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Differences in Airstream and Posterior Place of Articulation among N|uu Lingual Stops

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This paper describes the consonant inventory of the endangered southern African language N|uu. Our novel approach to segment classification accounts for all 73 N|uu consonants with just four phonetic dimensions (place, manner, phonation and airstream) and does away with the phonetically empty category *click accompaniment*. We provide ultrasound data showing that clicks' posterior constrictions are not produced at the "velar" place of articulation, and that posterior place differs with anterior place. We argue for a terminological shift from *velaric* to *lingual* airstream mechanism. The posterior place of articulation for N|uu's five lingual stops ([ʘ, |, !, ǂ, ǁ]) is the same as for N|uu's five linguo-pulmonic stops ([ʘ͡q, |͡q, !͡q, ǂ͡q, ǁ͡q]). We argue that the difference between these segment classes is best captured in terms of airstream, not place. Plain clicks use only the lingual airstream, while linguo-pulmonic segments are contour segments in airstream, in which the transition to the pulmonic airstream occurs within the segment, rather than at its boundary. Our evidence suggests that the contrast between "velar" and "uvular" clicks proposed for the related language !Xóõ is likely also one of airstream and that a contrast solely in terms of posterior place would be articulatorily impossible.

1. Introduction

N|uu is the only surviving language in the !Ui branch of the Tuu family (Güldemann 2005; formerly "Southern Khoesan"[i]). Until quite recently, it was thought to be extinct (cf. Traill 1999), but it is in fact still spoken by fewer than ten people in the Northern Cape Province of South Africa, and possibly by a few more in southwest Botswana. The only other Tuu language that has been documented with modern instrumental phonetic techniques is !Xóõ, the last remaining member of the family's Taa branch. Tuu languages are extremely interesting because of their unique consonant and vowel inventories, which are among the largest in the world (Traill 1985; Ladefoged and Traill 1994). In this paper, we compare phonetic data from N|uu with published reports on !Xóõ, G|ui (Khoe-Kwadi, "Central Khoeasn"), Khoekhoe (Khoe-Kwadi), ǂHoan (Juu-ǂHoan, "Northern Khoesan") and Ju|'hoansi (Juu-ǂHoan) in order to argue for our approach to click description and analysis. The data presented here is part of a larger project to document the lexical, syntactic, phonological and phonetic structures of the N|uu language.

This paper has four goals. The first is to document the consonant inventory of N|uu in a phonetically accurate way. N|uu is a severely endangered language from an understudied group of languages known for their exceptionally complex sound systems. A description of such a language must necessarily enhance our understanding of the ways these systems are structured. Our second goal is to offer a framework for classifying click-language segments that renders the idea of a click accompaniment unnecessary. The term accompaniment (Traill 1985), efflux in older terminology (Beach 1938), is a phonetically empty category that has been used as a catch-all for every type of modification to click closures and releases ever reported in a click language. We will show that the traditional articulatory concepts of place, manner, phonation and airstream can be applied to clicks just as easily as to other segments, and that using these linguistic phonetic descriptors allows us to present our inventory in a manner that is consistent with established IPA principles. Doing so also allows us to highlight typological similarities between N|uu click and non-click inventories. We believe that it will ultimately be possible to reanalyze the inventories of all click languages within the framework we propose, though the actual reanalyses are beyond the scope of this paper (see Miller 2007a for further discussion).

Our third goal is to show that the posterior constriction in all clicks involves an important pharyngeal component that makes them qualitatively different from velar stops. It has long been maintained that most clicks have a velar back constriction (Doke 1923; Beach 1938; Traill 1985; Ladefoged and Maddieson 1996, and references therein), hence the term velaric airstream mechanism. We will show that the different N|uu click types have different posterior constrictions, as Miller, Namaseb and Iskarous (forthcoming) have shown for a subset of Khoekhoe clicks. In order to fully describe the differences in posterior place of articulation found in clicks, pulmonic velar and pulmonic uvular consonants, we must distinguish between the upper and lower tongue root, which has not been shown to be a necessary distinction for pulmonic consonants, as well as between the upper and mid pharynx, two of the three oro-pharyngeal regions defined by Hess (1998). Clicks do not involve posterior constrictions in the lower pharynx, which Esling (1996, 2005) notes is used in the production of epiglottal consonants. We note that posterior place differences are predictable from anterior place contrasts in clicks. However, the phonological relevance of the distinction, which is shown by Miller (2007a) to account for a phonological C-V co-occurrence pattern known as the Back Vowel Constraint (Traill 1985), provides crucial data that this level of phonetic detail must be captured at a phonological level of representation. We follow Miller, Namaseb and Iskarous (forthcoming) in arguing for the articulatorily more accurate term lingual airstream mechanism.

Our final goal is to address claims that clicks can contrast exclusively in terms of their posterior constrictions. !Xóõ (Traill 1985; Ladefoged and Traill 1994) ǂHoan (Bell and Collins 2001), G|ui (Nakagawa 2006) and Kxoeii (Köhler 1981, Kilian-Hatz 2003) have all been described in terms of clicks with independently contrastive velar and uvular posterior constrictions. We will show that comparable segments in N|uu actually contrast in the timing and airstream of the click's posterior release, not its place of articulation, and that these segments are best seen as linguo-pulmonic airstream contour segments. Structurally, they are parallel to contours in manner (i.e., affricates) and nasality (i.e., pre-nasalized stops). In fact, we suspect that a contrast made solely in terms of posterior constriction location, independent of either the anterior constriction or the airstream mechanism, is unlikely. This insight, together with published phonetic descriptions of !Xóõ, ǂHoan and G|ui suggests that it will ultimately be possible to reanalyze these languages in a similar fashion. There are no available phonetic descriptions of Kxoe, so we do not know how the similarly transcribed sounds in that language are phonetically realized.

The structure of the paper is as follows. Section 2 provides the segment inventory for N|uu, along with a brief discussion of its key features and introduces our novel approach to classifying click-language segments. Section 3 presents our phonetic methodology. Section 4 summarizes our acoustic and articulatory data. Specifically, section 4.1 illustrates the range of contrastive closure properties found in N|uu clicks, section 4.2 provides acoustic and ultrasound data to characterize the different click types in terms of both anterior and posterior place of articulation differences, and section 4.3 presents contrastive release properties, including phonation type, manner of articulation and airstream contrasts. In this section, we provide evidence for a new type of contrastive segment, airstream contours, and we show that clicks involving airstream contours can also display contrastive contours in manner of articulation and phonation. Section 5 summarizes our conclusions.

2. The N|uu consonant inventory

The inventory presented below is based on a 1400-word lexicon (Sands et al. 2006) described in Sands, Miller and Brugman (forthcoming). Given the modest size of this corpus and the number of segments in the inventory, we expect that there may be accidental gaps, as well as systematic ones. These are discussed in Miller (2007a). Additionally, some segments are represented by only a small number of lexical items, but it is impossible to tell whether this is the result of highly skewed distributions, or just the small size of the corpus. Our focus here is on the N|uu consonant system; the vowel inventory is discussed in Brugman, Miller and Sands (2006). N|uu has dense lexical tone specifications similar to the tonal systems of other Khoesan languages (see e.g. Traill 1985 for !Xóõ; Miller-Ockhuizen 2003 for Ju|'hoansi, Haacke 1999 for Khoekhoe). The tonal system of N|uu is not described in this paper.

N|uu, like other Khoesan languages, has a limited set of native root shapes (CVV, CVCV, CVVCV and CVN) in which obstruent consonants are mostly confined to root-initial positions. Most CVVCV words on the surface are comprised of a CVV root and a CV function morpheme There are multiple non-root function words, clitics and suffixes of the shape (C)V. Note that the frame sentences in our acoustic and articulatory studies include such forms. There are however a few CVVCV roots that are clearly monomorphemic, such as the word ǂx'aqaba [ǂχ’ɑʕɑβɑ] ‘to slap’. See Miller-Ockhuizen (2003) for discussion of phonotactic constraints on root shapes in Ju|’hoansi and Miller (2007a) for a more detailed discussion of such patterns in N|uu.

The consonant inventory of N|uu is presented in Tables 1 and 2, and words exemplifying each of these segments are in Appendix A. Including marginal segments, there are 25 pulmonic consonants, 3 glottalic consonants, and 45 lingual consonants (clicks), for a total of 73 consonants. This is large by the standards of most languages, but is unexceptional in a Khoesan context: !Xóõ contrasts 119 consonants, Ju|’hoansiiii 89, Kua 79 and Khoekhoeiv 35 (Traill 1985:99).

PULMONIC							
	Bilabial	**Alveolar**		**Palatal**	**Velar**	**Uvular**	**Glottal**
		Central	**Lateral**				
Stop	p b	(t) (d)		c c^h ɟ $c^{χ}$	k k^h g	q[v]	ʔ
Affricate		ts					
Nasal	m	n		ɲ	ŋ[vi]		
Fricative	(f)	s z				x	ɦ
Liquid		ɾ	l				
GLOTTALIC							
Affricate		ts’			$k^{χ}$’	qx’[vii]	

Table 1: N|uu pulmonic and glottalic consonants

LINGUAL					
	Labio-uvular	**Denti-Pharyngeal**	**Alveolo-uvular**		**Palato-Pharyngeal**
			Central	**Lateral**	
Stop	ʘ	ǀ ǀ^h ᶢǀ	ǃ ǃ^h ᶢǃ	ǁ ǁ^h ᶢǁ	ǂ ǂ^h ᶢǂ
Nasal	ŋ̊ʘ^ʔ ŋʘ	ŋ̊ǀ^h ŋ̊ǀ^ʔ ŋǀ	ŋ̊ǃ^h ŋ̊ǃ^ʔ ŋǃ	ŋ̊ǁ^h ŋ̊ǁ^ʔ ŋǁ	ŋ̊ǂ^h ŋ̊ǂ^ʔ ŋǂ
LINGUO-PULMONIC					
Stop	ʘ͡q	ǀ͡q ǀ͡q^h	ǃ͡q ǃ͡q^h	ǁ͡q ǁ͡q^h	ǂ͡q ǂ͡q^h
Affricate	ʘ͡χ	ǀ͡χ	ǃ͡χ	ǁ͡χ	ǂ͡χ
LINGUO-GLOTTALIC					
Affricate		ǀ͡χ’	ǃ͡χ’	ǁ͡χ’	ǂ͡χ’

Table 2: N|uu lingual, linguo-pulmonic and linguo-glottalic consonants

Our inventory recognizes linguo-pulmonic sounds not recognized by Doke (1936) or Westphal (1953-1957). This is important because their presence makes the language more similar in its inventory to its closely related language !Xóõ. This might reflect differences in the language varieties we have worked on, or language change between when the earlier fieldwork was undertaken and the present. Sound files for each of the contrasts are provided at http://ling.cornell.edu/khoisan/nu/nu.htm.

Tables 1 and 2 are organized in line with the general principles of the International Phonetic Association (IPA 1999). Segments are sorted into columns by place of articulation and into rows by manner of articulation. Phonation type is indicated by the order of segments in each cell (plain, aspirated, glottalized, voiced). Though airstream contrasts are sometimes treated like manner contrasts in languages with smaller inventories (e.g., Amharic ejectives, Sindhi implosives and Hausa implosives and ejectives in IPA 1999), we present them as sub-divisions of the two tables because of the complexity of such contrasts in this language. This approach is also in keeping with the phonological evidence provided in Miller (2007a) that manner and airstream behave as separate phonological classes.

Segments in parentheses appear in our lexicon, but their phonemic status is still unclear, so we include them with qualifications. The segments [f], [t] and [d] appear only in words that have been fully adopted into the lexicon, but have not been completely phonologically assimilated. Code-switching occurs between Afrikaans and N|uu as well, but words used in code-switching are still recognized as Afrikaans words by the speakers. We expect that the degree of phonological assimilation is dependent on elicitation methods used. Loan-words seem to be assimilated to the native phonology more fully in the stories elicited by Collins and Namaseb (2005), than in lexical elicitation sessions using Afrikaans as the contact language. Barring a full-scale study of loanwords, we are not able to differentiate between these types of productions. [ɦ] and [l] also occurs primarily in loanwords, though we have identified a handful of words with each of these consonants that appear to be native roots. Therefore, we treat [l] and [ɦ] as low frequency native sounds, and do not place them in parentheses. Finally, the glottal stop occurs in only in word-initial position and in a few lexicalized forms. We follow Miller (2007a) and take it to be prosodically conditioned. For a possible alternative analysis, see Exter (2007). Since it is prosodically conditioned, and not present only in loan-words, we do not place it in parentheses.

In Tables 1 and 2, both click and non-click segments are sorted by place of articulation. In the case of clicks, this sorting requires some discussion, because such stops are characterized by both an anterior and a posterior place of articulation. These two constriction locations form the boundaries of a lingual cavity that is expanded to create a low-pressure air pocket. When the anterior constriction is released, air rushes into this pocket with a distinctive "popping" sound. The auditory impression of this pop is determined by the exact shape of the cavity between the anterior and posterior constrictions, as well as the speed and direction (central or lateral) of the release. In N|uu, there are five different types of cavity, which correspond to different click types: labial ([ʘ]), dental ([|]), central alveolar ([!]), lateral alveolar ([‖]) and palatal ([ǂ]). It joins !Xóõ, ǂHoan and Kxoe as being only one of four languages containing these five click types. However, there are other languages such as Mangetti Dune !Xung (Miller-Ockhuizen and Sands 1999) which contrast five coronal clicks.

As is clear from their names, click types have traditionally been defined in terms of the anterior constriction, largely because it was assumed that the posterior constrictions were all the same. It has been shown that this is not the case in Khoekhoe (Miller, Namaseb and Iskarous forthcoming), and we will show that it is also not the case in N|uu. For the sake of expositional clarity, we will continue to refer to the click types by their conventional names, but the column headings in Table 2 follow Miller-Ockhuizen (2003) in emphasizing that two different places of articulation are always involved. Regardless of the terminological details, the category click type has a coherent articulatory phonetic basis that has been demonstrated by palatographic studies in several languages: !Xóõ (Traill 1985; Ladefoged and Traill 1994), Khoekhoe (Beach 1938), G‖ana (Traill and Vossen 1997), G|ui (Nakagawa 2006), Sandawe (Wright, Maddieson, Ladefoged and Sands 1995; Maddieson, Ladefoged and Sands 1999), Hadza (Sands, Maddieson and Ladefoged 1996; Maddieson et al. 1999; Ladefoged and Maddieson 1996) and N|uu (Sands, Brugman, Exter, Namaseb and Miller 2007). This is not the case with click accompaniment.

Following IPA guidelines (IPA 1999:8), the rows of Tables 1 and 2 sort the N|uu consonant inventory by manner of articulation, with individual cells sub-divided by phonation type. With the pulmonic consonants, we find typical contrasts among stops, affricates, fricatives, nasals and liquids, but lingual consonants are restricted to just stops, affricates and nasals, because the lingual airstream requires a stop component. Note that both manner and phonation differences in lingual segments are superscripted. This is to indicate that they are not sequences of elements (e.g., a nasal and a click), but rather unary elements. The difference between [!] and [ŋ!], for instance, is equivalent to that between [p] and [m], while that between [!] and [g!] is equivalent to that between [p] and [b].

The final linguistic phonetic dimension required for our analysis of the N|uu inventory is that of airstream. N|uu uses all three airstream mechanisms recognized in the phonetic literature: pulmonic, glottalic and lingual. In addition, we will argue that certain segments are best viewed as airstream contours, namely those we call linguo-pulmonic and linguo-glottalic stops and affricates. Plain lingual stops are characterized by a shift to the pulmonic airstream that occurs at the onset of the following vowel, but in airstream contours, pulmonic or glottalic airflow begins midway through the segment, so that the release portion of the click is a pulmonic or glottalic stop or fricative. All clicks have a posterior release, but in most cases this release is inaudible. It is only in linguo-pulmonic and linguo-glottalic segments that the shift in airstream mechanism makes the posterior release perceptible. See Miller (2007a) for discussion of why pulmono-lingual, glotto-lingual, pulmono-glottalic or glotto-pulmonic segments are unattested. Our proposal that consonants can differ in the airstream mechanism employed within a single segment is novel, but it is not surprising given that it parallels proposals for contours on other linguistic phonetic dimensions. There are manner contours (affricates), nasality contours (prenasalized stops) and now airstream contours.

A final note on the representation of these segments is necessary. Clicks are dynamic segments, so discussing them in terms of two static places of articulation is a simplification. Both the anterior and posterior constrictions move in the formation of the low-pressure cavity, and we maintain that it is the nature of the constriction at the point of release that matters, at least with respect to phonological patterns like the Back Vowel Constraint (see Traill 1985; Miller et al. forthcoming; Miller 2007a for further discussion). We will show below that this posterior constriction is more similar to [q] than [k], and that it is different for the different click types. It is not, however, clear how best to symbolically represent these differences, so the pulmonic portion of all five linguo-pulmonic stops are represented with [q] for the time being following historical convention. Similarly, the voicing and nasality are shown in clicks historically with the velar and nasal pulmonic consonant symbols, [ɡ] and [ŋ]. We have maintained this convention, although our results suggest that this is also an oversimplification of the place of the posterior constriction during the closure where voicing and nasality are realized.

Our analysis of all N|uu consonants in terms of place of articulation, manner of articulation, phonation and airstream is meant to underscore the basic structural similarities among lingual and non-lingual inventories, and the presentation of clicks in an IPA-style chart is intended to emphasize the parallels with their pulmonic and glottalic counterparts. Both pulmonic and lingual stops, for instance, can be voiced, voiceless or aspirated. Both glottalic and linguo-glottalic stops are always voiceless affricates in this language. We argue that this approach is a considerable improvement over approaches that simply lump every modification of a particular click type in a particular language under the heading of accompaniment.

The idea of classifying clicks on the basis of type and accompaniment dates at least to Beach (1938), who uses the terms influx (i.e., ingressive airflow) and efflux (i.e, egressive airflow), respectively, to describe the inventory of Khoekhoe. The term click type is now the norm in discussing the location and direction (central or lateral) of ingressive airflow, while accompaniment has replaced efflux for referring to all the contrasts in egressive airflow associated with a given click type. As a result, the category click accompaniment groups together phonation contrasts (voiced vs. voiceless, aspirated vs. unaspirated), manner contrasts (oral vs. nasal, stop vs. affricate) and airstream contrasts. We maintain that the practice of lumping qualitatively different types of contrasts under a single heading has served to obscure important structural similarities between click and non-click inventories. Additionally, Miller (2007a) shows that decomposing sound classes into phonetically similar classes allows a straight-forward mapping between phonetic descriptions and phonological representations based on them, and phonologically motivated sound classes that pattern together.

There have been previous attempts to improve upon the mixed-bag approach. Nakagawa (1996a, 1996b, 2006) uses the term accompaniment to describe the inventory of G|ui, but also groups the segments according to their manners, while Miller-Ockhuizen (2003) presents Ju|’hoansi segments in an IPA-style chart, categorizing them as much as possible in terms of place and manner of articulation. The present organization follows these ideas to their logical conclusion, explicitly rejects the usefulness of the concept accompaniment and classifies segments exclusively with the principles of the IPA.

3. Methods

Our description of N|uu is based on recordings of the speech of seven N|uu elders, all of whom requested recognition for their contribution to our study: Ouma Katrina Esau (KE), Ouma Anna Kassie (AK), Ouma Hanna Koper (JK), Ouma |Una Rooi (UR) and Ouma Griet Seekoei (GS), who speak the Western dialect, and Ouma Hannie Koerant (HK) and Oupa Andries Olyn (AO), who speak the Eastern dialect. All are bilingual in Afrikaans and N|uu and are 65-75 years of age. Ouma Anna Kassie and Ouma |Una Rooi also speak some Khoekhoe, and the two Eastern N|uu speakers are also fluent in Setswana. None currently resides in a household with other N|uu speakers, and Afrikaans is the dominant language for all. Transmission of the N|uu language was seriously disrupted in 1931 when the ǂKhomani people were expelled from the area that became the Kalahari Gemsbok Park (Crawhall 2003, 2004), and families dispersed in search of work and other opportunities. Linguistic documentation and revitalization of N|uu began when community member Petrus Vaalbooi spoke with author Namaseb about writing down his mother's language (Chamberlin and Namaseb 2001; Namaseb 2006:42-43). Vaalbooi's mother, Ouma Elsie Vaalbooi, passed away before our project began, but she played an important role in spear-heading N|uu linguistic documentation and revitalization efforts.

Acoustic recordings reported in this paper were made with four different setups in various fieldwork trips by various subsets of the authors between 2003 and 2006 onto: (1) a Sony TCD D7 DAT recorder with a Sony ECM-MS907 microphone; (2) an Acer TravelMate 230 laptop using a Sound Devices USBPre combined pre-amp and A/D converter with an AKG C 420 head-mounted condenser microphone; (3) a Dell 8600 laptop using an Edirol UA-3B pre-amp in conjunction with a Sony ECM-144 electret condenser microphone; (4) a Marantz 670 digital audio recorder using a Shure SM10A head-mounted microphone. Recordings were made in Upington, South Africa in quiet rooms in the Belurana guest lodge or the SASI office.

Ultrasound investigations were undertaken with speakers AK, GS, KE and HK. Ultrasound videos were collected using a GE Logiqbook ultrasound machine with an 8C-RS 5-8 MHz pediatric transducer. Head and transducer stabilization were accomplished as in Gick, Bird and Wilson (2005). The acoustic signal was recorded with a Shure SM10A head-mounted microphone and channeled through a Shure FP23 pre-amp. All ultrasound recordings were made in the frame sentence [na ka _____, na ka qoaqî.], meaning 'I say _____, I say 'famished'.' Tongue traces of a particular token is always plotted with and discussed relative to the place of articulation of [k] and / or [q] in the frame sentence as in Brugman (2005). Note that all plots show the position of the tongue relative to the ultrasound probe, not the palate. For each token, we identified frames immediately before and after the lingual burst. With the linguo-pulmonic stops, we also identified the frames immediately before and after the pulmonic burst. The tongue edge was tracked for each of these frames with EdgeTrak (Li, Khambamettu and Stone 2005).

A complete description of the Cornell Phonetics Lab ultrasound setup used in this study, and the methodology used to align acoustic and articulatory data is provided in Miller et al. (2007).

4. N|uu clicks

The goal of this section is to present evidence supporting our claims about the inventory of N|uu lingual stops. As already noted, previous phonetic descriptions of clicks have lumped together phonation type, manner of articulation and airstream contrasts into the clicks' efflux (Beach 1938) or the click's accompaniment (Ladefoged and Traill 1994). We follow Thomas-Vilakati (1999) and Miller-Ockhuizen (2003) in orienting our discussion temporally by focusing on the characteristics of click closures (4.1), followed by a discussion of place of articulation contrasts (Section 4.2.), and release properties (Section 4.3). Section 4.2 provides acoustic and articulatory evidence for the anterior and posterior places of articulation and makes the case for the term lingual airstream mechanism. Section 4.3 separates contrastive release properties into phonation type, manner of articulation and airstream contrasts. Section 4.4 provides supporting evidence for our claim that clicks can not contrast solely in terms of posterior place of articulation, and provides evidence for contrastive airstream contours.

4.1 Closure contrasts

N|uu contrasts voiced and voiceless oral closures as well as voiced and voiceless nasal closures. Figure 1 provides waveforms that illustrate these possibilities with voiceless unaspirated, voiced unaspirated, voiceless nasal aspirated and voiced nasal central alveolar clicks. The degree of voicing, especially in the voiceless nasal aspirated clicks, is in part prosodically conditioned. We therefore show each click in two contexts, one where the closure is at a stronger prosodic boundary and one where it is at a weaker boundary. The stronger boundary correlates with longer closure duration as well as a lesser degree of closure voicing.

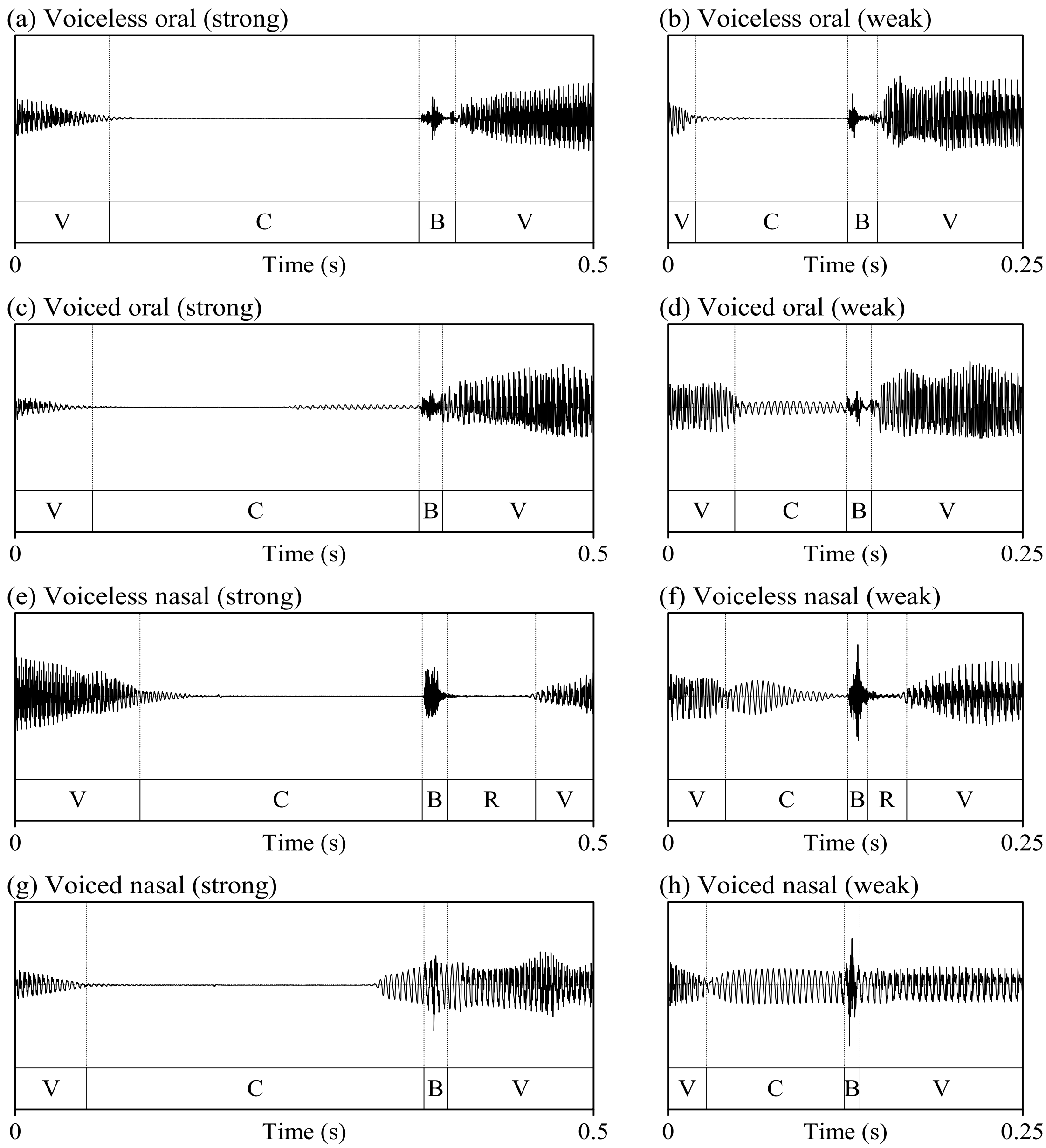


Figure 1: Waveforms of clicks with different types of closures excerpted from the frame sentences [na ka ___] ‘I say ____’ (left, stronger prosodic boundary) and [na ka a ____] ‘I say your [noun]’/’I say you [verb]’ (right, weaker prosodic boundary): (a-b) [ǁ͡χəe] ‘sister’, (c-d) [ᶢǁɑɑ] ‘night’, (e-f) [ŋ̊ǁʰɑɑsi] ‘uterus’ and (g-h) [ᵑǁɑɑ] ‘stay’. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R) (Speaker GS).

The difference between voiced (Figure 1 c-d) and voiceless (Figure 1 a-b) clicks is directly parallel to that of voiced and voiceless pulmonic stops in N|uu, with visible voicing in at least part of the segment's closure portion. Notice that prosodic context conditions differences in the degree of voicing in such segments in N|uu lingual and pulmonic stops, just as it does in English (Keating 1984), Hebrew (Kreitman 2007) and various other languages. The oral voiced click that comes after a stronger prosodic boundary in Figure 1(c) has weak voicing that starts only half-way through the closure, while the voicing across the weaker prosodic boundary in Figure 1(d) is much stronger. We see the same pattern in the voiced nasal click. It should be noted that the nasalization in the voiced and voiceless nasal clicks occurs throughout the closure and the release, indicating that these segments are not pre-nasalized stops, but are rather fully nasal. Further, the strong burst and their phonotactic patterns show that they are obstruents and not sonorants.

Voiceless nasal aspirated clicks (e.g., [ŋ̊!ʰ]) in N|uu are usually produced with at least some audible nasalization in the closure, but the voiceless nasal closure in clicks with a glottalized release (e.g., [ŋ̊!ˀ]) are much more variable across speakers, contexts and tokens (See Section 4.3.1.). There is usually at least some hint of nasalization, but the closure is much less likely to be voiced than that of a voiceless nasal aspirated click. This may be related to the fact that the glottis must close at some point prior to the click burst. Examples of the variation in such segments are provided in Miller et al (2007).

4.2 Place of articulation contrasts

In this section, we summarize the differences in anterior place of articulation and posterior place of articulation found in clicks. Section 4.2.1 summarizes anterior place of articulation differences reported in Sands et al. (2007) in terms of both the active articulator, and the location of the constriction. In Section 4.2.2., we provide evidence that posterior place of articulation differences also occur in N|uu, and argue that these differences are predictable from the anterior place of articulation differences. Though they are not independently contrastive, they are important and must be represented, because they account for phonological differences in the patterning of click classes with respect to the BVC in N|uu (Miller 2007a) and other languages (Miller-Ockhuizen 2003; Miller, Namaseb and Iskarous, forthcoming).

4.2.1 Anterior constrictions in click types

As shown above in Table 2, N|uu maintains a contrast in five click types - four that have a coronal anterior constriction, and one that has a labial anterior constriction. Miller et al. (2007) and Sands et al. (2007) provide palatographic and linguographic data for the four coronal click types in N|uu. Results show that the dental click has a laminal dental articulation, with a fairly broad area of contact. The central and lateral alveolar clicks are clearly alveolar in N|uu, and not post-alveolar as has been reported for IsiXhosa (Sands 1991), IsiZulu (Doke 1923) and !Xóõ (Traill 1985). Tongue contact largely involves the tongue tip as has been found for !Xóõ (Traill 1985). The palatal click displays an extremely wide contract area between the alveolar ridge and the palatal region. We suspect, based on our viewing of ultrasound movies of the articulation of this click in N|uu, and EPG data on production of palatal clicks in Khoekhoe (Miller 2007b) that the long laminal contact is due to dynamic movement of the anterior constriction during production of the palatal click, rather than a long laminal closure.

The bilabial click in N|uu has been assessed through video images of the lips during its production. As described in Miller et al. (2007) dynamic changes in lip posture in the video show lip compression and release over the initial 20 ms interval of production, which are followed by puckering of the lips over the final 20 ms of the approximately 40 ms duration of this click type. The rounding coarticulation on following vowels in N|uu is auditorily very salient, and words like ‘meat’ are realized as both ʘoe and ʘəe by the same speaker in the same context. We have documented a variant production of the labial click by Speaker HK that involves the lower lip making contact with the upper teeth, which has also been described by Ladefoged and

Maddieson (1996: 251) for !Xóõ. Our investigations of anterior place in N|uu clicks shows that clicks display individual phonetic variation similar to that documented for pulmonic consonants.

Figure 2 provides waveforms of words that begin with each of the five lingual stops and bark-scaled LPC spectra computed over a 25 ms window aligned with the right edge of the burst. The waveforms show that the bilabial, dental and lateral alveolar clicks are noisy, while the central alveolar and palatal clicks are abrupt, much like those reported for !Xóõ (Ladefoged and Traill 1994; Ladefoged and Maddieson 1996). That is, the bursts of the central alveolar and palatal clicks exhibit a sharp, intense transient, with little turbulent noise, while the bursts in bilabial, dental and lateral alveolar clicks are noisy, making it difficult to isolate the transient. The noisiness can be seen more clearly in linear FFT spectra, but even in Bark spectra provided here, the noisy clicks are characterized by a generally flatter energy distribution. The differences in noisiness correlate with durational differences. Noisy clicks are longer than abrupt ones.

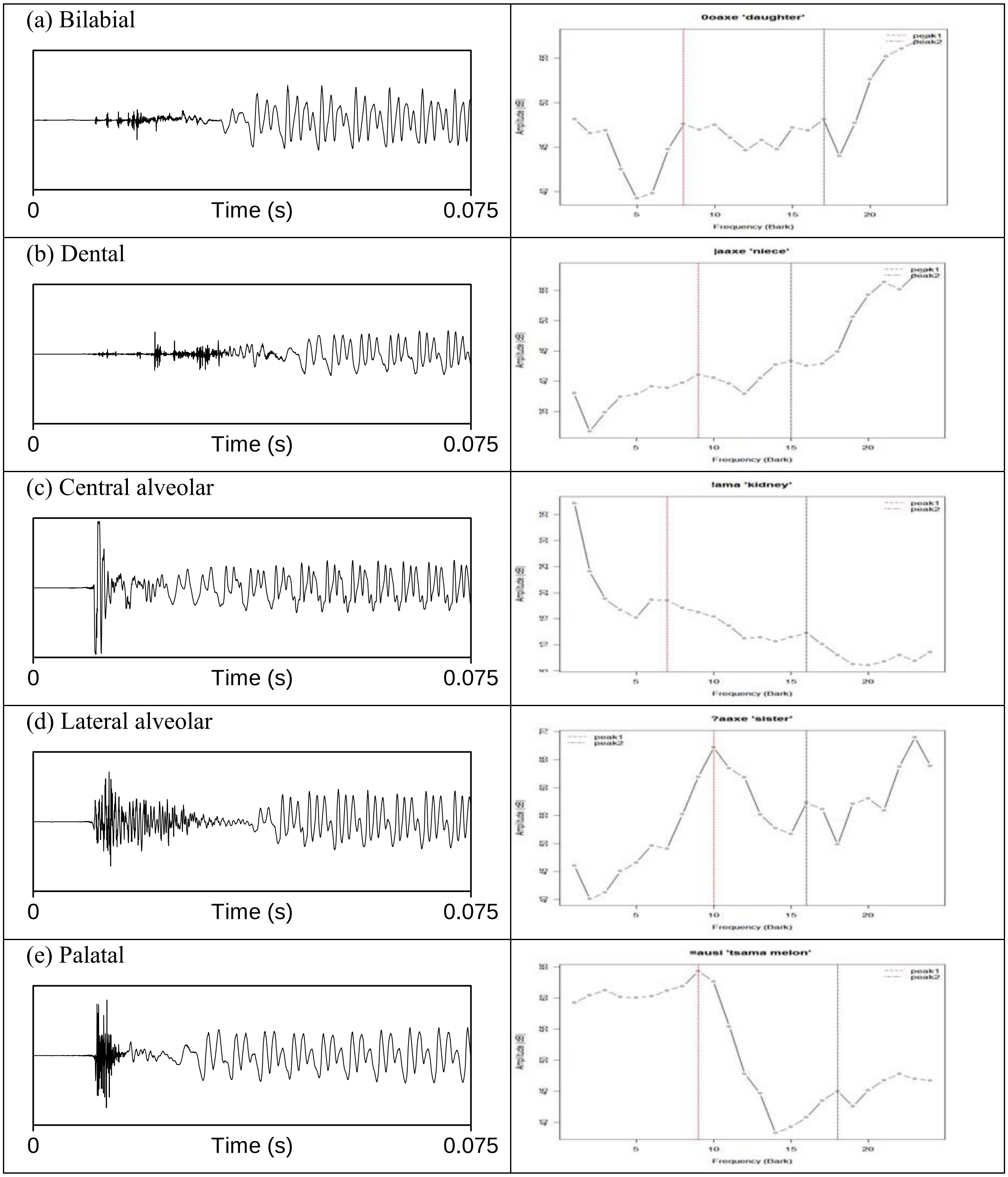


Figure 2: Representative waveforms and Bark-scaled LPC spectra of bursts in words extracted from the frame sentence [na ka ____, Na ka qoaqi.] ‘I say ____, I say ‘famished.’ for the five N|uu lingual stops in the words: (a) [ʘoɑχe] ‘daughter’, (b) [|ɑɑχe] ‘niece’, (c) [!ɑmɑ] ‘kidney’, (d) [‖ɑɑχe] ‘sister’ and (e) [ǂəusi] ‘tsama melon’ (Speaker KE).

Ladefoged and Maddieson (1996) attribute both the shorter duration and the dominance of the transient in the abrupt clicks to a faster anterior release. It is interesting to note that the clicks in most languages pattern like those in N|uu with respect to their abruptness, but Fulop et al. (2003) report that palatal clicks in the Bantu language Siyeyi tend to be longer and noisier, like the dental clicks, and that the lateral clicks are often sharp like the central alveolar clicks. We expect that cross-linguistic studies will show more complexity of this type, as found for pulmonic coronal stops in European languages (e.g., Dart 1998).

4.2.2 Posterior constrictions in click types

We now turn to a description of posterior places of articulation for all five N|uu click types ([ʘ, |, !, ‖, ǂ]), and their linguo-pulmonic counterparts, ([ʘ͡q, |͡q, !͡q, ‖͡q, ǂ͡q]). At least since Doke (1923), all phonetic literature has proclaimed that all click types involve a velar posterior place of articulation. However, Miller, Namaseb and Iskarous (forthcoming) and Miller et al. (2006) have shown that the palatal and post-alveolar clicks in Khoekhoe, and the palatal and alveolar clicks in N|uu contrast in the posterior place of articulation. Traill (1985), Ladefoged and Traill (1984, 1994) and Ladefoged and Maddieson (1996) claim that the main contrastive difference between the fully lingual stops and the linguo-pulmonic stops is posterior place of articulation. The IPA representation of linguo-pulmonic clicks involving a [q] after the click symbol, used throughout this paper is a historical artifact of the previous interpretation of the contrast in terms of posterior place. Our first goal is to show that the posterior constrictions are not velar in the alveolar and palatal clicks in N|uu. The nature of the posterior constriction is complicated and, we believe, tied to overall tongue shape.

Previous descriptions of clicks have focused on the location of the front part of the posterior constriction, which has generally been described as velar and equated with [k]. However, we will show that the shape and dynamics of the tongue root in clicks are actually very different from [k]. We believe that this is the result of muscle movement necessary for click production. We first address acoustic data in Section 4.2.2.1., and then turn to articulatory ultrasound data in Section 4.2.2.2.

4.2.2.1 Acoustic data for posterior place

Spectral differences of the click bursts seen clearly in the bark-scaled auditory spectra provided in Figure 2, and shown by Miller, Brugman and Sands (2007) provide evidence for both anterior and posterior place differences. We present Bark-scaled spectra in order to give a better sense of the auditory impression of the higher frequencies. Differences in energy distributions of N|uu lingual bursts are also consistent with those reported for !Xóõ (Ladefoged and Traill 1994; Ladefoged and Maddieson 1996), so that the dental and palatal bursts have more energy at higher frequencies, the central and lateral alveolar clicks have more energy at lower frequencies and the bilabial click has clear high and low frequency peaks. The LPC bark-scaled spectra of click bursts provided in Figure 2 and in Miller, Brugman and Sands (2007) also show that there are two clear spectral peaks in the burst spectra of all five click types in N|uu, and that the frequencies of these two peaks differentiate the five click types. We attribute the lower resonance frequency (P1) to the volume of the lingual cavity formed between the anterior and posterior constrictions, not to the cavity in front of the constriction as in pulmonic egressive stops (Fant 1960), as interpreted by Kagaya (1978). We attribute the higher resonance frequency (P2) to the volume of the cavity in front of the anterior constriction in the coronal clicks. In pulmonic stops, the cavity in front of the constriction is mostly relevant for stop burst spectra, but as the stop constriction is released, the front cavity and the cavity behind the posterior constriction become coupled, and the volume of the back cavity becomes relevant to the acoustic resonances of the latter part of the burst and the formant transitions. In contrast, in click production, the acoustic resonances are largely a product of the lingual cavity volume between the anterior and posterior constrictions, and since the sounds are ingressive, the volume of the cavity in front of the constriction becomes relevant at the release of the anterior constriction. The spectral differences seen must therefore be attributed to the overall volume of the lingual cavity, which is determined by both the anterior and posterior place of articulation differences in terms of both active and passive articulators.

It is important to note that there is no indication in these waveforms of a pulmonic burst between the click burst and the vowel. Auditory descriptions of clicks often claim that the release of the posterior constriction is a pulmonic stop, but it is crucial to our subsequent argument that this is not the case, and clearly in these waveforms there is no such burst. We sometimes find low-intensity events between the lingual burst and the vowel onset, and these events may well correspond to the release of the posterior constriction, but they are low amplitude and generally imperceptible, especially given their proximity to the high-amplitude click burst. Traill (1985:125-6), in fact, makes this same observation for !Xóõ. He cites Beach’s (1938:82) comment that the posterior closure in Khoekhoe clicks can be released “practically silently” and maintains that the same is true of !Xóõ. This observation will be crucial in our discussion of the distinction between lingual and linguo-pulmonic clicks in section 4.4, and we maintain that it is the norm rather than the exception in click production.

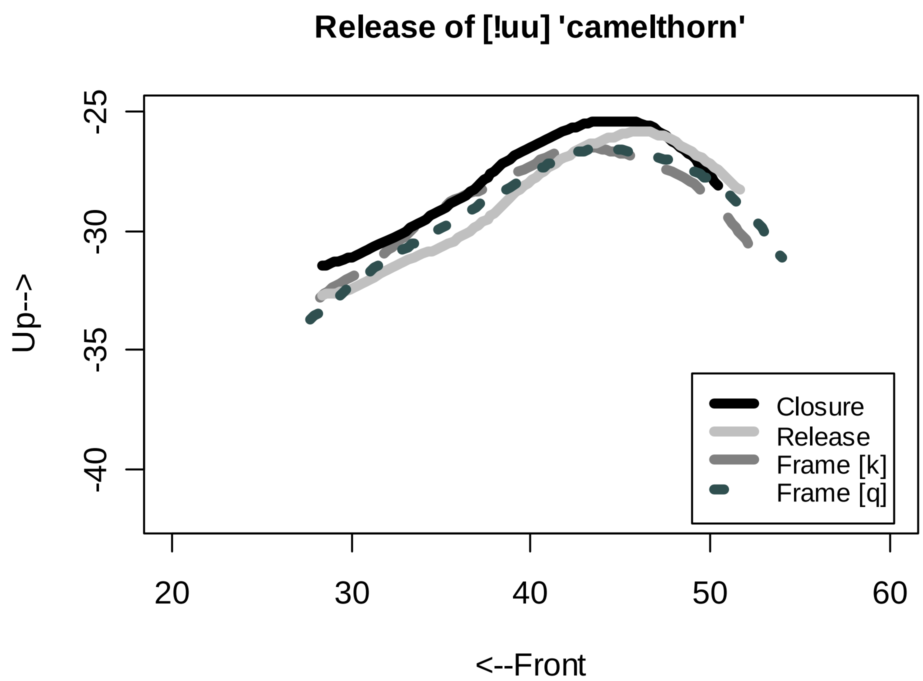
4.2.2.2 Articulatory data for posterior place

We now turn to an investigation of ultrasound data which allows us to pinpoint the part of the tongue used in the production of clicks, as well as to pinpoint the place of the release relative to velar and uvular consonants with better understood places of articulation. Our discussion in this section distinguishes between three posterior parts of the tongue, namely the dorsum, the upper tongue root and the lower tongue root. Generally, the tongue dorsum is at or in front of the posterior constriction during click closures, while the upper and lower tongue root are behind it.

By upper tongue root, we mean the part of the tongue that is at the interface between the oral and pharyngeal cavities in rest position, and by lower tongue root, we mean the part in the lower oropharynx. We also need to distinguish raising of the back of the tongue that occurs in high back vowels and is primarily a vocalic gesture as described by Esling (2005) from tongue root retraction involved in the alveolar clicks, which is a consonantal gesture. We show that the raising of the back of the tongue found in the uvulo-pharyngeal region in palatal clicks is in part at least articulated in the upper pharynx using Hess' (1998) terminology, and is very similar to the production of [u] which follows the clicks in this study. The tongue retraction occurs in Hess' mid pharyngeal region. The third region Hess distinguishes, the lower pharyngeal region, is not used in the clicks we have investigated. This third region is the region where the aryepiglottic sphincter mechanism described by Esling (1996, 2005) comes into play, which is involved in the articulation of epiglottal consonants in Arabic and Pacific Northwest languages, and in epiglottalized vowels found in Khoesan languages (Esling 1996, 2005; Traill 1986 and Miller-Ockhuizen 2003). We do not have evidence regarding possible laryngeal components of click production that Esling (2005) notes often accompany tongue root gestures. However, we note that there are no voice quality cues associated with plain voiceless click consonants, and thus we do not expect to find involvement of the ari-epiglottic folds in click production.

When interpreting tongue traces in this section, it is important to remember that they show the position of the tongue relative to the ultrasound probe, which was positioned beneath the jaw. That is, the origin of the plotting space is the ultrasound probe that emits the ultrasound rays. Raising and lowering of the tongue with respect to the jaw will generally result in raising and lowering with respect to the (hard) palate, but it will underestimate displacement that results from jaw movement. In addition, ultrasound is a poor technology for imaging the tip of the tongue. Ultrasound depends on transmission of sound waves through tissue, and the sublingual cavity associated with a raised tongue tip prevents transmission of these waves. We were not, therefore, able to trace the tip of the tongue reliably in the alveolar clicks. We do know from static palatography and from Traill's x-ray recordings of !Xóõ that the tongue tip is pointed upward in these clicks. We can also deduce the apical gesture from the concave tongue shape that we see in our ultrasound videos stretching from the front of the tongue through the tongue body and tongue dorsum. The tongue root gesture involves a convex tongue root shape. Our ultrasound studies concur with Esling's (2005) claim that the shape of the tongue body and root are independent.

Figure 3 provides ultrasound tongue traces from two frames of the alveolar and palatal lingual stops, along with traces of the pulmonic velar and uvular stops from the frame sentence.



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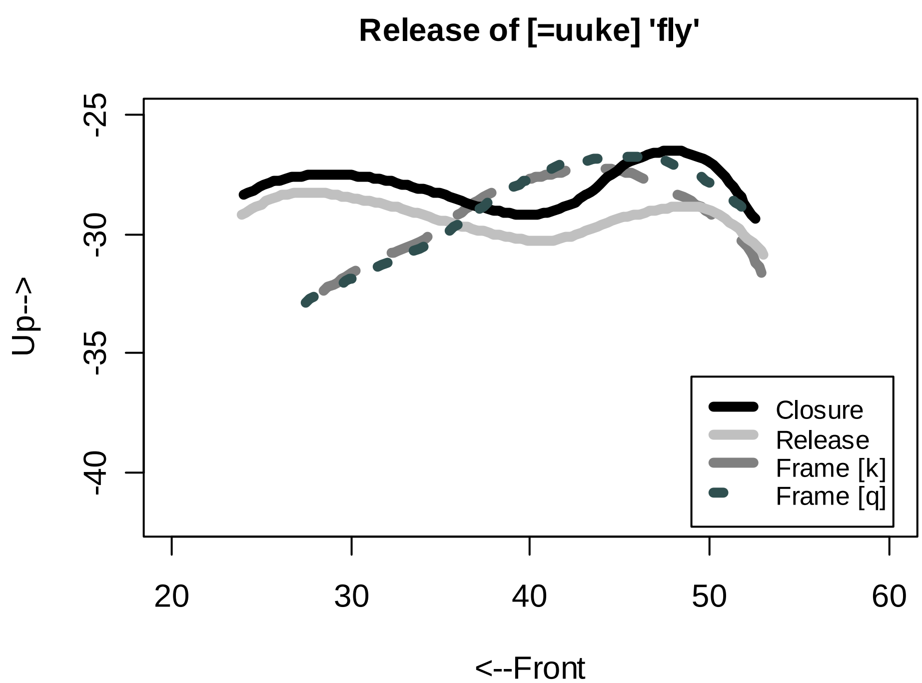


Figure 3: Tongue traces of the central alveolar [!] (top) and palatal [ǂ] (bottom) click types. Plots include traces associated with the closures and releases of the lingual stops, as well as with the closures of velar and uvular pulmonic stops in the frame sentence. (Note that "=" is used for "ǂ" in the plots)

These plots make the differences in the shape of the tongue in these two click types quite clear. Looking first at the top panel, we see small differences in the location of the upper tongue root (i.e., the back sides of the constrictions) in the velar stop [k], the uvular stop [q] and the posterior constriction of the closure in the central alveolar lingual stop [!]. Namely, the upper tongue root in [k] is most advanced, that in [q] is intermediate and that in [!] is most retracted. Our impression from viewing the dynamics of this segment in the source AVIs, as well as Traill's x-ray recordings of similar segments in !Xóõ, is that the same is true of the lower tongue root. One difference between velar and uvular pulmonic stops cross-linguistically is that uvular segments are characterized by tongue root retraction. Hess (1998) reproduces x-ray traces from Tunisian and Iraqi Arabic which show a much more retracted upper and lower tongue root in [q] than [k]. It is for this reason that we call [!] an alveolo-uvular segment.

Turning to the posterior constriction in the palatal click, we see that upper tongue root is raised into the upper pharynx, hence the description palato-pharyngeal in Table 2. The constriction is technically uvulo-pharyngeal, with contact at the back of the uvula, which is raised in the production of the palatal click. There cannot be a complete pharyngeal constriction, nor can the velum be completely raised in these clicks, because there is nasal airflow during nasalized palatal clicks. We do, however, see pronounced retraction in the videos. We know that the upper tongue root is raised and the tongue dorsum is retracted into the upper pharynx, presumably causing bunching. This is akin to the raising gesture that Esling (2005) finds in high back vowels, and differs from the retraction gesture in uvular consonants. We surmise the raising of the upper tongue root from hyoid movement, which is visible as movement of the hyoid shadow in the ultrasound recordings. In pulmonic pharyngeal segments, it is traditionally assumed that the lower tongue root makes contact with the back wall of the lower pharynx. In the palatal click, the upper tongue root contacts the upper pharynx. That is, the uvulo-pharyngeal constriction found in the palatal click is not a retraction gesture as found in epiglottals, but is rather a raising gesture as Esling (2005) describes in the production of high back vowels. The similarity between the [u] gesture which follows the clicks in our data and the palatal click posterior tongue gesture is quite striking. We are not aware of pharyngeal pulmonic obstruents with such high pharyngeal constrictions. However, Ladefoged and Maddieson (1996: 169-70) describe a somewhat similar high pharyngeal constriction found in the Danish approximant [ʁ]. It might be that the pharyngeal component of the posterior gesture in the palatal click is more similar to this more open constriction in the Danish approximant. We can not ascertain the degree of constriction with our current ultrasound recordings, as we have not been able to trace the palate. However, it is clear that the back part of the posterior lingual gesture found in the palatal clicks is a more open gesture, rather than a more constricted consonantal gesture.

In addition to the clear differences in overall tongue shape, our ultrasound recordings also display differences in the timing of the anterior and posterior releases. In recordings of the central alveolar click [!], we sometimes see the tongue tip moving downward from the apical articulation which suggests the uncurling of an extreme concave tongue shape. The deep concave tongue body shape indicates a high volume, large, deep cavity between the two constrictions. In general, the front of the tongue in this click seems to move down faster than the back, which is probably related to the extreme jaw lowering involved in its production. In the palatal click, on the other hand, the two constrictions seem to be lowered more simultaneously, as is suggested from the successive frames traced in the bottom panel of Figure 3. The cavity between the constrictions is much shallower in this click. These differences in tongue shape and the resultant differences in cavity size account for the spectral differences shown above.

Our impression from viewing the ultrasound video is that the relationship between the anterior constriction location, the posterior constriction location and resulting cavity volume are highly constrained by the tongue musculature. The tongue muscles are interconnected and the tongue can be divided into four main extrinsic muscles (Zemlin 1968; Harris et al. 1992; Honda 1996) that are divided into two groups of compatible vs. incompatible muscles. We expect that there is a muscular incompatibility between apical alveolar and upper pharyngeal articulations that involve raising of the back of the tongue, as well as between laminal dental or laminal pre-palatal anterior constrictions and uvular posterior constrictions that involve consonantal tongue root retraction. In the palatal click, the tongue body is raised upwards and forwards by posterior genioglossus muscle activity, which goes hand and hand with the advancement and raising of the upper tongue root accomplished through the compatible hyoglossus muscle activity found in high back vowels (Esling 2005). These movements are surmised from the swinging action of the hyoid bone that can be deduced from the movement of its shadow seen in the ultrasound movies of the production of every token of the palatal lingual stops in N|uu and Khoekhoe that we have viewed. Additionally, we surmise that the alveolar click is produced using styloglossus activity that pulls the tongue dorsum upward, and the tongue root backward. See Miller, Namaseb and Iskarous (forthcoming) for a further discussion of the muscular activity involved in palatal and alveolar clicks in Khoekhoe.

In showing that the posterior closures in these segments involve post-velar constrictions and that they are qualitatively different from [k], we aim to make the case for a terminological shift from velaric airstream mechanism to the articulatorily more accurate lingual airstream mechanism (Miller, Namaseb and Iskarous, forthcoming). The use of velaric as a descriptor for clicks dates to Beach (1938:74), whose definition of click encompasses all segments with ingressive airflow. That is, he distinguishes between velaric, glottalic and pulmonic clicks, which in current terminology would be clicks, implosives and pulmonic ingressive segments (e.g. Ladefoged and Maddieson 1996). In a system that describes "clicks" in terms of "…the inner boundary of the chamber wherein the air is rarefied", velaric makes sense, but as the name of an airstream it is problematic. The other two airstream mechanisms have names that reflect the anatomical source of the airflow — the lungs in the case of the pulmonic airstream and the glottis in the case of the glottalic airstream. By extension, the term velaric suggests that this airstream is somehow initiated by the velum or that it involves a velar stop, and this is clearly not the case. Rather, the tongue is used to create a low pressure cavity, the anterior release of which initiates the ingressive flow of air. For this reason, we adopt the term lingual airstream mechanism in describing these segments.

4.3 Release contrasts in lingual stops

In this section, we provide acoustic data for phonation and manner contrasts found in N|uu. Contrastive N|uu lingual stop releases are unaspirated, aspirated, glottalized or nasal aspirated. All releases in N|uu are voiceless. Waveforms illustrating these possibilities with the lateral click are provided in Figure 4.

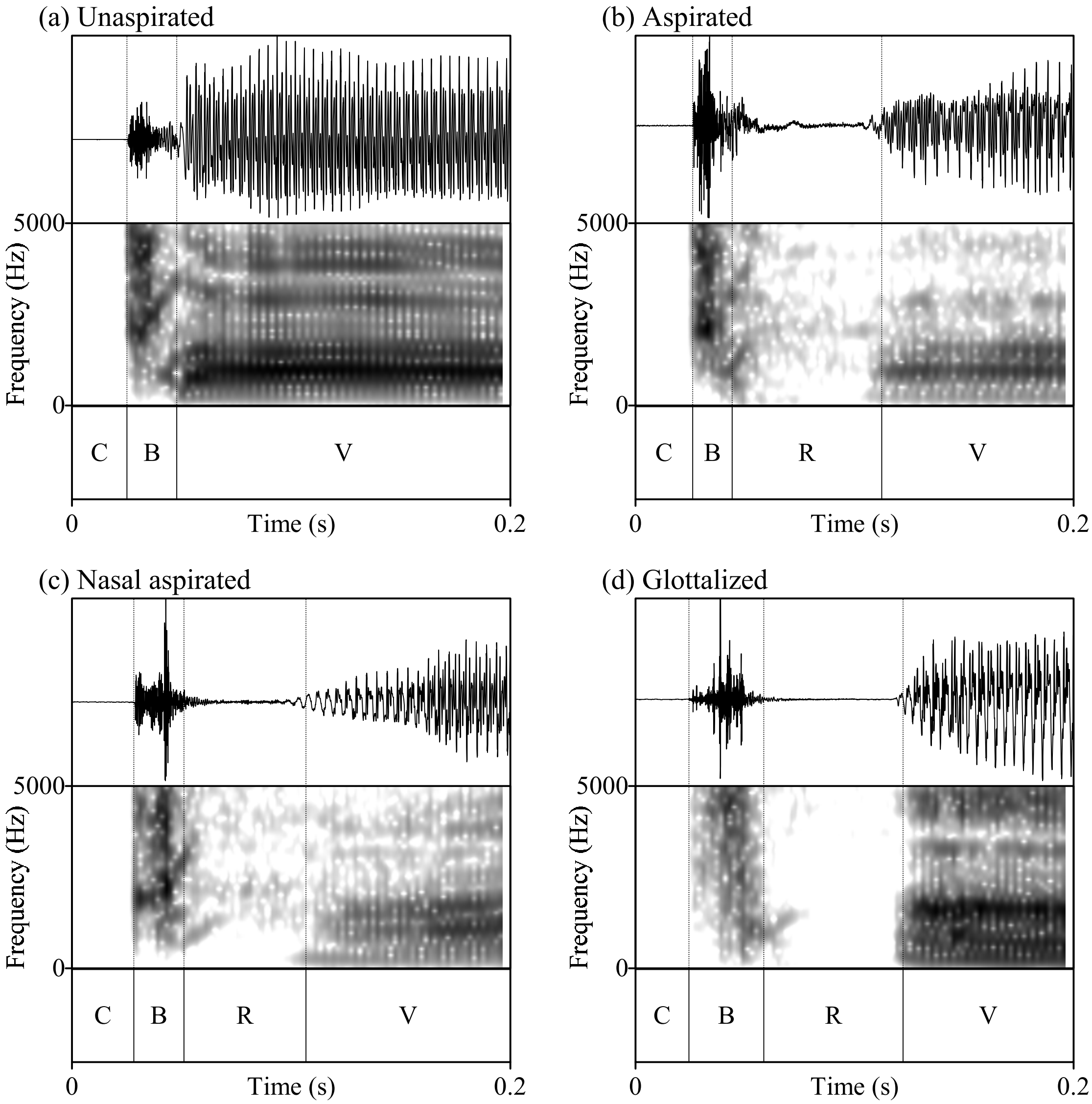


Figure 4: Four lingual stop release types in words extracted from the frame sentence [na ka ______] ‘I say _____’: (a) [ǁɑɑχe] ‘sister’, (b) [ǁ^{h}ɑɑ] ‘break’, (c) [ŋ̊ǁ^{h}ɑɑsi] ‘uterus’ and (d) [ŋ̊ǀ^{ʔ}ɑɑ] ‘dead’. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R) (Speaker GS).

The plain release in Figure 4(a) and the aspirated release in Figure 4(b) look much like those we would see with pulmonic stops. The waveforms and spectrograms of the two aspirated releases in Figures 4(b) and 4(c) appear similar, but there is a clear auditory impression of nasality in segments like Figure 4(c), and the slow rise in vowel amplitude is also characteristic of this release. See Ladefoged and Traill (1984) for a discussion of these segments in Khoekhoe and !Xóõ. Finally, the glottalized release in Figure 4(d) is exactly what we would expect to see in a pulmonic glottal stop: a period of silence followed by an abrupt onset of the vowel. This is the canonical production, but we have also noticed a tendency for these speakers to produce tokens with "leaky" closures and more gradual, laryngealized vowel onsets. The waveforms in Figure 4(c-d) are examples of such onsets. While this observation is not surprising given the strong cross-linguistic tendency for glottal stops to be realized with incomplete closures (Ladefoged and Maddieson 1996:75), this phenomenon has not been observed in other Khoesan languages.

Interestingly, we see a difference in the realization of voiceless nasal aspirated clicks in the same environment where we see a difference in the voiced oral and nasal clicks described in Section 4.1. above. Though the closure in this segment and the glottalized click discussed below is by default a voiceless nasal, and though it always lacks voicing in isolation, such closures tend to become voiced in a post-vocalic context, sometimes producing a noticeable "intrusive nasal" (Ladefoged and Traill 1984). The degree of voicing (though not nasal airflow, which is always present) is prosodically conditioned in Khoekhoe (Brugman 2003; Spencer 2004), and the waveforms in Figure 4 show that this is also the case in N|uu. The N|uu case is, however, more interesting because N|uu, unlike Khoekhoe, also has a voicing contrast in oral clicks. Though it is difficult to see from these waveforms, the beginning of the click closure in Figure 4(e) is characterized by a short period of voiced nasalization, but most of the closure is voiceless. In contrast, nearly the entire closure in Figure 4(f) is voiced. This type of voicing seems different from that in the voiced click in Figure 4(c-d), which is unsurprising given that a voiceless nasal closure in N|uu, as in Khoekhoe, is never independently contrastive.viii

Our analysis of the segments in Figure 4(a-c) is much like those of previous authors, but our analysis of Figure 4(d) is subtly different from most. We follow Miller-Ockhuizen (2003) in treating the glottalized release as a type of phonation. Miller-Ockhuizen motivates this treatment phonologically in Ju|’hoansi, where segments of this type pattern with aspirated segments with respect to the Guttural OCP. Moreover, such patterns are also attested outside of Khoesan in consonants produced with the pulmonic airstream. Ladefoged and Maddieson (1996:74) describe two contrasting stop series in Siona (Tucanoan, Colombia/Ecuador), which are realized as [p^h, t^h, k^h] and [$p^ʔ$, $t^ʔ$, $k^ʔ$] in word-initial and post-consonantal positions. Ladefoged and Maddieson report that their impression of recordings of the latter series is of “silence between the oral release of a ‘glottalized’ stop and the beginning of voicing for a following vowel.” This sounds strikingly like the glottalized release in Khoesan clicks. Interestingly, Wheeler and Wheeler (1962) and Wheeler (2000) note that the glottalized stop series alternates with a voiced series in intervocalic position, suggesting that glottalization behaves like phonation in this language as well. It should be noted that our recognition of the glottalized release as a type of phonation, together with the airstream analysis discussed below, removes any motivation for phonotactically problematic analyses of segments like these as complex onsets consisting of distinct lingual and pulmonic segments (see e.g. Nakagawa 2006).

4.4 Airstream contours

In this section we provide evidence that sounds previously described as contrasts in place of the posterior constriction can be analyzed in terms of airstream contours. In section 4.4.1., we provide evidence from waveforms and burst spectra which show that linguo-pulmonic clicks clearly display a change in airstream from ingressive lingual to egressive pulmonic within the segment. In Section 4.4.2., we provide ultrasound data, which shows that there are timing differences in the release of the posterior constriction found between fully lingual and linguo-pulmonic stops. Such temporal differences account for the acoustic temporal differences. The ultrasound data also shows that the posterior place of articulation does not differ between lingual and linguo-pulmonic stops, nor between the points in time of the anterior constriction release and the posterior constriction release. In Section 4.4.3, we describe the various types of airstream contours found in N|uu that contrast in terms of manner and phonation as well as airstream.

4.4.1 Acoustic evidence for airstream contours

Our final goal is to show that the clicks we transcribe as [ʘ͡q, ǀ͡q, !͡q, ǂ͡q, ǁ͡q] contrast with [ʘ, ǀ, !, ǁ, ǂ] in terms of airstream and not location of the posterior release. Traill (1985) and Ladefoged and Traill (1984, 1994) argue that !Xóõ, also a Tuu language, contrasts a series of clicks with a velar posterior constriction and a series with a uvular posterior constriction. The supposed existence of such a contrast leads Ladefoged and Maddieson (1996) to transcribe every click with either a velar or uvular pulmonic stop, as in [k!, g!, ŋ!] and [q!, ɢ!] on the grounds that every click has some sort of accompaniment, even if it is a voiceless unaspirated velar stop, despite Traill's (1985:125) observation that the inaudibility of this release "makes it somewhat misleading to include it in a list of accompaniments all of which have very prominent auditory characteristics". Bell and Collins (2001) and Nakagawa (2006), among others, follow this practice and describe the supposedly "velar" and "uvular" clicks in ǂHoan and G|ui as if they had such accompaniments. N|uu has classes of segments similar to those in !Xóõix, ǂHoan and G|ui (and perhaps Kxoe). We provide acoustic and ultrasound evidence that these two classes in fact have identical posterior constrictions and that the difference between them lies only in the timing and airstream associated with the posterior release.

Figure 5 provides waveforms and spectra for the four coronal linguo-pulmonic stops. There are no labial linguo-pulmonic stops followed by [a] in our N|uu lexicon (Sands et al. 2006), and thus none are included in Figure 5. However, results are provided in Miller, Brugman and Sands (2007) for all five clicks in the [u] context. As seen here and in Miller et al. (2007) and Miller, Brugman and Sands (2007), the durations of the lingual bursts and the voice onset times are comparable in the lingual and linguo-pulmonic segments having the same anterior constrictions. Linguo-pulmonic stops differ from their lingual counterparts in that the lingual burst is followed by a period of silence and a second, pulmonic burst. In lingual stops, the posterior constriction is released shortly after the lingual burst. As discussed above, this release is sometimes visible on waveforms, but it is generally inaudible because pulmonic egressive airflow is not aligned properly for an actual burst. Linguo-pulmonic stops, on the other hand, have posterior releases that are associated with audible pulmonic bursts. In N|uu, the timing is such that the two bursts are generally separated by a significant period of silence we take to be the extended closure of the posterior constriction. It is the differences in amplitude and frequency that provide cues to the airstream mechanism involved in the production of the constriction. The properties of the two bursts provide evidence that the airstream mechanism shifts from an ingressive lingual airstream to a pulmonic egressive airstream prior to the release of the posterior constriction involved in the linguo-pulmonic clicks, and is thus conclusive acoustic data showing that there is a change in the source and direction of airstream within the segment, consistent with our analysis of these sounds as contour segments on the airstream dimension. The lingual stop bursts that occur when the anterior constriction of a click is released and ingressive air is sucked in, is characteristically high amplitude and contains high frequency energy in the spectrum due to the smaller lingual cavity involved in clicks. The second posterior burst is clearly pulmonic, as can be seen by its characteristically low amplitude. Quantitative results in Miller et al. (2007) and Miller, Brugman and Sands (2007) show that this contrast is consistently realized this way for the three speakers studied, and provides additional evidence from pulmonic burst spectra in linguo-pulmonic stops showing that these stop bursts have characteristically lower frequency than found in the lingual bursts.

While it is possible to interpret the silence found between the lingual and pulmonic bursts as the result of a second posterior constriction being formed and released following the release of the posterior click closure, we see no positive evidence for such an analysis. We also note that Traill (1985:125-6) reports comparable acoustic differences in the !Xóõ sounds. He observes that the voice onset time with [ǂ] is approximately 12 ms, while that with [ǂ͡q] is closer to 40 ms. He also observes that [ǂ͡q] is characterized by an audible release, while [ǂ] is not. Despite Traill's analysis of the contrast as a difference in posterior place, his acoustic results are compatible with our analysis, as are the G|ui (Nakagawa 1996a, 1996b, 2006) and ǂHoan (Bell and Collins 2001) data. No acoustic data is available for the Kxoe sounds described by Köhler (1981) and Kilian-Hatz (2003).

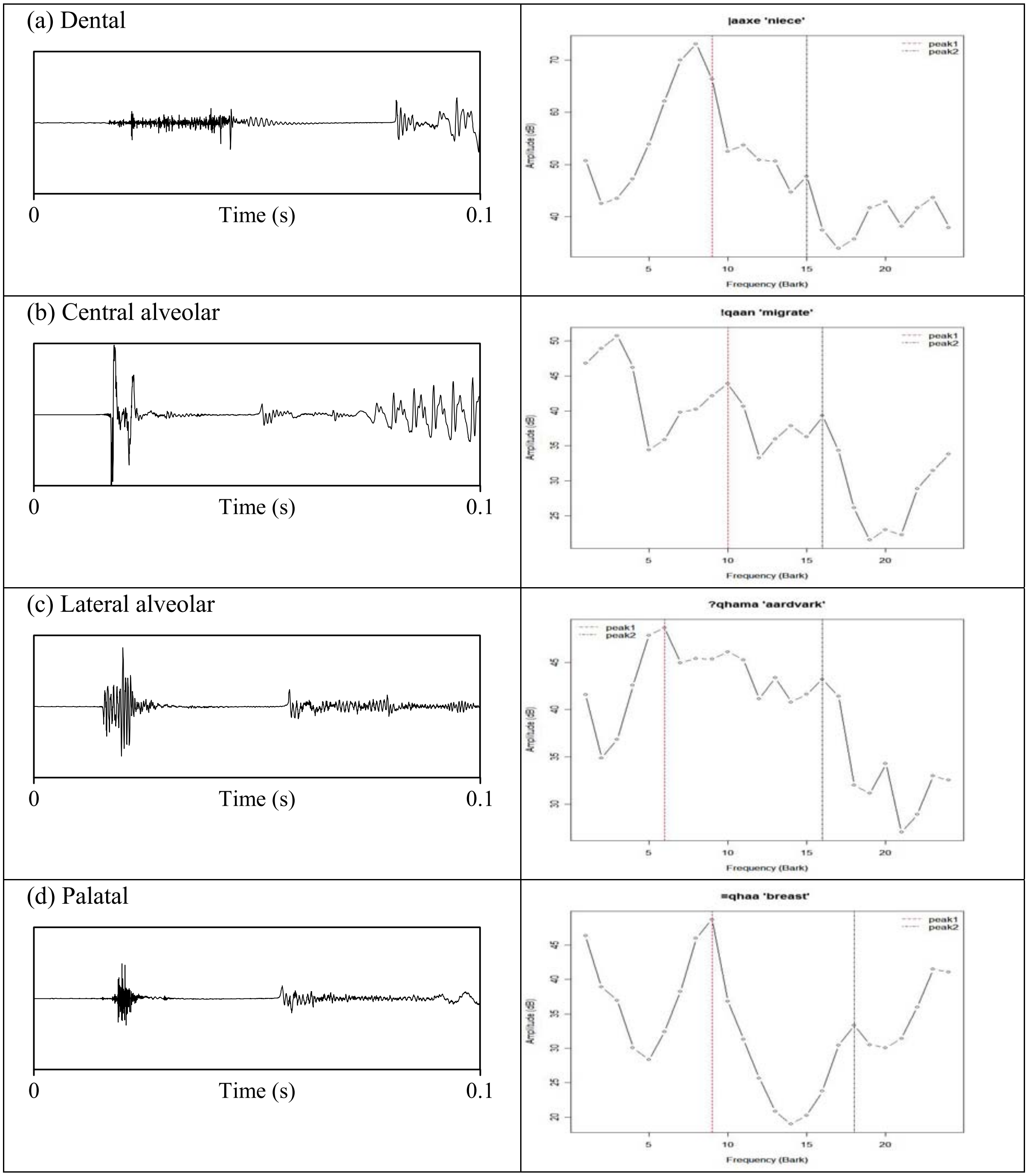


Figure 5: Representative waveforms and Bark-scaled LPC spectra of bursts in words extracted from the frame sentence [na ka ____, Na ka qoaqi.] 'I say ____, I say 'famished.' for the five N|uu linguo-pulmonic stops in the words: (a) [ǀ͡qɑɑ] 'shiny' (b) [!͡qɑ^{n}ɑ^{n}] 'migrate'[x] (c) [ǁ͡q^{h}ɑmɑ] 'aardvark' and (d) [ǂ͡q^{h}ɑɑ] 'breast' (Speaker KE).

As we have discussed, previous analyses of the !Xóõ inventory have argued that the language has a contrast in the posterior constriction locations of all click types. Specifically, Ladefoged and Traill (1994) have claimed that !Xóõ has clicks of all types that display a contrast between clicks with velar posterior constrictions and uvular posterior constrictions. Nakagawa (1996a, 1996b, 2006), Bell and Collins (2001) and Köhler (1981) and Kilian-Hatz (2003) follow this analysis in their descriptions of G|ui, ǂHoan and Kxoe respectively. If these segments really contrasted in posterior place of articulation, we would expect the burst spectra to be different. Results reported in this section and in Miller et al. (2007) show that this expectation is not met. Additionally, quantitative analysis of the spectra of the pulmonic bursts found in the linguo-pulmonic stops provided in Miller, Brugman and Sands (2007) show that the posterior constriction location differs by click type, but that the posterior constrictions in the lingual and linguo-pulmonic stops that have the same anterior place are the same. We now turn to ultrasound evidence which confirms that the posterior release is delayed in the linguo-pulmonic clicks, but that the place of the posterior constriction does not differ between fully lingual and linguo-pulmonic stops.

4.4.2 Ultrasound evidence for airstream contours

We now turn to the articulatory evidence for our claim. In Figures 6 and 7, we provide tongue traces for the central alveolar and palatal lingual and linguo-pulmonic stops.

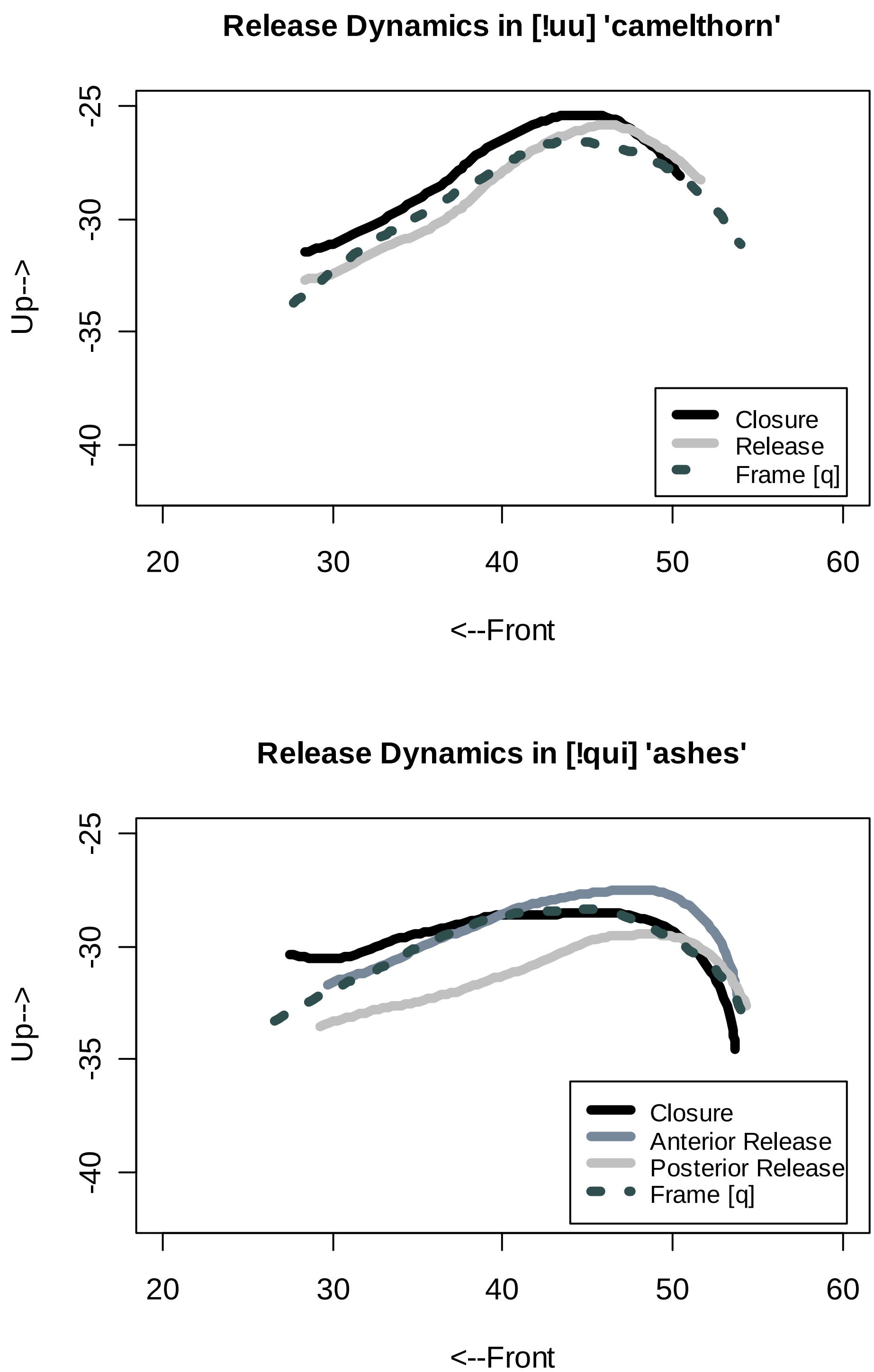
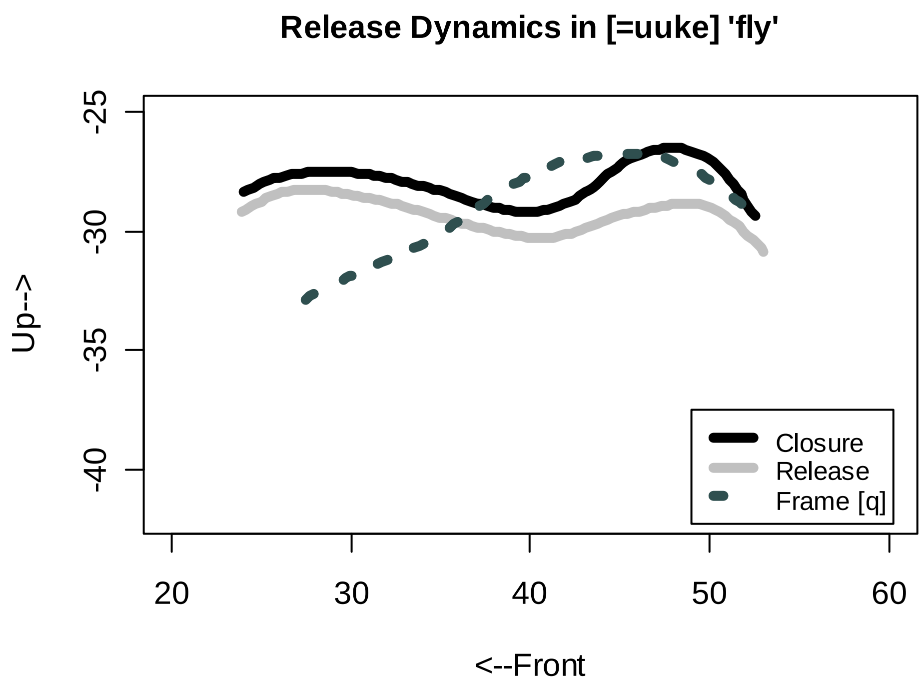


Figure 6: Tongue traces of central alveolar lingual [!] (top) and linguo-pulmonic ([!͡q] (bottom) stops. Plots include traces associated with the closures and releases of the lingual stops, as well as with uvular pulmonic releases in the frame sentence.



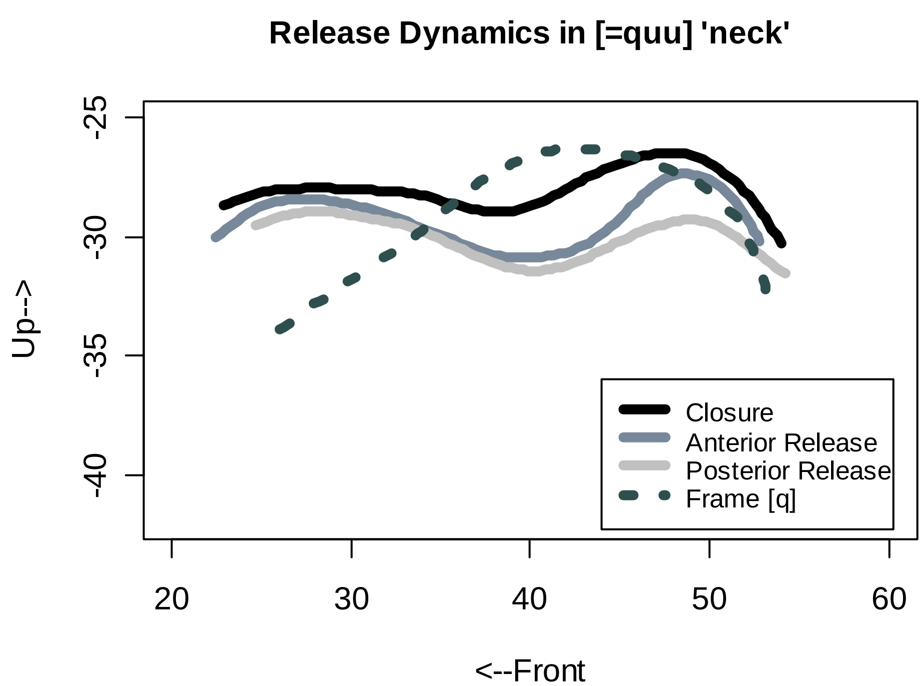


Figure 7: Tongue traces of palatal lingual [ǂ] (top) and linguo-pulmonic [ǂ͡q] (bottom) stops. Plots include traces associated with the closures and releases of the lingual stops, as well as with uvular pulmonic releases in the frame sentence. (Note that "=" is used for "ǂ" in the plot)

The lingual stops have two traces, while the linguo-pulmonic stops have three. For the sake of clarity, they include traces of the uvular but not velar pulmonic stops from the frame sentence. The most striking aspect of Figures 6 and 7 is the similarity between the lingual and linguo-pulmonic segments. Comparing the central alveolar lingual (top) and linguo-pulmonic (bottom) stops in Figure 7, we see that the posterior closure in the lingual alveolar stop is just slightly behind the location of the uvular stop in the first trace of the lingual stop (though it has moved further back in the second trace), while the posterior constriction in all three traces of the linguo-pulmonic stop are behind the uvular constriction. Similarly, both the palatal lingual and linguo-pulmonic stops in Figure 7 have tongue root positions that are higher and further back than those in the uvular stops. These patterns are consistent across all of our data.

In the lower panel of Figure 6, the upper part of the tongue root appears to be raised at the time of the release of the anterior constriction than in the closure frame, where both constrictions are in place. There are two possible explanations for this effect. The most likely explanation is that this apparent tongue root raising is actually due to the lowering of the jaw at the time of the anterior release, given that these data were collected with minimal control for head movement. Another possibility is that the soft palate and the upper tongue root are raised slightly at the time of the anterior release as we find in [ǂ].

Note that we are transcribing the pulmonic portion of the linguo-pulmonic clicks with the IPA symbol [q], which represents a uvular stop, but we do not intend this to mean that the pulmonic releases are exactly like [q] in terms of their degree of constriction, or that they are the same for all click types. We maintain this earlier convention because it is not obvious what IPA symbol could be used for the upper pharyngeal pulmonic portion of the segment that follows the anterior release of the palatal click. We note that the pharyngeal constriction in the palatal click is in contact with the very back part of the soft palate, which we do not know of being used for pulmonic segments. The long posterior constriction stretches from a very back uvular constriction to an upper pharyngeal constriction that might be most similar to the Danish uvular approximant [ʁ].

The question, then, is how Traill (1985) came to conclude that the corresponding segments in !Xóõ differed primarily in posterior place of articulation, given that he also noticed the differences in the timing and airstream of the release. We surmise that Traill may have been inadvertently misled by x-ray traces of lingual and linguo-pulmonic segments from different vowel contexts. Specifically, he compares [ǂ] before [e] with [ǂ͡q] before [o] (Traill:1985: 126-8). Despite the common assertion that “clicks do not coarticulate” (Dogil et al. 1997; Sands 1991), the position of the tongue root in different vowel contexts is precisely where we would expect to see coarticulation if there was any. Given that Traill finds greater pharyngeal constriction with [ǂ͡q] than [ǂ], and that he also finds such constriction in [o] but not [e], we suspect that Traill’s measurements reflect vowel context rather than a difference in the posterior place associated with [ǂ] and [ǂ͡q]. We find this quite plausible given the degree of coarticulation we see in our ultrasound recordings. Traill (1985) may also have struggled with the same issue we are facing, which is what to call a constriction made with the upper tongue root in the upper pharynx, where it is making contact with the very back part of the soft palate. We adopt the term pharyngeal because the constriction is farther back than the constrictions found in N|uu uvular stops and similar stops found in languages such as Arabic. Of course, complete reanalysis of !Xóõ, as well as G|ui, ǂHoan and Khoe will depend on acoustic and articulatory studies of these languages, but on the basis of published descriptions and the few recordings we have been able to listen to, we are confident that the contrasts in these languages will prove to be comparable to those we argue for in N|uu.

4.4.3 Phonation and manner contrasts in N uu airstream contours

N|uu segments that display a contour on the airstream dimension, also display contrasts in terms of manner and phonation. Figure 8 provides waveforms for the N|uu linguo-pulmonic (unaspirated stop, aspirated stop and affricate) and linguo-glottalic (ejected) click releases.

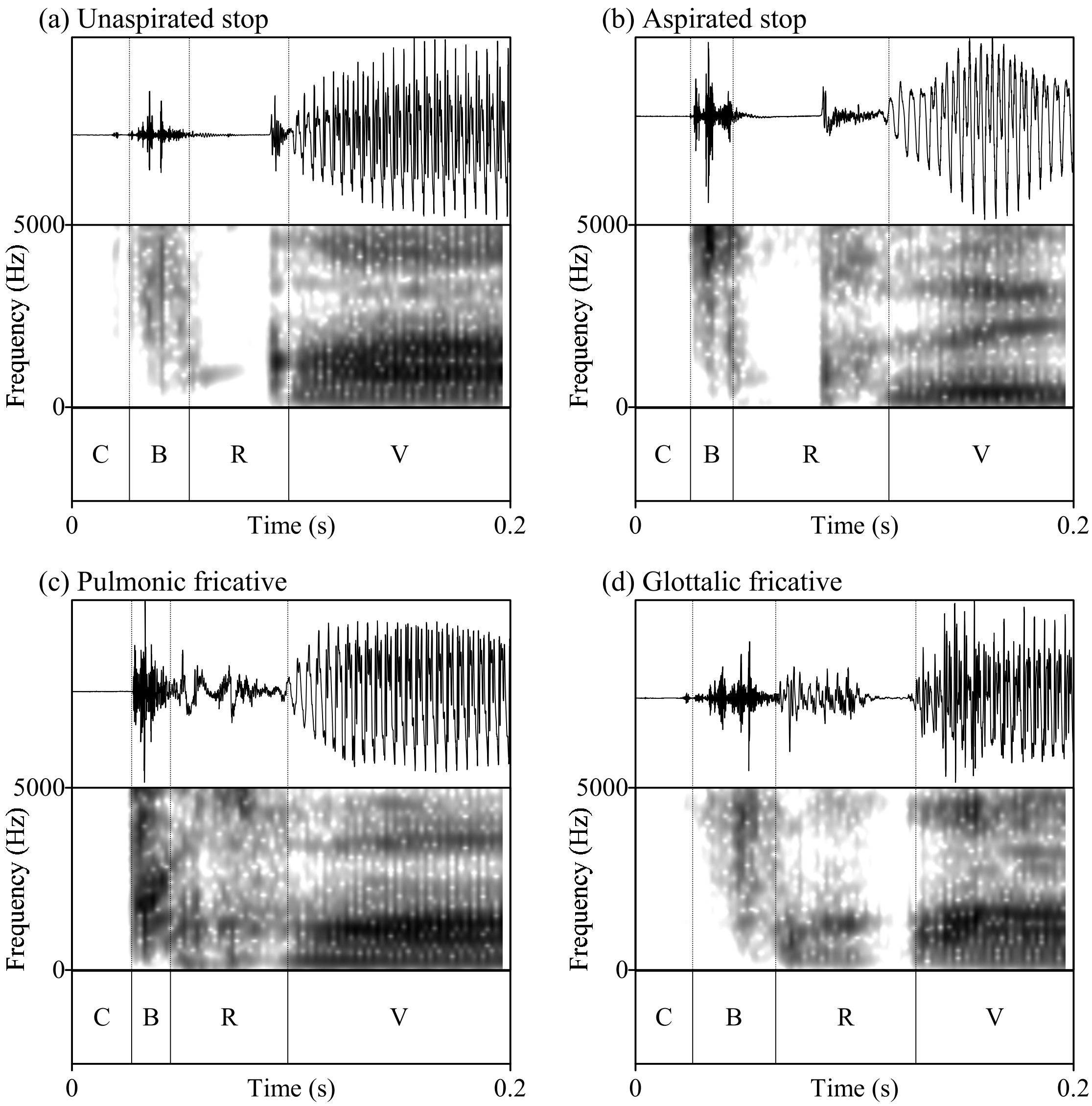


Figure 8: N|uu linguo-pulmonic and linguo-glottalic releases in words excerpted from the frame sentence [na ka _____] 'I say _____': (a) [|͡qɑɑ] 'shiny', (b) [|͡q^{h}əisi] 'bird', (c) [ǁ͡χɑ^{n}ɑ^{n}] 'sack' and (d) [|͡χ'ɑɑ] 'hand'. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R) (Speaker GS).

The three linguo-pulmonic clicks in Figure 8(a-c) differ in the phonation and manner of the pulmonic release. In Figure 8(a), the lingual stop is followed by an unaspirated pulmonic egressive release of the click's posterior constriction. In Figure 8(b), the release is also a pulmonic egressive stop, but here it is aspirated. In Figure 8(c) the pulmonic egressive release is a fricative, so that the segment is a manner contour (affricate). Note that the difference between the aspirated release in Figure 8(b) and the fricated release in Figure 8(c) is clear in both the waveform and the spectrogram for these sounds. The fricated release in Figure 8(c) is characterized by a distinct 'scraping' sound, as would be expected of a uvular or uvulo-pharyngeal fricative. However, this N|uu contrast does not seem to involve a voice onset time component, as found in the similar contrast in Ju|'hoansi (Miller-Ockhuizen 2003). The ejected release of the linguo-glottalic click in Figure 8(d) looks and sounds like an ejected uvular fricative. As with the glottal stop release in Figure 8(d) above, there is generally an abrupt onset of the following vowel after this segment. While the releases in Figure 4(d) and Figure 8(d) both involve glottal closure, it is important to remember that the glottal closure in Figure 4(d) is one of phonation, while that in Figure 8(d) is associated with the glottalic airstream. We are not aware of a language outside of Khoesan that makes such a distinction.

5. Conclusions

This paper provides a complete consonant inventory for the Southern African language N|uu, spoken today by just a handful of elderly speakers. It is only the second language in a family known for its phonetic complexity to be documented by modern instrumental techniques, and so offers an important opportunity to significantly improve our understanding of the sound structures of such languages. We describe the consonant inventory of this language in a phonetically accurate way and provide acoustic and articulatory evidence for the classification of all N|uu clicks in terms of just four linguistic dimensions: place of articulation, manner of articulation, phonation and airstream. This description includes discussion of the five different click types, as well as the range of closure and release properties found in these segments. Closure properties in N|uu include nasality and voicing, categories directly analogous to those found in pulmonic stop inventories across languages. Releases are characterized by contrasts in phonation, manner and airstream. Such categorization classifies segments in phonetically natural ways, using principles that are well established for non-click consonants. Our analysis obviates the lack of need for the phonetically empty category of accompaniment and highlights fundamental similarities between click- and non-click consonants, and the languages that make use of clicks. Khoesan languages may have large, complex inventories, but they are merely making maximal use of categories that are well-motivated cross-linguistically. Like Hawaiian and other languages with unusually small inventories, Khoesan languages represent endpoints in the spectrum of inventory size, not a fundamentally different type of system.

The crucial insight for our analysis is the recognition of airstream contours. We argue against the idea that clicks can contrast exclusively in their posterior places of articulation and offer an alternative explanation for segments previously known as “uvular” clicks. Our acoustic and ultrasound results show clearly that the bursts and posterior releases of lingual and linguo-pulmonic segments are the same In plain clicks, the posterior release is inaudible, while the clicks we transcribe [!͡q] have a second, pulmonic burst that corresponds to the posterior release. The high amplitude anterior burst, and the low amplitude pulmonic burst is best captured with airstream contours, analogous to contours in manner (affricates) and nasality (prenasalized stops). Previous phonetic descriptions of !Xóõ (Traill 1985), ǂHoan (Bell and Collins 2001) and G|ui (Nakagawa 2006) consonants indicate their amenability to such an analysis.

The idea of accompaniments has always been a problematic one, and releases that involved a pulmonic stop have always been the most difficult to deal with without resorting to a prosodically problematic cluster analysis. By showing that the posterior constrictions are the same and by recognizing that it is only the airstream of the release that differentiates these segments, the system reduces to one that can be readily explained in terms of existing categories.

Finally, despite our position that clicks cannot differ exclusively in terms of their posterior constrictions, we seek to emphasize that different click types differ not only in their anterior constrictions, but also in the locations of their posterior constrictions. This runs contrary to descriptions dating back at least to Doke (1923). Like Miller, Namaseb and Iskarous (forthcoming) and Miller et al. (2006), we use ultrasound data to show that the central alveolar [!] and palatal [ǂ] clicks differ in the position of the tongue root and that these clicks both have post-velar posterior places of articulation. It is our impression from our recordings of the dental [|] and lateral alveolar [ǁ] clicks and preliminary ultrasound analysis that the dental click will have an upper pharyngeal (uvulo-pharyngeal) posterior constriction that uses a raising gesture found in high back vowels, much like the palatal, and that the lateral alveolar click will be similar to the central alveolar click in involving a consonantal uvular posterior constriction involving lower TR retraction. Given that the anterior constriction in the labial click does not involve the anterior part of the tongue, we expect the posterior gestures involved in this click type to be more unconstrained, and we expect that there may be more variability both within a single language, and across languages. Furthermore, we believe that these posterior places of articulation are largely tied to the anterior places of articulation in the coronal clicks because of muscular constraints on overall tongue shape. We believe that such constraints make a contrast in only posterior constriction location improbable, if not impossible.

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Appendix A: Words illustrating N|uu segments

Note: Columns represent: 1) Phoneme, 2) Allophone, 3) Orthographic representation (Namaseb et al. 2005) 4) Example word in transcription, 5) Example word in orthography and 6) Glosses in English and Afrikaans

Vowels

Modal Vowels

/i/	[i]	i	[ᵑ̊|ˀii]	|’ii	‘fire’/‘vuur’
	[i]		[piɾi]	piri (W)/	‘goat’/‘bok’
	[i]		[miɾi]	miri (E)	
/e/	[e]	e	[|ee]	|ee	‘wildebeest’/ ‘blouwildebees’
	[ɛ]		[ɟeβe]	jebe	‘salt’/‘sout’
/ɑ/	[a]	a	[ᵑ̊‖ˀaa]	‖’aa	‘bat-eared fox’/ ‘bakoor jakkal’
	[a]		[‖ɑβɑ]	‖aba	‘bone’/‘been’
	[ə]		[‖əβe]	‖abe	‘leopard’/’luiperd’
/o/	[o]	o	[ǂoo]	ǂoo	‘man’/‘man’
	[ɔ]		[ǂɔɾo]	ǂoro	‘moon’/‘maand’
	[o]		[ŋ̊ǂˀoβo]	ǂ'obo	‘be exhausted’/ ‘uitgepit’

/u/	[u]	u	[g|uu]	g|uu	‘to tell a lie’ / ‘lieg’
	[u]		[ᵑ̊!ˀuɾu]	!’uru	‘tortoise shell container’/ ‘skilpaddophouer’

Nasalized Vowels

/iⁿ/	[iⁿ]	î	[kʰiiⁿ]	khîi	‘leg’/‘been’
/ɑⁿ/	[ɑⁿ]	â	[‖͡χɑⁿɑⁿ]	‖xâa	‘bag’/‘sak’
/uⁿ/	[uⁿ]	û	[ᵑ̊|ʰuⁿuⁿ]	|’huû	‘cold’/’koud’

Epiglottalized Vowels

/eˤ/	[eˤ]	eq	[zeˤeˤ]	zeqe	‘to fly’/‘vlieg’
/ɑˤ/	[ɑˤ]	aq	[!ɑˤɑˤ]	!aqa	‘heaven’/‘hemmel’
/oˤ/	[oˤ]	oq	[‖oˤoˤ]	‖oqo	‘chameleon’/ ‘verkleurmannetjie’
/uˤ/	[uˤ]	uq	[ts’uˤm]	ts’uqm	‘to choke’/ ‘verstik’

Nasal Epiglottalized Vowels

/ɑˤⁿ/	[ɑˤⁿ]	âq	[ǂɑˤⁿɑˤⁿ]	ǂâqa	‘street between the dunes’/ ‘straat tussen die duine’
/oˤⁿ/	[oˤⁿ]	ôq	[‖oˤⁿno, ‖oˤⁿlo]	‖ôqno (W)/ ‖ôqlo (E)	‘lung’/’long’

Modal Diphthongs

/ɑe/	[ɑe]	ae	[!ɑe]	!ae	‘gemsbok’/‘gemsbok’
/əi/	[əi]	ai	[!əi]	!ai	‘to run’/‘hardloop’
/ɑo/	[ɑo]	ao	[!ɑo]	!ao	‘stone’/‘klip’
/əu/	[əu]	au	[|əu]	|au	‘bow’/‘boog’
/oɑ/	[oa]	oa	[^{g}‖oɑ]	g‖oa	‘spoon’/‘lepel’
/oe/	[oe]	oe	[ʘoe]	ʘoe (W)	‘meat’/‘vleis’
/ui/	[oi]	ui	[ǂui]	ǂui	‘eggs’/‘eiers’

Nasalized Diphthongs

/ə^{n}i^{n}/	[ə^{n}i^{n}]	âi	[‖^{h}ə^{n}i^{n}]	‖hâi	‘teeth’/‘tande’
/ə^{n}u^{n}/	[ə^{n}u^{n}]	âu	[‖ə^{n}u^{n}]	‖âu	‘brother’/‘broer’
/o^{n}ɑ^{n}/	[o^{n}ɑ^{n}]	ôa	[|͡χ’o^{n}ɑ^{n}]	|x’ôa	‘hunt’/‘jag’
/o^{n}e^{n}/	[o^{n}e^{n}]	ôe	[ǂ͡qo^{n}e^{n}]	ǂqôe	‘short’/‘kort’
/u^{n}i^{n}/	[u^{n}i^{n}]	ûi	[su^{n}i^{n}]	sûi	‘to sit (one person)’/ ‘sit (een persoon)’

Epiglottalized Diphthongs

/ɑˤeˤ/	[ɑˤeˤ]	aqe	[‖ɑˤeˤ]	‖aqe	‘shoulder’/‘skouer’
/ɑˤoˤ/	[ɑˤoˤ]	aqo	[bɑˤoˤ, mɑˤoˤ]	baqo (W)/ maqo (E)	‘to bark’/‘blaf’
/oˤɑˤ/	[wˤɑˤ]	oqa	[|^{h}oˤɑˤ]	|hoqa	‘poison’/‘gif’
/oˤeˤ/	[oˤeˤ]	oqe	[!oˤeˤ]	!oqe	‘back of body’/‘rug’

Nasalized Epiglottalized Diphthongs

/ɑ^{ˤ}u^{ˤn}/	[ɑ^{ˤn}u^{ˤn}]	âqu	[‖ɑ^{ˤn}u^{ˤn}]	‖âqu	'raptor'/ 'lammervanger'
/oe^{ˤn}/	[o^{ˤn}e^{ˤn}]	ôqe	[^{ŋ}ǂo^{ˤn}e^{ˤn} cu]	nǂôqe cu	'navel'/'nael'
/o^{ˤn}ɑ^{ˤn}/	[o^{ˤn}ɑ^{ˤn}]	ôqa	[so^{ˤn}ɑ^{ˤn}]	sôqa	'blow nose'/ 'neus uitblaas'
/ɑ^{ˤn} i^{ˤn}/	[ɑ^{ˤn}i^{ˤn}]	âqi	[!ɑ^{ˤn}i^{ˤn}]	!âqi	'be pregnant'/'swanger'

Consonants

Pulmonic Stops

/(p)/	[p]	p	[puɾukutsi]	purukuts	'butterfly'/'skoenlapper'
/b/	[b]	b	[bɑ^{ˤ}o^{ˤ}, mɑ^{ˤ}o^{ˤ}]	baqo (W)/ maqo (E)	'bark(of a dog)' / 'blaf'
	[β]	b	[!ɑβɑsi]	!abasi	'calabash'/'kalbas'
/(t)/	[t]	t	[tiɾi]	tiri (E)	'mouse'/'muis'
/(d)/	[d]	d	[doŋkisi]	dongkisi	'donkey'/'donkie'
/c/	[c]	c	[cuuke]	cuuke	'men'/'manne'
/c^{h}/	[c^{h}]	ch	[c^{h}oe]	choe	'be naked'/'kaal'
/c^{χ}/	[c^{χ}]	cx	[c^{χ}um]	cxum	'strand of beads'/ 'krale'
/ɟ/	[ɟ]	j	[ɟum]	jum	'throat'/'keel, sluk'
/k/	[k]	k	[kɑmɑku]	kamaku	'outside'/'buite kant'
/k^{h}/	[k^{h}]	kh	[k^{h}ɑnɑ]	khana	'wide'/'wyd'
/g/	[g]	g	[gum]	gum	'cow'/'bees'
/q/	[q]	q	[qə^{n}i^{n}]	qâi	'be startled'/'skrik'
/(ʔ)/	[ʔ]	N/A	[ʔeinki]	eenki	'father, Dad' / 'Pa'

Pulmonic Affricates

/ts/	[ts]	ts	[tsɑ^{ˤ}m]	tsaqm	'cane'/'kierie'

Pulmonic Nasals

/m/	[m]	m	[mɑnɑ]	mana	‘Afrikaans language’/ ‘Afrikaanse taal’
/n/	[n]	n	[^{n}ǂonɑ]	nǂona	‘knife’/‘mes’
/ɲ/	[ɲ]	ny	[ɲɑ^{ʕ}n]	nyaqn (W)	‘share’/‘ou, offer’
/ŋ/	[ŋ]	ng	[ŋ]	ng	‘I’/‘ek’

Pulmonic Fricatives

/(f)/	[f]	f	[fadukusi]	fadukusi	‘dishrag’/‘vadoek’
/s/	[s]	s	[sɑɑsi]	saasi	‘Bushman’/‘Boesman’
/z/	[z]	z	[ze^{ʕ}e^{ʕ}]	zeqe	‘to fly’/‘vlieg’
/χ/	[χ]	x	[χuu]	xuu	‘face’/‘gesig’
/ɦ/	[ɦ]	h	[ɦoo]	hoo	‘find / get’

Pulmonic Liquids

/ɾ/	[ɾ]	r	[!͡χ’əɾu]	!x’aru	‘cheetah’/‘jagluiperd’
/l/	[l]	l	[ts’o^{ʕ}le]	ts’oqle	‘pinch’/‘knyp’

Glottalic Affricates

/ts’/	[ts’]	ts’	[ts'a^{n}a^{n}]	ts'âa	‘to like’ / ‘hoe van’
/k^{χ}’/	[k^{χ}’]	kx’	[k^{χ}’ə^{n}i^{n}]	kx’âi	‘to drink’/‘drink’
/q^{χ}’/	[q^{χ}’]	q’	[χɑnoq^{χ}’osi]	xanoq’osi	‘frost bush’/ ‘kapokbos’

Lingual Stops

/ʘ/	[ʘ]	ʘ	[ʘoo]	ʘoo	‘wood’/‘hout’
/ǀ/	[ǀ]	ǀ	[ǀɑɑ]	ǀaa	‘berry bush’/ ‘bessie bos’
/ǀ^{h}/	[ǀ^{h}]	ǀh	[ǀ^{h}ee]	ǀhee	‘grass’/‘gras’
/^{g}ǀ/	[gǀ]	gǀ	[^{g}ǀuu]	gǀuu	‘tell a lie’/‘lieg’
/!/	[!]	!	[!oo]	!oo	‘aardwolf’/‘weerwolf’
/!^{h}/	[!^{h}]	!h	[!^{h}uɾu]	!huru	‘mid-day’/‘middag’
/^{g}!/	[g!]	g!	[^{g}!ɑe]	g!ae	‘springbok’/‘springbok’
/ǁ/	[ǁ]	ǁ	[ǁɑ^{n}ɑ^{n}]	ǁâa	‘to look for’ / ‘soek’
/ǁ^{h}/	[ǁ^{h}]	ǁh	[ǁ^{h}ɑ^{ʕ}βɑ]	ǁhaqba	‘korhaan’/‘korhaan’
/^{g}ǁ/	[gǁ]	gǁ	[^{g}ǁɑɑ]	gǁaa	‘night’/‘nag’
/ǂ/	[ǂ]	ǂ	[ǂɑ^{n}ɑ^{n}]	ǂâa	‘other’ / ‘ander’
/ǂ^{h}/	[ǂ^{h}]	ǂh	[ǂ^{h}un, ǂ^{h}uɲ]	ǂhun (W)/ ǂhuny (E)	‘dog’/‘hond’
/^{g}ǂ/	[gǂ]	gǂ	[^{g}ǂəɾu]	gǂaru	‘sheep’/‘skaap’

Lingual Nasals

/ᵑ̊⊙ˀ/	[ᵑ̊⊙ˀ]	⊙’	[ᵑ̊⊙ˀui ʔi]	⊙’ui i	‘sick’/‘siek’
/ᵑ⊙/	[ᵑ⊙]	m⊙	[ᵑ⊙oɑ]	m⊙oa	‘cat’/‘kat’
/ᵑ̊|ʰ/	[ᵑ̊|ʰ]	|’h	[ᵑ̊|ʰəu]	|’hau	‘stomach fat’/ ‘pensvet’
/ᵑ̊|ˀ/	[ᵑ̊|ˀ]	|’	[ᵑ̊|ˀee]	|’ee	‘insert’/‘insit’
/ᵑ|/	[ᵑ|]	n|	[ᵑ|ucu]	n|ucu	‘nose’/‘neus’
/ᵑ̊!ʰ/	[ᵑ̊!ʰ]	!’h	[ᵑ̊!ʰɑɑ]	!’haa	‘caracal cat’/‘rooikat’
/ᵑ̊!ˀ/	[ᵑ̊!ˀ]	!’	[ᵑ̊!ˀuu]	!’uu	‘two’/‘twee’
/ᵑ!/	[ᵑ!]	n!	[ᵑ!uⁿuⁿ]	n!ûu	‘dune’/‘duin’
/ᵑ̊‖ʰ/	[ᵑ̊‖ʰ]	‖’h	[ᵑ̊‖ʰəni]	‖’hani	‘blanket for carrying child’/ ‘abakaros’
/ᵑ̊‖ˀ/	[ᵑ̊‖ˀ]	‖’	[ᵑ̊‖ˀɑɑ]	‖’aa	‘bat-eared fox’/ ‘bakoor jakkal’
/ᵑ‖/	[ᵑ‖]	n‖	[ᵑ‖ɑɑ]	n‖aake	‘thornbush’/’haakbos’
/ᵑ̊ǂʰ/	[ᵑ̊ǂʰ]	ǂ’h	[ᵑ̊ǂʰɑɑ]	ǂ’haa	‘open veld’/‘plat veld’
/ᵑ̊ǂˀ/	[ᵑ̊ǂˀ]	ǂ’	[ᵑ̊ǂˀɑosi]	ǂ’aosi	‘rib’/‘rib’
/ᵑǂ/	[ᵑǂ]	nǂ	[ᵑǂɑˤɑˤ]	nǂaqa	‘to kick’/’skop’

Linguo-Pulmonic Stops

/⊙͡q/	[⊙͡q]	⊙q	[⊙͡quisi]	⊙qui(si) (W)	‘sweat’/sweet’
/|͡q/	[|͡q]	|q	[|͡qəi]	|qii	‘peer’/‘ewe oud’
/|͡qʰ/	[|͡qʰ]	|qh	[|͡qʰuɾu]	|qhuru	‘hip’/‘heup’
/!͡q/	[!͡q]	!q	[!͡qəβe]	!qabe	‘sleep’/‘slaap’
/!͡qʰ/	[!͡qʰ]	!qh	[!͡qʰɑɑ]	!qhaa	‘water’/‘water’
/‖͡q/	[‖͡q]	‖q	[‖͡qoe]	‖qoe	‘pan’ / ‘pan’ (geographical feature)
/‖͡qʰ/	[‖͡qʰ]	‖qh	[‖͡qʰɑmɑ]	‖qhama	‘aardvark’/‘erdvark’
/ǂ͡q/	[ǂ͡q]	ǂq	[ǂ͡quu]	ǂquu	‘neck’/‘nek’
/ǂ͡qʰ/	[ǂ͡qʰ]	ǂqh	[ǂ͡qʰee]	ǂqhee	‘duiker’/‘duiker’

Linguo-Pulmonic Affricates

/ʘ͡χ/	[ʘ͡χ]	ʘx	[ʘ͡χuu]	ʘxuu	'smear, rub'/'vryf'
/ǀ͡χ/	[ǀ͡χoˤoˤ]	ǀx	[ǀ͡χoˤoˤ]	ǀxoqo	'ghost'/'spook'
/!͡χ/	[!͡χ]	!x	[!͡χaa]	!xaa	'scar'/ 'merk'
/ǁ͡χ/	[ǁ͡χ]	ǁx	[ǁ͡χɑɑ]	ǁxaa	'to break'/'breek'
/ǂ͡χ/	[ǂ͡χ]	ǂx	[ǂ͡χuu]	ǂxuu	'big man'/'hoof man'

Linguo-Glottalic Affricates

/ʘ͡χ'/	[ʘ͡χ']	ʘ͡χ'	[ʘ͡χ'oβa qosi]	ʘx'oba qosi	'stink bug' / 'stink gogga'
/ǀ͡χ'/	[ǀ͡χ']	ǀx'	[ǀ͡χ'ɑɑ]	ǀx'aa	'hand'/'hand'
/!͡χ'/	[!͡χ']	!x'	[!͡χ'əru]	!x'əru	'cheetah'/'jagluiperd'
/ǁ͡χ'/	[ǁ͡χ']	ǁx'	[ǁ͡χ'əm]	ǁx'am	'to wash'/'was'
/ǂ͡χ'/	[ǂ͡χ']	ǂx'	[ǂ͡χ'oo]	ǂx'oo	'salt'/'sout'

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[i] Though the spelling *Khoisan* is prevalent in the academic literature, the communities that speak these languages prefer *Khoesan* because it more closely represents the spelling in their orthographies. Note also that we use *Khoesan* throughout as a cover term for languages from several unrelated southern African families with similar segment inventories and phonotactic patterns, but few if any established inter-family relationships. See Güldemann and Vossen (2000) for discussion.

[ii] Kxoe has also been spelled Khwe, and the recent change to Kxoe has been requested by the language community.

[iii] Note that Ju|'hoansi is also known in the literature as !Xũ (Snyman 1970) and Zhu|'hõasi (Snyman 1975). See Miller-Ockhuizen and Sands (1999) for discussion of these terms.

[iv] Khoekhoe has also been called Hottentot (Beach 1938), though this is now considered pejorative, and Nama (Hagman 1977). See Haacke (1999) for discussion of the name *Khoekhoe*.

[v] Mats Exter notes that the uvular stop does not sound as far back as uvular stops found in Arabic and Wowego. The contrast between [k] and [q] only occurs in back vowel contexts.

[vi] The velar nasal consonant only occurs in the nucleus of syllables, and never as an onset or coda consonant.

[vii] There is a great degree of variability in the degree of frication found in uvular glottalic affricates, which ranges from no frication to a great deal of frication noise following the stop closure and preceding the glottalic release. This variability is particular to uvular and upper pharyngeal constrictions, because it is also found the linguo-glottalic clicks, but not in the coronal and velar glottalic affricates.

[viii] !Xóõ does contain an independently contrastive voiceless nasal click without aspiration (Traill 1994).

[ix] There are apparent cognates that contain the segments such as [!͡qʰàa] 'water, rain' (!Xóõ) and [!͡qʰɑɑ] 'water' (N|uu), as well as [ǂ͡qʰùe] 'wind' (!Xóõ) and [ǂ͡qʰoe] 'wind'(N|uu).

[x] Here and throughout we depart from the conventions of the IPA by using a superscripted coronal nasal consonant to indicate nasalization on the preceding vowel. This is consistent with Miller-Ockhuizen (2003, 2007), and is motivated by readability concerns in languages with voice quality, tones and nasalization, which are all realized within the IPA with diacritic marks.