 critical value, i.e. the zones from -50° to -29° (“tongue root”) and from -5° to +22° (“tongue tip”).*

## Results

We compared the members of each of the five vowel pairs with FDA (Fig. 7).

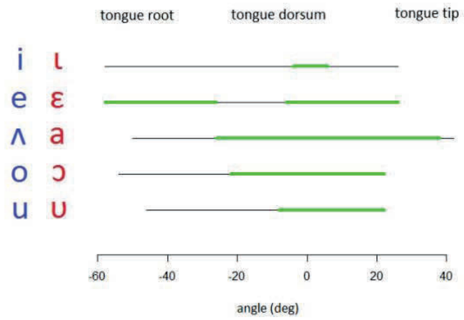

*Figure 7. Areas of significant (p<0.05) differences (green zones) between the tongue contours of the vowel pairs.*

For all pairs there was a significant difference in the frontal and/or medial region of the tongue contours, i.e. in the region of the tongue tip and the tongue dorsum respectively (Fig. 7). In all of these regions the class 1 (blue), i.e. the assumed +ATR vowels showed higher position of the contour as opposed to their class 2 (red), i.e. the assumed -ATR counterparts (Fig. 7). However the pharyngeal region of the contour (i.e. the tongue root) was only found to be significantly different in the case of the front mid-open pair /e/ versus /ɛ/. As expected, in this case, the class 1 (blue) variant /e/ exhibited an advanced tongue root as opposed to its class 2 counterpart /ɛ/ (see Fig. 5).

## Discussion

In the present study we addressed the question, whether the feature ±ATR controls vowel harmony in Zande by the use of UTI. According to our results, in all but one cases the main difference between the corresponding tongue shapes in the claimed ±ATR pairs was found in the frontal-medial region of the tongue, implying that the vowels of Zande are not regularly distinguished by the ±ATR feature, but tongue body elevation. The only exception found was the front mid-open pair /e/ and /ɛ/, as these vowels showed an additional difference of the contours in the pharyngeal/tongue root region beyond the elevation of the tongue body.

In the analysis of tongue positions, the UTI technique has a severe disadvantage compared to magnetic resonance imaging (MRI) or cineradiography technique, since in UTI it is not possible to record the entire shape of the tongue root (due to the shadow of the hyoid bone). In spite of this disadvantage, however, in the present paper we argue that we can draw reliable conclusions from UTI data regarding the issue of the phonetic implementation of the claimed ±ATR feature.

There is evidence from previous studies, that the tongue root shows a high degree of independence from the rest of the tongue body for languages using the ±ATR feature, thus (i) in this case the position of the tongue root is not predictable from the position of the dorsum (see Whalen et al. 1999), and (ii) its advancement does not cause further positional differences (e.g. dorsal elevation) in the tongue body by default. Studies using cineradiographic techniques (Ladefoged 1968, Lindau 1974) and MRI (Tiede 1996) showed that the ±ATR feature causes a forward-backward movement of the tongue root, but no (or only a slight) additional upward-downward movement of the tongue dorsum. Consequently, a potential difference in tongue height may not be considered to be the articulatory correlate of the ±ATR feature.

Our results, however, do show a clear difference in tongue height for all of the vowel pairs studied (Fig. 7). Therefore, even if we assume that in our UTI data the position of the tongue root may not be evaluated readily, we must conclude that the phonetic implementation of the assumed ±ATR opposition in Zande is different from those found in other languages using this feature (and includes an additional tongue body elevation gesture).

Although the present data were obtained from isolated Zande vowels spoken by one speaker only, our findings suggest, that the linguistic feature responsible for the vowel harmony in Zande is correlated primarily with a difference in tongue height and not with a movement of the tongue root in the phonetic domain.

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