EPG AND AERODYNAMIC EVIDENCE FOR THE COPRODUCTION AND COARTICULATION OF CLICKS IN ISIZULU

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ABSTRACT

This study examines both the nature and relative timing of the component gestures of click consonants in IsiZulu, a Bantu language of the Nguni cluster, spoken in South Africa. Differences between the three click types in the timing and rate of rarefaction reflect coproduction differences between their gestures. Coarticulation with adjacent vowels is illustrated by its effect on the rarefaction rate for the alveolar click type. Results thus far show that multigestural segments can coarticulate with adjacent segments despite claims to the contrary [5].

1. INTRODUCTION

Click consonants are complex segments which involve coordination of not only the tongue blade and tongue dorsum but of the tongue body and its lateral edges as well. Air is sealed between the tongue dorsum and tongue blade closures. Downward movement of the tongue body rarefies the trapped air, thereby creating a click when the anterior closure is released [3]. Although this general aerodynamic strategy involved in click production is well understood, many details regarding the timing of tongue blade, tongue dorsum and tongue body (which refers to the center of the tongue used in rarefaction) have not been systematically studied. This paper examines the nature and intrasegmental timing of the multiple gestures of the three click types as produced in IsiZulu, namely the dental, alveolar and lateral clicks. Click consonants have been characterized by acoustic data [1, 5], aerodynamic data [3], static pal-atography and linguagraphy [4], perception studies [5, 7] and x-ray cineradiology [6]. These studies provided invaluable information on the acoustic characteristics of the click bursts, on the timing of various click accompaniments, and on the tongue blade articulations as well as place of articulation. Traill's x-ray cineradiology study concluded that the tongue blade for some click types retracted during the closure. Traill also highlighted the different tongue body positions that the different clicks assumed just prior to release. The alveolar, lateral and bilabial clicks had a lower tongue body position than the dental and palatal clicks.

click	tongue blade	burst	tongue body [6]	intraoral pressure
dental	laminal	affricated	high	high
alveolar	apical	abrupt	low	low
lateral	apical	affricated	low	intermed.

Table 1: Articulatory descriptions of IsiZulu click types.

Table 1 gives the articulatory/acoustic characteristics of those click types which occur in IsiZulu (intraoral pressure values follow Kagaya's [1] estimates and are negative). This paper focuses primarily on differences between these click types. Later reports will delineate individual speaker strategies and vowel effects.

2. METHODOLOGY

This study used a combination of three techniques to capture the dynamic movement involved in click production. They were Electropalatography (EPG), aerodynamic data and static palatography and linguagraphy (SPG). While this paper focuses primarily on aerodynamic data, qualitative analyses are also reported from EPG data in order to provide a multi-dimensional perspective on the issues being discussed. Further quantitative analyses on EPG and SPG data will be the focus of future reports.

2.1 Speakers and Corpus

Three native IsiZulu speakers, 2 male and 1 female, were recorded. The corpus consisted of the voiceless unaspirated dental, alveolar (often referred to as palato-alveolar and henceforth in this paper, abbreviated as pal-alv) and lateral clicks of real words, in the carrier phrase *Bathi ____. They say ____.* Each click type was placed in the penultimate (stressed) syllable in the symmetrical vowel contexts of /a/, /e/ and /o/. The same words were used for the EPG, SPG and aerodynamic studies.

2.2 Apparatus

Aerodynamic: A multichannel simultaneous recording of audio, intraoral pressure, oral airflow and pharyngeal pressure records were obtained using CSL. The audio channel was recorded at a sample rate of 5000 HZ using a free-standing microphone. Data from this channel served mainly as reference points for vowel onsets and offsets as well as onsets of consonantal releases. Oral airflow was collected by means of a modified Rothenberg mask. Pharyngeal pressure data was collected by inserting a small diameter polyethylene tube into the pharynx by way of the nostril. Pharyngeal pressure data was used to assess tongue dorsum movement [2]. Intraoral pressure of the click cavity was measured by means of a custom-fitted acrylic pseudo palate approximately .02mm thick. A small polyethylene tube was fixed to this at the highest point of the hard palate with dental adhesive. The tube was threaded from the palate leftward at a 45 degree angle, looped around the back-most molar and then threaded out of the mouth along the outer gumline. Figure 1 provides a sample of the overall data as obtained from these four channels. The tag in channel 1 as well as the time-aligned cursors in channels 2, 3 and 4 mark the burst.

EPG (Kay Elemetrics, 96 electrodes) allowed examination of tongue/palate contact over the course of the entire utterance. EPG frames were sampled at 100HZ. Simultaneous acoustic data was collected at a sample rate of 12.5kHZ. In many cases tongue dorsum contact was also evident, such that a complete seal on the palate was observable.

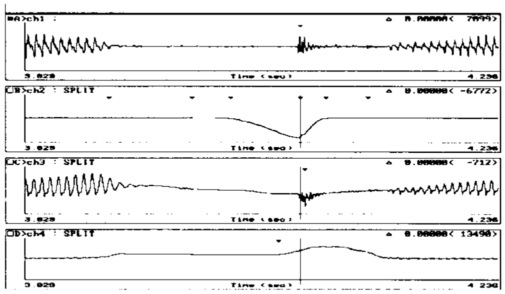


Figure 1: Simultaneous recording of audio, intraoral pressure, oral flow and pharyngeal pressure, on channels 1, 2, 3 and 4, respectively.

3. DATA ANALYSIS

IsiZulu clicks, regardless of place of articulation, can be described articulatorily in terms of three phases. They are tongue dorsum lead (Tdld), tongue blade seal (Tbsl) and tongue dorsum lag (Tdlg). Tdld represents the duration between the tongue dorsum closure and the initial seal made by the tongue blade. (Tongue blade refers to both the broad portion of the blade as well as the tip). Tbsl represents the entire closure duration of the tongue blade from its initial closure to the burst (burst refers to the onset of acoustic energy of the tongue blade release). Tdlg represents the time period from the click burst to the velar burst. Figure 2 depicts these various phases as they were measured from the intraoral pressure data. The tags are numbered from 1-6, where 1 represents the tongue dorsum closure, 2 the tongue blade seal, 3 the onset of rarefaction, 4 the click burst, 5 the offset of the click burst and 6 the velar burst. Tdld was characterized by a measure of onset latency (OL(from 1-2)). For all click types in IsiZulu, tongue dorsum closure always preceded tongue blade closure. The tongue dorsum closure was demarcated at the offset of the vowel from the audio channel, while the tongue blade seal was demarcated by the initial perturbations seen in the intraoral pressure channel.

Tbsl was characterized by three measurements. They were overlap (OVLP(2-4)), average rate of rarefaction (AVEL(3-4)) and peak negative pressure (PNEG (near 4)). OVLP is a duration measurement, expressed in msec, from the onset of the tongue blade seal as measured from channel 2, to the click burst, which was observable from the audio channel. OVLP represents the time during which double closure occurs. OVLP can also be expressed as a percentage of the total click duration, calculated from the tongue dorsum closure to the tongue dorsum release (1-6).

AVEL represents the rate of rarefaction, measured from the onset of rarefaction, marked by the first negative pressure number obtained on the graph, to peak negative pressure, expressed in cm H_20/msec. PNEG (cm/H_20) was determined by locating the maximum negative value on the intraoral pressure curve. Tdlg was characterized by calculating the offset latency, in msec (OFL(4-6)), measured from the onset of the click burst to the velar burst. The click burst itself was characterized by calculating the offset velocity (OFVEL(4-5)) of the intraoral pressure curve from the click burst to atmospheric pressure.

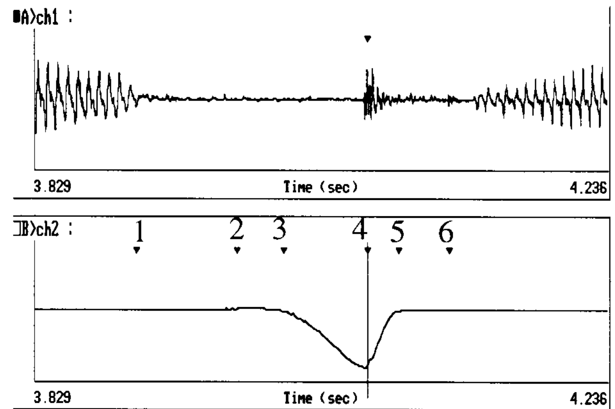


Figure 2: Intraoral pressure graph depicting OL, OVLP, OFL, AVEL, PNEG, OFL and OFVEL calculations.

4. RESULTS and DISCUSSION

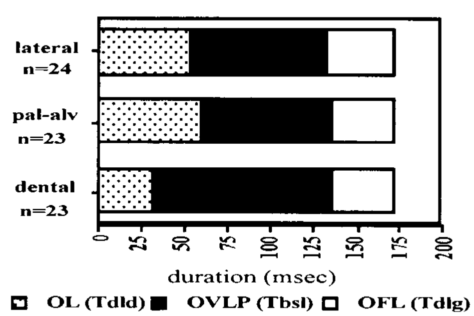
4.1. Aerodynamic Data

A three-factor ANOVA was performed with the main independent variables of CLICK, SPEAKER and VOWEL on the following dependent variables: OL, OVLP, OFL, AVEL, PNEG, OFVEL. Post-hoc comparisons were made using Fisher's PLSD at a 95% confidence level.

OL: The clicks differed significantly in their onset latency (($F(2, 43)=10.006$, $p < .001$). Post-hoc comparisons showed the dental click differed significantly from the palato-alveolar and lateral click types while the palato-alveolar and lateral click types did not differ.

OFL: No significant differences were found.

OVLP: The clicks differed significantly in their overlap ($F(2, 34)=10.884$, $p<.001$). Post-hoc comparisons showed that the dental click, at 59% overlap (102 msec), differed significantly from the pal-alv and lateral click types; but the pal-alv and lateral clicks, at 41% (74 msec) and 46% (79 msec), respectively, were not significantly different. Figure 3 depicts these Tdld, Tbsl and Tdlg as measured by OL, OVLP and OFL. Time zero marks the tongue dorsum closure.



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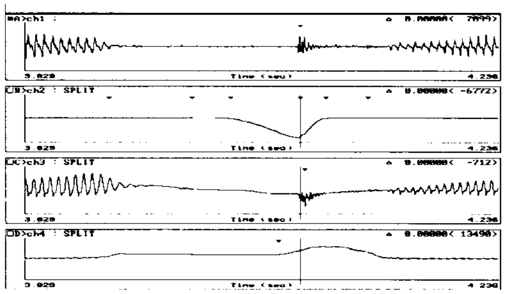

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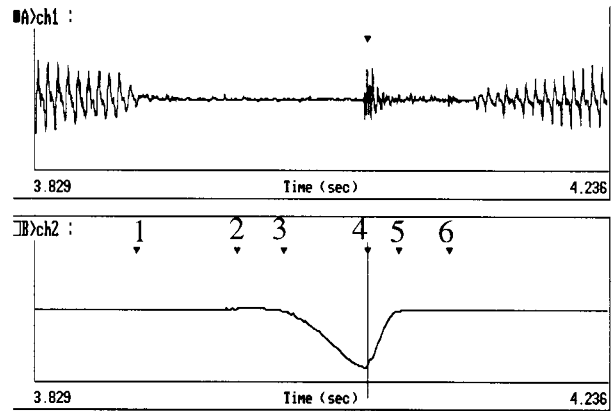

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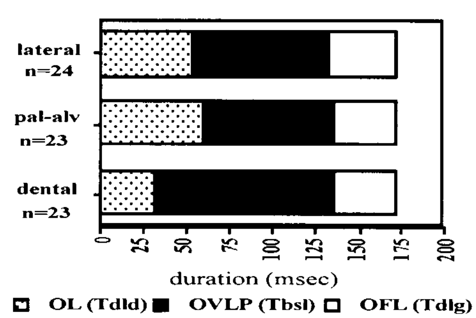

Figure 3: Articulatory phases of IsiZulu clicks

necessitates contact on the palate, thereby inhibiting lowering. Traill's x-ray data showed that this click had a low tongue body. This result from his data may have been obtained because the technique used could not measure lateral contact, only mid-sagittal movement. Perhaps half of the tongue body is lowered, such that a mid-sagittal view may have misleadingly lead to the conclusion that the entire tongue body was low. The slow offset velocity suggests that this click type was affricated.

EPG data of the palato-alveolar clicks showed a clear backward movement of the tongue tip during the closure for all speakers. It is probable that the fast movement of the tongue body in rarefaction, with its resulting large negative pressure, pulls the tongue tip backwards along the palate. (Alternatively, the backward movement could be an active movement in order to facilitate tongue body lowering.) The rapid downward movement of the tongue body, facilitated by tongue tip retraction, pulls the tongue tip back and abruptly off of the palate. This description of the pal-alv click has been previously described in phonetic descriptions of Xhosa, a related language with a similar click inventory (5). The abruptness of this release gesture is apparent in the EPG frames, which go directly from complete closure to a full loss of contacted electrodes in the anterior region, with no intermediate frames showing sustained fricative-like channels. The alveolar click in !Xóõ does not show tongue blade retraction as was observed for this click type in IsiZulu. The lack of movement observed in !Xóõ might result from the need to maintain a clear distinction between the palatal and the alveolar clicks, a need that does not arise in IsiZulu because it lacks a palatal click. It appears that there are two different mechanisms at work in producing this click type, which has broadly been classified as alveolar. EPG data showed that, for IsiZulu, the more appropriate place description for this click type is palato-alveolar.

4.3. Coarticulation

Given the precise timing observed in clicks as well as the concomitant use of tongue blade, tongue body and tongue dorsum, the question of intersegmental timing is at issue. Sands concluded that clicks cannot coarticulate due to the precise timing and placement required in the production of this class of consonant [*cf.* 7]. This report briefly looks at one type of coarticulation in click consonants. The palato-alveolar click type was considered in three symmetrical vowel environments, /a/, /e/ and /o/. Since the palato-alveolar click in this study was determined to have a low tongue body position prior to release, the low vowel should not be in conflict with the rarefaction gesture needed to produce the click. However, /e/ and /o/ may perturb this click type because the tongue body configuration for these vowels is higher [6]. AVEL was analyzed precisely because it was hypothesized to reflect tongue body height. A two-factor ANOVA of SPEAKER x VOWEL resulted in a significant main effect of VOWEL on AVEL, $F(1,9)=16.478$ $p<.01$, with the average rarefaction rate for /a/ being -3.92 while /e/ was -3.29 and /o/ -2.97 cm H_2O/msec. Post-hoc comparisons showed /a/ was significantly different from /e/ and /o/; the higher vowels did not significantly differ from each other. The results are depicted in Figure 5. (Absolute values were used for AVEL). AVEL seems to be a good indicator of tongue body height because it patterns predictably based on what is a well attested height distinction for vowels. These results confirm that the hypothesized tongue body positions for the different click types are ordered by AVEL, as previously noted.

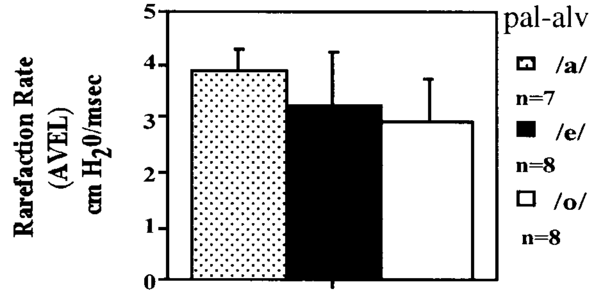

Figure 5: Effect of vowel height on rarefaction rate of pal-alv click

5. CONCLUSIONS

This study has detailed the internal structure of three click types as they are produced in IsiZulu. The co-production patterns for the dental and lateral clicks were characterized by (1) more durational overlap of tongue blade and dorsum, (2) slower rarefaction velocity and (3) slower offset velocity. The abrupt click showed (1) less durational overlap of tongue blade and dorsum, (2) greater rarefaction velocity and (3) greater offset velocity. Specifically, the affricated/abrupt nature of the various click types was shown to be the articulatory/ acoustic target; the resultant effect of their particular internal organization. These results indicate that clicks should be considered discrete entities, with a complex articulatory structure, which itself has a specific articulatory and acoustic goal. In spite of the complexities of this consonant type, it was none-the-less shown to coarticulate with adjacent segments. Future analyses will focus on delineating coarticulatory strategies for the various click types as well as individual speaker strategies used in click production.

6. REFERENCES

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