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Rarefaction Gestures and Coarticulation in Mangetti Dune !Xung Clicks

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Abstract

We provide high-speed ultrasound data on the four Mangetti Dune !Xung clicks. The posterior constriction is uvular for all four clicks—front uvular for [ᶢǀ] and [ǂ] and back uvular for [ᶢ!] and [ᶢǁ]. [ᶢ!] and [ᶢǁ] both involve tongue center lowering and tongue root retraction as part of the rarefaction gestures. The rarefaction gestures in [ᶢǀ] and [ǂ] involve tongue center lowering. Lingual cavity volume is largest for [ᶢ!], followed by [ᶢǁ], [ǂ] and [ᶢǀ]. A tongue tip recoil effect is found following [ᶢ!], but the effect is smaller than that seen in IsiXhosa in earlier studies.

Index Terms: click consonants, rarefaction gestures, lingual airstream, tongue tip recoil

1. Introduction

Mangetti Dune (M.D.) !Xung is a member of the Ju branch of the Ju-ǂHoan family, spoken in Northeastern Namibia [1]. This paper presents the results of high-speed ultrasound investigation of all four of the language's contrasting clicks.

While ultrasound investigations have previously been undertaken for the alveolar and palatal clicks in Khoekhoe [2] and N|uu [3], this is the first study to investigate the articulation of the lateral alveolar [ᶢǁ] and dental clicks [ᶢǀ] with ultrasound. In addition, this is the first high-speed ultrasound data recorded in a fieldwork setting on a Khoesan language.

M.D. !Xung contrasts the four coronal clicks recognized in the International Phonetic Alphabet [4]: dental ([ǀ]), central alveolar ([!]), lateral alveolar ([ǁ]), and palatal ([ǂ]). Miller-Ockhuizen and Sands [5] had documented a fifth click type in M.D. !Xung, although the spectral properties were not very distinct. Miller and Shah [6] show that this fifth forward released lateral click is not contrastive.

This study investigates the coarticulatory effects on vowels following different click types. Sands [7] showed that there were no differences in F1 and F2 of vowels following different click types in IsiXhosa, which led Dogil, Mayer and Roux [8] to claim that clicks do not coarticulate. However, Thomas-Vilakati (1999 [9], [10] showed that clicks display large coarticulatory effects from the following vowel. Miller-Ockhuizen [11] showed that vowels following [!] on the one hand, and [ǀ], [ǂ] on the other hand, display different F2 values in Ju|'hoansi. The M.D.!Xung data presented here displays large coarticulatory effects from clicks on a following [i] vowel.

M.D. !Xung, like many other Khoesan languages, has an active Back Vowel Constraint [12], which lowers and retracts an underlying /i/ vowel to the [əi] / [ɘi] allophone following central alveolar and lateral alveolar clicks. In M.D. !Xung, however, an unexpected finding is that underlying /i/ vowels following the palatal clicks are also variably realized as [əi] for the speaker studied here. This is the first Khoesan language to exhibit this pattern.

Clicks were originally thought to all have a velar posterior constriction. However, more recent production studies have shown that both anterior and posterior constriction locations are uvular, and the dynamics of the release vary across languages. Ladefoged and Traill [13] have shown with 30 fps X-ray videos published in Traill [14] that the anterior constriction location moves during the production of central alveolar and palatal clicks from the onset of the click closure to the point just before release in !Xóõ. High-speed ultrasound investigations undertaken in this study allow us to view the dynamics of all four clicks, to see whether the posterior constriction location changes during the release. This study also allows us to investigate the differences in rarefaction gestures found among M.D. !Xung clicks, and to compare them to the rarefaction gestures found in !Xóõ, N|uu and IsiZulu clicks. Thomas-Vilakati [10] investigated IsiZulu click articulation with a combination of electropalatography, airflow and static palatography. She showed that the rarefaction strategy in the dental click involves tongue center lowering, the palato-alveolar click involves both tongue center lowering and tongue dorsum retraction, and the lateral alveolar click involves lowering one part of the tongue center. The current study also contributes a description of the [ǂ] click rarefaction gesture, as that click does not occur in IsiZulu.

The CHAUSA (Corrected High-speed Anchored Ultrasound with Software Alignment) method and architecture [15] used here and in Miller's [16] investigation of the IsiXhosa alveolar click, has enabled researchers to view new aspects of click dynamics that were not visible in earlier studies. Miller [16] uncovered tongue tip recoil in the production of [!] for one IsiXhosa speaker. This study shows that at least some M.D. !Xung speakers' [!] click productions also exhibit tongue tip recoil. Tongue tip recoil provides evidence for the mass spring model of speech production in Task Dynamics [17].

2. Methods

The wordlist in Table 1 was recorded with the CHAUSA ultrasound architecture for four speakers of M.D. !Xung in Mangetti Dune, Namibia. All speakers are bilingual with Afrikaans, but speak primarily M.D. !Xung. Words were recorded in the frame sentence Mà o kx'úí ____, kà djàlà. 'I say ____, (and) it is good.'

The CHAUSA architecture is described in Miller [16], and Miller and Finch [15]. The ultrasound machine was a GE Logiqbook, with an 8C-RS 5-8 MHz transducer. An Ultrasound stabilization headset [18] was used to achieve probe anchoring to the head, and head and probe movement correction were undertaken using Palatoglossatron [19]. The camera used for filming the head movement and Palatoglossatron sticks was a Prosilica GigE GE680C camera. The ultrasound frame rate and head video frame rate were both 114 fps, which allowed us to capture a frame of the tongue and head every 9 ms. Head movement correction was undertaken on the output of each individual frame using Palatoglossatron.

Table 1. *Mangetti Dune !Xung Wordlist*

ᶢ|íí	'to exit'
ǂȉʱȉʱ	'malaria'
ᶢ!ə́í	'to carry on the shoulder'
ᶢ‖ə̀ì	'tortoise'

3. Results

Figure 1 provides five sagittal tongue traces during the production of the dental [ᶢ|] click, as well as a trace of the first frame and a frame of the peak palatal gesture in the following [i] vowel. Trace 1 is the frame prior to the beginning of the click formation and trace 5 is the frame prior to the anterior release. As the click closures in these tokens were about 200 ms, there were about 25 traces total during each click. Traces 2 and 3 are intermediate traces chosen to best illustrate the dynamics seen throughout the duration of the clicks. The main movement we see in the dental click [ᶢ|] between traces 1-5 is tongue center lowering, which leads to a gentle concave tongue shape at trace 5 for this click. The primary rarefaction gesture in the dental click is tongue center lowering, similar to that for the [|] click in IsiZulu [10].

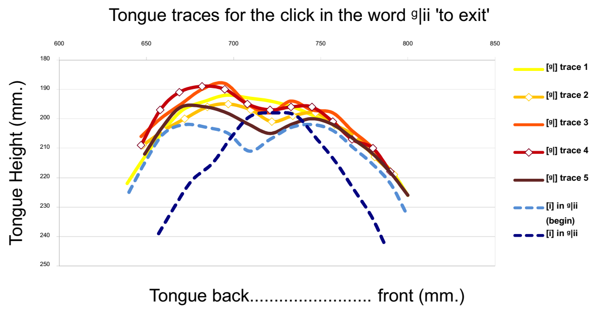

Figure 1: *Five sagittal tongue traces during the production of the [ᶢ|] click and two traces during the target [i] vowel in the word ᶢ|íí 'to exit'.*

The frame from the beginning of the [i] vowel following the dental click in the word *ᶢ|ii* displays a clear double-peaked tongue shape with coarticulation from the preceding consonant. The tongue straightens out over a period of 18 frames (≅ 160 ms), and eventually reaches the target shape seen in the peak palatal gesture in Figure 1.

The tongue dorsum, root and tongue front seem to lower simultaneously in this click, as there is no frame where the anterior constriction has been released while the posterior constriction is still in place. The other 6 repetitions of this word that we have viewed and plotted look similar to this one.

Figure 2 provides five sagittal tongue traces during the production of the alveolar [ᶢ!] click, as well as a trace from the beginning of the [əi] vowel and a trace showing the peak palatal gesture in the front vowel portion of the diphthong. The posterior constriction moves further back during the course of traces 1-5, and the posterior constriction reaches its most posterior position at frame 5, just prior to the anterior constriction release.

The tongue tip constriction is apical alveolar, and the tongue center lowering is rather extreme. Slight backward movement of the anterior constriction is visible in traces 3-5.

As with the dental click, the vowel immediately following the [ᶢ!] click displays two constrictions. The tongue center is much lower in this [ə] portion of the diphthong compared with the [i] vowel that follows the [ᶢ|] click in Figure 1. The low tongue center position is the same for the click and the beginning of the following vowel. The tongue root has retracted in this frame. The peak palatal gesture in the front vowel is higher in this click, and is similar to the [i] found at the end of the word *kx'ui* in the frame sentence (trace 1). The other 6 repetitions of this word that we have viewed and plotted look similar to this one.

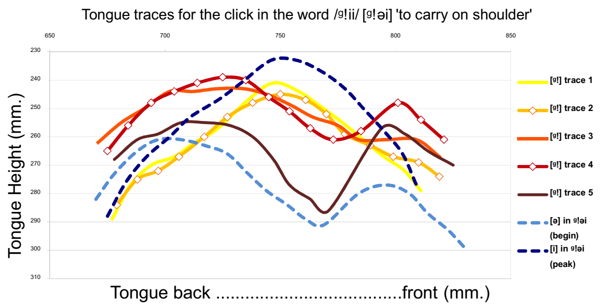

Figure 2: *Five sagittal tongue traces during the production of the [ᶢ!] click, a trace at the beginning of the target vowel, and a trace showing the peak palatal gesture of the [i] vowel in the word ᶢ!ə́í 'to carry'.*

Figure 3 provides five sagittal tongue traces during the production of the lateral [ᶢ‖] click, as well as a trace of the first frame in the vowel and the peak palatal gesture in the front vowel portion of the following [əi] diphthong. Tongue root retraction is visible in this token between frames 4-6, which constitute the posterior release of the click and the transition into the vowel. The lingual cavity in trace 5, which is the frame just prior to the anterior constriction release, displays tongue center lowering that is intermediate between that found in the dental and alveolar clicks. The lateral click lingual cavity is longer than the alveolar click lingual cavity, and about the same length as the dental click cavity.

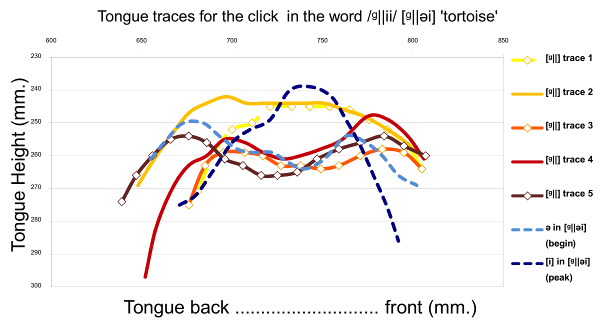

Figure 3: *Five sagittal tongue traces during the production of the click, the first frame immediately following the click and the target vowel in the word ᶢ‖ə̀ì 'tortoise'.*

The tongue front constriction is wider than that found in the central alveolar click, suggesting a more apico-laminal anterior constriction. The other 6 repetitions of this word that we have viewed and plotted show more variability than with the other clicks.

Figure 4 provides five sagittal tongue traces during the production of the palatal [ǂ] click, a trace of the tongue in the first frame of the vowel following the click, as well as a trace of the peak palatal gesture in the following [əi] vowel.

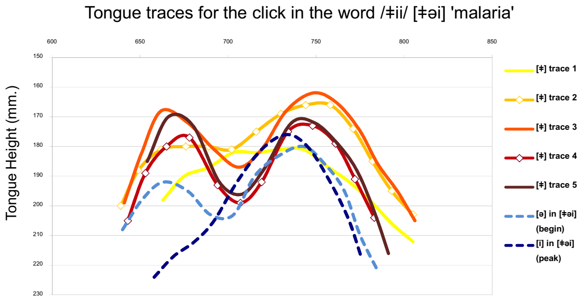

Figure 4: *Five sagittal tongue traces during the production of the click, the first frame in the [i] vowel following the click release, and the peak palatal gesture in the target vowel in the word /ǂĩʱĩʱ/, [ǂə̃ʱĩʱ] 'malaria'.*

The M.D. !Xung palatal ([ǂ]) click shows a greater degree of tongue center lowering than found in Traill's [14] X-ray study of the !Xóõ [ǂ] click and Miller et al's [3] 30 fps study of the N|uu [ǂ] click. It is likely that the low speed of these earlier studies missed the lowering extremum position found in the rarefaction gesture of this click. As with the dental click, the palatal [ǂ] exhibits tongue center lowering and no tongue dorsum/root retraction. The dorsal constriction seen in the vowel beginning trace, which is the first trace after the release, is almost at the same location as in Trace 5, which is just before the posterior release.

The anterior constriction in the palatal click is not as narrow as in the alveolar click and is more similar to that found in the lateral click, suggesting that the constriction is apico-laminal. The first frame in the vowel immediately following the click exhibits two constrictions similar to those found in the click. While the posterior constriction has dissolved by the peak palatal target in the front vowel, the anterior constriction remains in place, resulting in a more forward coronal constriction that matches the location of the anterior constriction in the click.

The posterior constriction in the palatal click is much narrower than that found in the other three clicks, and is far narrower than that seen in the [k] in the frame sentence. We were not aware that the tongue dorsum could achieve such a narrow constriction. The other 6 repetitions of this word that we have viewed and plotted look similar to this one.

Figure 5 provides zoomed in traces of the tongue front in the first ten frames in the vowel following the [ᶢ!] click. The 'begin' frame is the same frame shown in Figure 3 above (the first frame in the vowel). There is a tongue tip recoil effect following this click similar to the one following the [!] click in IsiXhosa [16]. As a consequence of improved imaging of the tongue tip in these data compared with the IsiXhosa data in Miller [16], it is possible to ascertain more details of tongue tip dynamics. The tongue tip lowers between the begin frame and frame 4. In frames 5 and 6, a constriction is formed slightly further back, which at first appears to be moving toward the beginning of the [i] vowel gesture. However, in frame 7, the tongue flattens out again prior to the beginning of the palatal gesture in the [i], which is located between the two click constrictions. Thus, the re-formation of a anterior tongue constriction in frames 5-6 cannot be attributed to the palatal gesture in the [i] part of the diphthong. Rather, it is due to a recoil effect of the tongue after the extremely fast tongue tip release. The recoil effect in these data is not as large as the effect found with the IsiXhosa [!] click by Miller [16]. The difference in the strength of the effect could be due to speech rate, as the IsiXhosa speaker in the earlier study was using more careful lab speech, while the M.D. !Xung data was more natural. Alternatively, it could be a language specific difference.

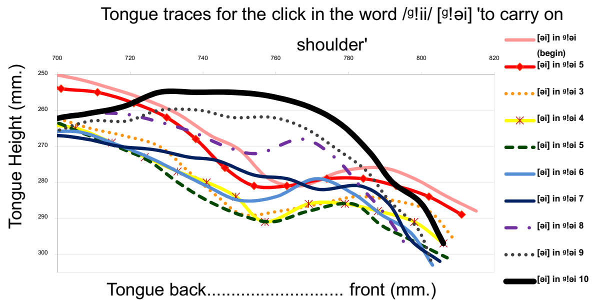

Figure 5: *First ten sagittal tongue traces in the vowel following the [ᶢ!] click in the world ᶢ!ə́í 'to carry'*

4. Discussion

The four clicks in M.D. !Xung display very different rarefaction gestures. The dental ([ᶢ|]) and palatal ([ǂ]) clicks display tongue center lowering, while the central alveolar click ([!]) displays tongue center lowering, tongue tip retraction and tongue root retraction. The lateral alveolar click displays the widest region of tongue center lowering, and involves formation of a low tongue center plateau (as opposed to the narrow tongue wells seen with the other clicks).

Earlier researchers [20], [21], [14], [22] termed the posterior constriction in clicks velar, but Miller, Namaseb and Iskarous [2] and Miller et al. [3] showed that N|uu and Khoekhoe clicks involve uvular posterior constrictions. Miller [16] found that the posterior constriction in the IsiXhosa alveolar [!] click starts out as velar and retracts to uvular during the release. She pointed out that the visible articulatory differences found between IsiXhosa on the one hand, and N|uu and Khoekhoe on the other hand, could be due to language differences, or methodological differences. That is, the subtler change in place found in IsiXhosa could have been missed in the earlier articulatory studies on !Xóõ, Khoekhoe and N|uu because of the lower frame rates used in these earlier studies (30 fps). The data reported here shows that the posterior place of articulation differs among the four click types in M.D. !Xung. The palatal click displays the furthest back posterior constriction. The lateral and dental clicks display slightly more anterior constrictions. The posterior constriction of the alveolar click is the farthest forward. The dorsal constrictions in the clicks do not change much throughout the rarefaction gestures, showing that the !Xung [ᶢ!] click differs from the IsiXhosa [!] click. The [ᶢ!] and [ᶢ‖] clicks both display tongue root retraction. The tongue tip recoil effect found with the central alveolar click provides evidence for the mass spring model of speech production inherent in Task Dynamics [17].

The posterior constrictions among the clicks differ in their widths. The palatal click displays a rather narrow posterior constriction, unlike any we have seen before, while the [k] segments display rather wide constrictions.

Thomas-Vilakati [10] shows that the anterior and posterior releases in the dental [ᶢ|] click in IsiZulu occur simultaneously, contrary to Ladefoged and Maddieson's [22] diagram, which shows the anterior constriction releasing prior to the posterior release. The M.D. !Xung data shows a high degree of release overlap for both constrictions of all clicks (with the least overlap in [ᶢ!]). The overlap of the coronal and dorsal releases, as well as the tongue root retraction that occurs as part of the release of the tongue dorsum, point to the hydrostatic nature of the tongue [23], [24].

Clear distinctive coarticulatory effects on the following vowel are seen for each click type in this study. The vowel following all clicks starts out with two constrictions. The palatal click displays a lasting coarticulatory effect on the following vowel that is maintained up until the peak palatal gesture. Future research will determine how the effect changes in different vowel contexts and with different speakers.

With high-speed ultrasound, we can now explore coarticulation involving the whole tongue at sampling rates up to 124 fps [16]. This will allow the comparison of coarticulation between languages, and provide deeper insight into theories of coarticulation. It also allows us to investigate the timing of multiple gestures in multiply articulated consonants. This study has shown that the overlap of coronal and dorsal gestures in clicks is greater than previously thought.

Our understanding of the Back Vowel Constraint as a categorical process that results in two allophones, [i] and [əi] is a simplification of the phonetic reality. The facts with respect to the dental, alveolar and lateral clicks are systematic, and in keeping with the linguistic analyses. However, Snyman [25] has reported lowering associated with the palatal click [ǂ]. We also viewed retraction, which has not been reported before, as one speaker (JF) retracts and lowers the vowel. The other three speakers display variable lowering with no retraction. All four speakers' alveolar and lateral clicks display systematic lowering and retraction.

5. Conclusions

This study has documented the production of all four clicks in M.D.!Xung. Results show that dental ([ᶢ|]) and palatal ([ǂ]) clicks use tongue center lowering as a rarefaction strategy, while the alveolar and lateral clicks use a combination of tongue center lowering and tongue dorsum/root retraction. Tongue center lowering creates a narrow well at the tongue center for the dental, alveolar and palatal clicks, while the lateral click involves creation of a wider plateau involving lowering of a larger tongue segment. The lingual cavity is the smallest for the dental click, followed by the palatal click, the lateral click and the alveolar click. The cavity sizes are consistent with the center of gravity results for the M.D. !Xung clicks provided by Miller and Shah [6].

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