ACOUSTIC AND AUDITORY ANALYSIS OF N|UU LINGUAL AND LINGUO-PULMONIC STOP BURSTS[1]

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ABSTRACT

We provide data on Centers of Gravity (COG) and resonances of two spectral peaks (P1 and P2) in bark-scaled acoustic spectra of N|uu lingual (L) [ʘ, ǀ, !, ǁ, ǂ] and linguo-pulmonic (LP) stops: [ʘ͡q, ǀ͡q, !͡q, ǁ͡q, ǂ͡q]. COG, P1 and P2 values for click bursts in L and LP stops do not differ, indicating that the L/LP contrast is not one of posterior place. We find lower values for [ʘ, !, ǁ] than for [ǀ, ǂ] suggesting a difference in posterior place among different click types. We argue these are uvular and upper pharyngeal, respectively, and that they are predictable from the anterior place of articulation. Place differences lead to differences in tongue body shape and lingual cavity volume, which result in the acoustic differences found.

COG, P1 and P2 values for the pulmonic (P) bursts of LP stops do not differ for the different click types, nor do the LP stop bursts differ from [q] bursts. This is consistent with earlier treatments of the place of the LP stops as different from the place of the posterior constriction in the lingual portion of these sounds.

Keywords: clicks, center of gravity, airstream, contour segments, complex segments

1. INTRODUCTION

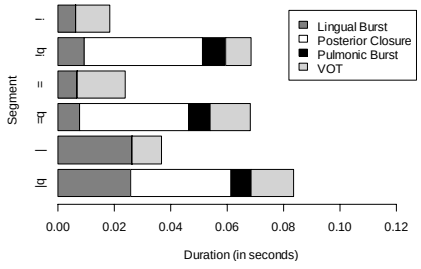
Click consonants are sounds produced with two constrictions in the oral cavity, and what has been previously termed an ingressive velaric airstream. Clicks are widely thought to only contrast in the anterior place of articulation [1,3,5,6,7,11,13]. Anterior place of articulation is known as the click influx [1], or the click type [6, 7, 13]. [4] and [6] claim that clicks all have velar posterior places of articulation. [9] and [10] show that the N|uu and Khoekhoe alveolar and post-alveolar clicks have a uvular posterior constriction, while the palatal clicks have an upper pharyngeal posterior constriction. [9,10] adopt the more accurate term lingual airstream to replace velaric airstream [1,3,6,7,13].

N|uu, also known as ǂKhomani [4] is an endangered language spoken in Upington, South Africa, with less than 12 remaining speakers. The language contrasts five clicks that differ in both the anterior and posterior places of articulation. N|uu also contains a series of LP stops recognized by [9] but not [4]. [9] shows that LP stops are similar to !Xóõ sounds, which [7,13] claim contrast from the plain clicks in posterior place (velar/uvular).

Figure 1 provides durational phases showing that the L stops exhibit a single L burst, while LP stops display a L burst, followed by a silent interval and a pulmonic burst. The silent interval in LP stops is fricated, typical of post-velar stops.

We provide analyses of auditory spectra of the L stop bursts in the five N|uu L and LP stops: COG and the frequencies of two spectral peaks (P1 and P2). P1 and P2 frequencies display different patterns for the 5 click types. We attribute the lower peak (P1) to the cavity volume in front of the anterior constriction, and the higher peak (P2) to the volume of the lingual cavity formed between the anterior and posterior constrictions.

Figure 1. Duration of phases of Lingual and Linguo-pulmonic stops (3 speakers)



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We provide COG and the resonance of two spectral peaks in the pulmonic bursts found in the LP stops and [q], which show that the pulmonic bursts in the LP stops are all post-velar.

2. Spectral Properties of N|uu Lingual bursts

Experiment 1 tests the hypothesis that N|uu clicks differ not only in the anterior place of articulation, but also in the posterior place of articulation. COG and two spectral peaks were measured. P1 values are attributed to the volume of the cavity in front of the anterior constriction. P2 values are attributed to the mid tongue shape, which is linked to volume, and thus determines the resonance frequency of the lingual cavity.

2.1. Methods

Seven tokens of each word in Table 1 were produced in the frame sentence *Na ka ___. 'I say ____.'* by three female speakers: Anna Kassie, Griet Seekoei and Katrina Esau, and were recorded on a Marantz PMD60 Digital recorder. Auditory spectra on the bark scale were created over a 30 ms window centered over the L bursts, using 24 point LPC analysis. The wordlist is in Table 1. Data from only two speakers are used, since one of the speakers did not produce one word.

Table 1: N|uu lingual and linguo-pulmonic stops

	Lingual	Linguo-pulmonic
Labio–uvular	[⊙uu^{n}] 'son'	[⊙͡q^{h}ui.a] 'sweat'
Denti-pharyngeal	[|uu^{n}] 'boil'	[|͡quu] 'tobacco'
Central Alveolo-uvular	[!uu] 'acacia'	[!͡qui] 'ashes'
Lateral Alveolo-uvular	[‖uu] 'grass-hopper'	[‖͡quu] 'urine'
Palato-pharyngeal	[ǂuuke] 'fly'	[ǂ͡quu] 'neck'

COG, P1 and P2 were measured. Logarithmic spectra were used, rather than linear spectra, based on the fact that previous studies of Naro clicks [6], found 2 peaks for [!], but 1-3 peaks for [ǂ]. Auditory spectra in [5] and here consistently exhibit 2 spectral peaks. Preliminary spectral investigation revealed that P2 classifies clicks into 2 classes targeted by the BVC [13].

P1 and P2 frequency ranges were identified interactively using a peak-picking algorithm in Praat [5] using the ranges provided in Table 2. A series of repeated measures ANOVAs tested the statistical significance of COG, P1, and P2 values. Three factors were used: Subject, Place and Airstream. Subject was coded as a random factor, and place and airstream were coded as fixed factors. Place had five levels, and airstream had two levels, as encoded in Table 1. Place had 4 df, and airstream and subject each had 1 df.

Table 2. P1 and P2 ranges used to identify two spectral peaks in lingual stop burst spectra

	P1	P2
[!], [!͡q]	6-10	13-17
[ǂ], [ǂ͡q]	7-11	13-18
[|], [|͡q]	4-10	15-18
[‖], [‖͡q]	6-10	13-16
[⊙],[⊙͡q]	2-10	15-22

2.2. Results

Figure 2 provides the frequencies of two peaks found in the spectra of L and LP stop bursts. In Figure 2, dental and labial clicks display the lowest P1 values, followed by central and lateral alveolar clicks and palatal clicks. Neither place, nor airstream, nor subject, was a significant predictor of P1 values by themselves. However, there was an interaction between place and airstream, such that P1 values for [!] and [!͡q] differed significantly.

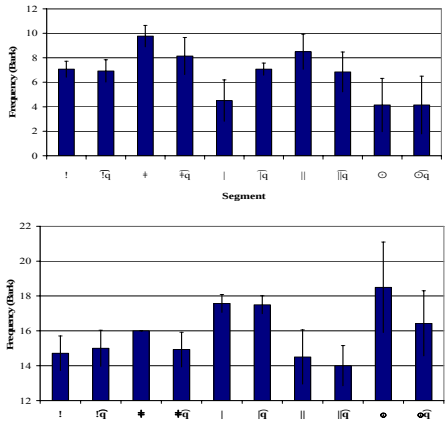
P2 frequency values in Figure 2 display a different pattern. The central and lateral alveolar L bursts display the lowest values, with palatal L stops displaying higher P2 values, and labial and dental bursts displaying the highest P2 values. Place was found to be significantly different at the level of $p<.01$, while neither airstream nor subject were significantly different by themselves. There were no interactions between place and airstream, place and subject, or airstream and subject. COG results were not significant at the level of $p<.05$.

2.3. Discussion

The fact that P2 values associated with the L bursts of the L and LP stops do not differ significantly with respect to airstream, provides strong evidence that there is no contrast in the place of the posterior constriction of L and LP

stops as proposed by [7, 13]. Rather, the contrast between L and LP stops is as argued for in [8], one of airstream. The L stops exhibit a change from lingual to pulmonic airstream that is aligned closely with the release of the posterior constriction. The LP stops exhibit a shift in direction and source of the airstream prior to the release of the posterior constriction.

Figure 2. P1 (upper) and P2 (lower) in the lingual bursts of five N|uu click types (error bars represent one standard deviation)



Previous analyses of clicks [1, 7, 11, 13] characterize the posterior constriction in most clicks as velar, using only the tongue dorsum. Ultrasound studies of palatal and alveolar clicks in Khoekhoe [10] and N|uu [9] have shown that the upper tongue root makes contact with the upper pharynx in palatal clicks, while the mid tongue root retracts in the mid pharynx in alveolar clicks. Acoustic results shown here are consistent with these articulatory results.

We have shown that there are two clear spectral peaks found in click bursts that differentiate two subclasses of clicks. This is an important point methodologically, given the earlier variation seen in the number of peaks found in palatal clicks [6].

The dental and labial clicks have the lowest P1 values, followed by the central and lateral alveolar clicks, and palatal clicks. We attribute P1 differences to anterior place differences.

P2 values classify clicks into those that co-occur with front vowels (dental and palatal), and those that do not (alveolar and labial), due to a co-occurrence constraint known as the Back Vowel Constraint [13]. As argued by [10], this can be attributed to interactions at the muscular control level. Following [8], it can be characterized phonologically in terms of tongue body shape.

These data provide evidence that the contrast between so-called velar, [ʘk, ǀk, !k, ǁk, ǂk], and uvular, [ʘq, ǀq, !q, ǁq, ǂq], clicks as portrayed by [7,13], is not an accurate phonetic representation of the contrast, since the two clicks of each type that have similar anterior constrictions display similar acoustic spectral properties. The similar P2 values show that the volume of the lingual cavity is similar for each type of L and LP stop.

3. Spectral Properties of N|uu Pulmonic Bursts

Experiment 2 compares spectral properties of the pulmonic bursts in LP stops to uvular pulmonic stops. Results show that the pulmonic portion of LP stops and [q] were both quite fricated, and the frequency ranges employed are higher than that for the stop [k]. Therefore, [k] is not compared. Experiment 2 will provide evidence for place of articulation of the pulmonic release in LP stops. Earlier transcriptions in [7,13] predict all of the LP spectra to be similar to [q]. This is particularly true of analyses that represent LP stops as clusters of clicks followed by uvular stops [11]. If, however, the pulmonic constriction is maintained at the same place as in the posterior constriction of the click, we expect the pulmonic bursts to fall into two subclasses: uvular and upper pharyngeal.

3.1. Methods

The LP words in Table 1, as well as the word [qoaqî] 'famished', were analyzed. Bark spectra were created over a 30 ms window centered over the pulmonic stop bursts, using 24 point LPC analysis. As with the previous experiment, ranges for P1 and P2 were identified, where all of the peaks could be identified within the window. A single range was usable for all LP stops, 5-6 Bark for P1, and 13-20 Bark for P2. The P1 and P2 ranges were 5-7 and 13-20 Bark for [q].

A series of repeated measures ANOVAs were run for dependent variables COG, P1 and P2. One random factor, subject, and 2 fixed factors, place and airstream were used. Levels were the same as in Experiment 1, except that Experiment 2 compares P and LP airstreams. Airstream and Subject had 1 df, while place had 4 df.

3.2. Results

Figure 3 provides P1 and P2 of the pulmonic bursts of the LP stops and [q]. The high range found in P1 and P2 for the pulmonic portion of LP stops, shows that the portion is quite fricated, as is [q]. [!͡q] shows a lower mean P1 than the other LP stops and [q]. [ǂ͡q] displays a lower mean P2 than found in the pulmonic portion of the alveolar and labial LP stops, and [q]. Repeated measures ANOVAs showed neither of these differences, nor COG values (not shown here), to be significant.

3.3. Discussion

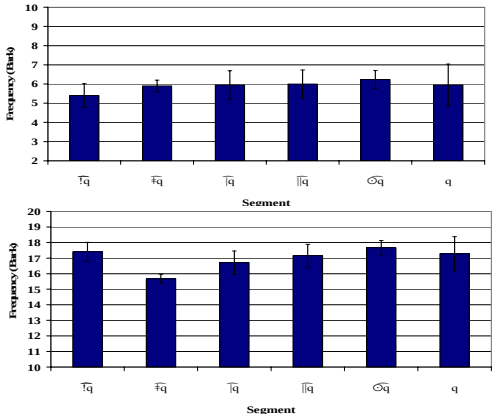
Experiment 2 results are consistent with analyses in [7, 11, 13]. Preliminary ultrasound results in [9] show that the pulmonic release in LP stops in N|uu has tongue root retraction like N|uu uvular stops, but tongue dorsum positions similar to those found in the posterior constrictions of the lingual portion of these contour segments. Quantitative results currently being analyzed are expected to provide a definitive answer as to whether there is an articulatory difference between the posterior constriction location of the lingual portion of these stops and the pulmonic constriction that follows it as advocated by [7, 11, 13]. It must be determined if similarities are due to coarticulation or phonological representation.

4. Conclusion

We conclude, based on results in Experiment 1, that the posterior constrictions in lingual stops and the L portion of LP contour segments, differs in conjunction with anterior place of articulation. Dental and palatal clicks have upper pharyngeal constrictions and high flat tongue bodies, which lead to smaller lingual cavities, and correspondingly higher anterior bursts. Alveolar and labial clicks have uvular posterior constrictions, which go hand in hand with convex tongue body shapes and larger lingual cavity volumes. For the coronal clicks, the posterior place is predictable from the anterior place. The relationship between anterior and posterior place of labial clicks is a question for future investigation.

Contrastive LP stops differ from lingual stops in that they are contour segments in airstream. The place of the pulmonic portion of LP stops is clearly post-velar. Experiment 1 results suggest that the posterior constriction is the same in L and LP stops at the time of the anterior release. Experiment 2 results show no difference in the place of the posterior release in the pulmonic portion of these stops. Further investigation is needed to explain articulatory differences in [10].

Figure 3. P1 and P2 in the pulmonic bursts associated with the pulmonic portion of LP stops and [q]



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