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The Sounds of N|uu: Place and Airstream Contrasts*

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We provide a phonetic description of all 73 consonants of the endangered southern African language N|uu. Our segment classification uses just four linguistic dimensions (place, manner, phonation and airstream) and avoids the phonetically empty category *click accompaniment*. We provide acoustic, linguographic and palatographic evidence for active and passive articulators in the anterior constrictions of lingual (click) and linguo-pulmonic stops. We provide acoustic and ultrasound evidence showing that all click posterior constrictions involve the tongue root.. Contrastive lingual and linguo-pulmonic segments with the same anterior and posterior places of articulation differ in terms of airstream. Lingual stops employ a single airstream, while linguo-pulmonic stops are airstream contours. Structurally, linguo-pulmonic stops are parallel to affricates and prenasalized stops. Our evidence suggests that a contrast between "velar" and "uvular" clicks in !Xóõ is also a contrast of simple vs. airstream contours, and that a click contrast solely in posterior place is anticipatorily impossible.

1. Introduction

N|uu is the only surviving language in the !Ui branch of the Tuu family (Güldemann 2005; formerly Southern Khoesan[1]). Until quite recently, it was thought to be extinct (cf. Traill 2002), 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

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[1] 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 section 3.2 and Güldemann and Vossen (2000) for discussion.

and Traill 1994). The data presented here is part of a larger project documenting the lexical, syntactic, phonological and phonetic structures of the N|uu language.

This paper has three main goals. The first is to document the segmental 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 segment classification that renders the idea of a *click accompaniment* unnecessary. The term *accompaniment* (Traill 1985), *efflux* in older terminology[2] (Beach 1938), is a phonetically empty category that has been used as a catch-all for every modification to click closures and releases 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's 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 final goal is to show that the posterior constriction in all clicks involves an important pharyngeal component. 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. We follow them in arguing for the articulatorily more accurate *lingual airstream mechanism*. In addition, we will address claims that clicks can contrast exclusively in

[2] There is, in fact, a subtle difference between Beach's *efflux* and Traill's *accompaniment*. An *efflux* is an integral part of a complex segment, while *accompaniment* is intended as a phonologically neutral way of describing sounds that might be analyzed as either single segments or clusters.

terms of their posterior constrictions. !Xóõ (Traill 1985; Ladefoged and Traill 1994) ǂHoan (Bell and Collins 2001) and G|ui (Nakagawa 2006) have all been claimed to have clicks with independently contrastive velar and uvular posterior constrictions. We will show that similar 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 contours. 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 descriptions of these languages, suggests that it will ultimately be possible to reanalyze these languages along the lines we propose for N|uu.

The structure of the paper is as follows. Section 2 provides our proposed segment inventory for N|uu, along with a brief discussion of its key features. In section 3, we discuss the relationship of this paper to our larger documentation project (3.1), the historical and sociolinguistic context of the language (3.2) and our data acquisition process (3.3). In section 4, palatographic, linguographic, acoustic and ultrasound data are used to support our claims about the nature and structure of the N|uu lingual stop system. Section 5 summarizes our conclusions.

2. The N|uu segment 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.

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. There are also 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. See Miller-Ockhuizen (2003) for discussion of such phonotactic constraints in Ju|'hoansi and Miller (2007a) for a more detailed discussion of such patterns in N|uu, as well as a prosodic analysis of their distribution. The main focus of this paper is the N|uu consonant system, so the vowels are discussed only briefly in section 2.1, while the consonant inventory is covered in detail in section 2.2.

2.1 N|uu vowels

N|uu has five basic vowels and a contrast among modal, nasalized, epiglottalized and nasal epiglottalized versions of these, as illustrated in Table 1. The modal and epiglottalized vowels can be short or long, but phonemic nasalization occurs only in long vowels. Because of prosodic constraints outlined in Miller (2007a), long vowels occur only in monosyllabic roots and lexicalized forms. Nasalized and nasal epiglottalized vowels only occur as long vowels in monosyllabic roots.

Modal	i	e	a	o	u
Nasalized	i^{n}		a^{n}		u^{n}
Epiglottalized		$e^{ʕ}$	$a^{ʕ}$	$o^{ʕ}$	($u^{ʕ}$)
Nasal epiglottalized			$a^{ʕn}$	$o^{ʕn}$	

Table 1: N|uu vowels

Overall, there are fewer contrasts among the nasalized and epiglottalized vowels than their modal counterparts. Our lexicon contains examples of epiglottalization on all vowels except [i], but [$e^{ʕ}$] and [$u^{ʕ}$] are much less common than [$a^{ʕ}$] and [$o^{ʕ}$], and [$u^{ʕ}$] is most likely an allophone of [$o^{ʕ}$]. Just three roots with [$e^{ʕ}$] have been elicited: [$ze^{ʕ}e^{ʕ}$] 'fly (v)', [$je^{ʕ}βe$] 'have arms crossed' and [$^{ŋ}ǂ^{h}e^{ʕ}βe$] 'close your skirt'. To the best of our knowledge, these are the only examples of front epiglottalized vowels that have been reported in a Khoesan language.

Like other Khoesan languages, N|uu also has a large number of surface diphthongs, all of which begin with a back vowel. These are shown in Table 2.

Modal	ae	əi	ao	əu	oa	oe	ui
Nasalized		əi^{n}		əu^{n}	oa^{n}	oe^{n}	ui^{n}
Epiglottalized	ae^{ʕ}		ao^{ʕ}		oa^{ʕ}	oe^{ʕ}	
Nasalized epiglottalized	ae^{ʕn}		ao^{ʕn}			oe^{ʕn}	

Table 2: N|uu diphthongs

Of particular interest is the contrast between [ae] and [əi] on the one hand, and [ao] and [əu] on the other. Such contrasts are common across the Khoesan languages. Like the monophthongs, diphthongs can be nasalized, epiglottalized or both. Neither [əi^{ʕ}] nor [əu^{ʕ}] was found in our 1400 word lexicon (Sands et al. 2006), which is not surprising given the lack of [i^{ʕ}] and the marginal status of [u^{ʕ}] in the inventory. More detailed discussion of these contrasts can be found in Brugman, Miller and Sands (2006).

2.2 N|uu consonants

The consonant inventory of N|uu is presented in Tables 3 and 4. Including marginal segments, there are 25 pulmonic consonants, 3 glottalic consonants, and 45 click consonants, for a total of 73. This is large by the standards of most languages, but is unexceptional in a Khoesan context: !Xóõ contrasts 119 consonants, Ju|'hoansi[3] 89, Kua 79 and Khoekhoe[4] 35 (Traill 1985:99).

[3] 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.
[4] Khoekhoe has also been called Hottentot (Beach 1938), though this is now considered derogatory, and Nama (Hagman 1977). See Haacke (1999) for discussion of the name *Khoekhoe*.

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	(ʔ)
Affricate		ts					
Nasal	m	n		ɲ	ŋ		
Fricative	(f)	s z				χ	(ɦ)
Liquid		ɾ	(l)				
GLOTTALIC							
Affricate		ts’			k^{χ}’	q^{χ}’	

Table 3: N|uu pulmonic and glottalic consonants

LINGUAL					
	Labio-uvular	**Denti-pharyngeal**	**Alveo-uvular**		**Palato-pharyngeal**
			Central	**Lateral**	
Stop	⊙	| $\|^h$ $^{ɡ}\|$	! $!^h$ $^{ɡ}!$	‖ $‖^h$ $^{ɡ}‖$	ǂ $ǂ^h$ $^{ɡ}ǂ$
Nasal	$^{n̥}⊙^{ʔ}$ $^{n}⊙$	$^{n̥}\|^h$ $^{n̥}\|^{ʔ}$ $^{n}\|$	$^{n̥}!^h$ $^{n̥}!^{ʔ}$ $^{n}!$	$^{n̥}‖^h$ $^{n̥}‖^{ʔ}$ $^{n}‖$	$^{n̥}ǂ^h$ $^{n̥}ǂ^{ʔ}$ $^{n}ǂ$
LINGUO-PULMONIC					
Stop	⊙͡q	|͡q $\|͡q^h$	!͡q $!͡q^h$	‖͡q $‖͡q^h$	ǂ͡q $ǂ͡q^h$
Affricate	⊙͡χ	|͡χ	!͡χ	‖͡χ	ǂ͡χ
LINGUO-GLOTTALIC					
Affricate		|͡χ’	!͡χ’	‖͡χ’	ǂ͡χ’

Table 4: N|uu lingual, linguo-pulmonic and linguo-glottalic consonants

Tables 3 and 4 are organized in line with the general principles of the International Phonetics 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 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 we take to be unassimilated loanwords or nonce borrowings, but barring a full-scale study of loanwords, we are not able to differentiate between these types of productions. The segment [l] also occurs primarily in loanwords, though speakers of the Eastern dialect often use [l] where the Western dialect has [ɾ]. In addition, we have identified a handful of words with epiglottalized vowels in which speakers of both dialects use [l]. Since we have identified no words with [ɾ] adjacent to an epiglottalized vowel, it is possible that the liquids are in complementary distribution in this environment. Finally, the glottal stop occurs only in word-initial position and in a few lexicalized forms. There is disagreement among the authors as to whether it is phonemic (Exter 2007) or prosodically conditioned (Miller 2007a). For the remainder of this section, we will discuss the details of the inventory as they relate to these linguistic phonetic dimensions and our rationale for structuring these charts in the ways we have.

In Tables 3 and 4, 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 locations form the boundaries of an oral cavity that is expanded to create a low-pressure air pocket. When the anterior constriction is released, air rushes into the low-pressure pocket with a distinctive "popping" sound. The auditory impression of this pop is determined by the exact shape and volume 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 ([⊙]), dental ([|]), central alveolar ([!]), lateral alveolar ([‖]) and

palatal ([ǂ]). In this respect N|uu is like !Xóõ and ǂHoan, the only other languages reported to contrast these five different types of 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 et al., 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 4 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) and Hadza (Sands, Maddieson and Ladefoged 1996; Maddieson et al. 1999; Ladefoged and Maddieson 1996). As we will see, this is not the case with *click accompaniment*.

Following IPA guidelines (IPA 1999:8), the rows of Tables 3 and 4 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 the 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.

This 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 those 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* (ingressive airflow) and *efflux* (egressive airflow), respectively. 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) and manner contrasts (oral vs. nasal, stop vs. affricate), as well as the differences we argue are associated with a change in airstream. 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.

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 in order to emphasize the similarity of the lingual and non-lingual inventories. The present analysis 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. We will now turn to the data that forms the basis of our analysis of the inventory.

3. Background and methodology

This section provides a description of our larger project on N|uu (3.1), the historical and sociolinguistic situation of the language (3.2), which has in many ways influenced our methodology, and our methods of quantitative phonetic data collection (3.3).

3.1 Descriptive and theoretical studies of N|uu

This paper is one part of a larger documentation project on N|uu that was undertaken during various field trips to the Northern Cape Province of South Africa by various subsets of the authors between October 2003 and November 2006[5]. Our goal has been to document the lexicon, phonetics, phonology and syntax of the language, and to investigate the theoretical implications that arise from our analyses of the sound patterns and syntactic structures.

The present paper introduces the consonant and vowel inventories of N|uu, and summarizes the main results of our phonetic analysis of N|uu consonants. A more detailed analysis of the vowels is presented in Brugman et al. (2006), and Exter (2007) undertakes a more detailed acoustic analysis of the consonants not included in this paper. A phonological analysis of the N|uu inventory and phonotactic patterns is presented in Miller (2007a). Phonological patterns discussed there serve as a large part of the justification for the classification of the consonants presented in this paper.

The acoustic analyses discussed in this paper were made possible by a 1400 word lexicon that has been elicited and transcribed from the N|uu elders. Each word has been elicited and checked by at least two independent researchers in the field. Lexical items were elicited and generally recorded with one set of speakers, and then checked with another set. The entire team has participated in the transcription of the words. This lexicon is discussed in some detail in Sands et al. (forthcoming).

Authors Collins and Namaseb have been focusing on N|uu syntax and oral literature. Collins and Namaseb (2005a) present a descriptive grammar of the language, while Collins (2005) discusses the syntax of the linker and its absence in double object

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constructions. Transcriptions and translations of stories from several of the N|uu elders can be found in Collins and Namaseb (2005b) and Namaseb (2006).

Finally, we have worked with the community to develop an orthography and a primer (Namaseb, Sands, Miller and Brugman 2005), which author Namaseb has been using to teach young people in the community to read, write and pronounce N|uu words. This supplements the teaching of N|uu culture found in the primary schools by Ouma |Una Rooi and in an after school program organized by Ouma Katrina Esau.

3.2 Historical and sociolinguistic context

Khoesan was once thought to be a single language family (Greenberg 1963), but despite striking segmental and phonotactic similarities among many of these languages, there is now a consensus among Khoesan historical linguists that a monophyletic Khoesan group is untenable (cf. Sands 1998; Güldemann and Vossen 2000; Elderkin 2004). Comparative evidence supports the grouping of Southern African Khoesan languages into three main families: Tuu, Juu-ǂHoan and Khoe-Kwadi (cf. Güldemann 2004, 2006; Honken 2004). Added to these are the Eastern African Khoesan languages Hadza and Sandawe, which have not been convincingly linked to any of the southern African families (Sands 1998; Güldemann and Elderkin, forthcoming). In this paper, we compare phonetic data from N|uu, a Tuu language (!Ui subgroup), with !Xóõ (Taa subgroup of Tuu), G|ui (Khoe-Kwadi), Khoekhoe (Khoe-Kwadi), ǂHoan (Juu-ǂHoan) and Ju|'hoansi (Juu-ǂHoan). It should be noted that our discussion of linguo-pulmonic segments will involve languages from all three southern African Khoesan families: Tuu (N|uu and !Xóõ), Juu-ǂHoan (ǂHoan) and Khoe-Kwadi (G|ui).

N|uu was once part of the N‖ng dialect chain (Güldemann 2000, forthcoming), which comprised a set of lects known variously as ǂKhomani (Maingard 1937; Doke 1936; Traill 1999), Ng|huki (Westphal 1953-57) and ‖ŋ!ke (Bleek 1929; Güldemann 2000, forthcoming). The N‖ng lects were spoken in an area roughly delimited by the Orange River in the south, the Langeberg Mountains in the east, the Namibian border to the west and the Botswana border to the north. N|uu is still characterized by Western

and Eastern dialects that differ only slightly, and is also known as ǂKhomani, which is possibly a |'Auni exonym (Bleek 1937).

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 |Una Rooi (UR), Ouma Anna Kassie (AK), Ouma Hanna Koper (JK), Ouma Griet Seekoei (GS) and Ouma Katrina Esau (KE), 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 also speaks 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. Recent work on N|uu began when community member Petrus Vaalbooi spoke with Levi Namaseb about writing down his mother's language (Chamberlin and Namaseb 2001; Namaseb 2006:42-43). Ouma Elsie Vaalbooi passed away before our phonetic documentation project began, but she played an important role in beginning the language revitalization process.

3.3 Phonetic data acquisition

The 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; or (4) a Marantz 670 digital audio recorder using a Shure SM10A head-mounted microphone. When necessary, sound files were digitally transferred and resampled in Praat (Boersma and Weenink 2006) at 22,050 Hz.

Recordings were made in Upington, South Africa in quiet rooms in the Belurana Guest Lodge, in the SASI (South African San Institute) Upington office or a private residence.

Palatography and linguography were undertaken with speakers AK, HK, GS, KE and AO using the method described in Ladefoged (2003). Photos were taken with a Canon PC1045 PowerShot A300 digital camera. A hand-made metal holder held the mirrors a fixed distance from the camera for the palatograms.

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 with the methods described 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. The ultrasound video signal was converted to an analog signal with a Tview micro adaptor, and mixed with the audio signal in a Canopus ADVC Video converter. The mixed signal was channeled into a Dell 8600 laptop, where it was captured with Adobe Premiere Pro at a frame rate of 29.97 fps. AVI files without audio were also created on the Logiqbook at 50 fps. These AVIs were used for the analysis because of the higher frame rate and superior image quality, but the 29.97 fps files were used for reference in the acoustic-to-articulatory mapping. AVI files were converted to a series of JPGs and the tongue edge was tracked with EdgeTrak (Li, Khambamettu and Stone 2005).

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, though in the cases we present below, the frame before the pulmonic burst was the same as the frame after the lingual burst. Because of a 4-5 frame offset between the acoustic and video signals in the 29.97 fps AVIs, we used the acoustic waveform to estimate the location of target video frames (Brugman 2005). Each recording included three tokens of the target word, and we identified the time of each frame sentence [k] burst. Since the acoustic-to-articulatory mapping for [k] is both simpler and better understood than that for clicks, we used these bursts to determine the offset for each recording. We visually identified the release of each [k] in the 50 fps

recordings, checked these against the 29.97 fps recordings, and used this information to predict the location of the click burst. Before plotting, we checked that the predicted frame indeed corresponded to an appropriate landmark in the gesture. Relevant frames are summarized in Table 5.

	Lingual Stop		**Linguo-pulmonic Stop**	
	Articulatory Landmark	**Acoustic Landmark**	**Articulatory Landmark**	**Acoustic Landmark**
Lingual release	Abrupt downward movement of anterior constriction	Lingual burst	Abrupt downward movement of anterior constriction	Lingual burst
Pulmonic release	N/A	N/A	Abrupt downward movement of posterior constriction	Pulmonic burst

Table 5: Frames identified in ultrasound data

All ultrasound recordings were made in the frame sentence [na ka ___, na ka q'u^{n}i], meaning 'I say ___, I say fine.' Place of articulation for a particular token is always plotted with and discussed relative to the place of articulation of [k] in the frame sentence as in Brugman (2005), or relative to [q] in the frame sentence in the word 'fine'. Note that all plots show the position of the tongue relative to the ultrasound probe, not the palate. The data presented here are for the words [!uu] 'camelthorn', [ǂuuke] 'fly', [!q͡ui] 'ashes' and [ǂq͡uu] 'neck'.

Acoustic data for the contrasting lingual and linguo-pulmonic stops, as well as the pulmonic stops [k] and [q], were recorded in an [u] vowel context, with the exception of the stop [k], which was recorded in a [ə] context. The complete wordlist is provided in the appendix. The anterior and posterior stop burst edges were labeled in Praat and FFT spectra were calculated over the entire anterior burst using a rectangular 25 ms window. With short bursts this window included part of the silent interval preceding the burst. The center of gravity was also calculated using the Praat function.

4. N|uu clicks

The goal of this section is to present evidence supporting our claims about the inventory of N|uu lingual stops. In section 4.1 we discuss our articulatory data for the different click types (linguography and palatography for the four coronal clicks, and video images of the lips for the bilabials) and relate this to the acoustic properties of these segments. Section 4.2 provides acoustic evidence for the various closure and release phases we have identified in N|uu lingual stops, while section 4.3 covers our evidence for the location of the posterior constriction in different clicks, including those with a unique contour in airstream mechanism.

4.1 Anterior constrictions and click types

In this section, we consider the anterior places of articulation in all five N|uu click types ([⊙, |, !, ‖, ǂ]). Ladefoged and Traill (1994) and Ladefoged and Maddieson (1996) have documented considerable variability with respect to the articulatory descriptions and classifications of different clicks in the Khoesan language literature. They note, however, that no language contrasts more than five types of click, and so they take the clicks in all languages to fall into one of these five basic categories. In section 4.1.1, we present our findings on the anterior place of articulation for the N|uu coronal clicks, and in section 4.1.2 we provide a brief discussion of bilabial click articulation. In sections 4.1.3 and 4.1.4 we summarize our acoustic findings and relate these to our articulatory data.

4.1.1 Coronal lingual stops

In Figures 1-4, we provide representative linguograms and palatograms for the four lingual stops that involve coronal anterior constrictions. In order to better compare the constrictions shown by the linguograms (on the left) and the palatograms (on the right), the images are displayed with the back of the mouth at the top and the front of the mouth at the bottom of each image. The following description is based on palatograms and linguograms for speakers GS, KE, JK, AK and AO.

The dental click [|] in N|uu is best characterized as a laminal dental articulation, as we see in Figure 1.

Figure 1: Linguogram (left) and palatogram (right) of the N|uu dental click type (speaker GS) in the word [|aa] 'hold'.

The linguogram and palatogram in this figure show that the area of contact is broader than that seen for the central alveolar click [!], shown in Figure 2. The front teeth are obscured in the palatogram by the speaker's lip, but contact for this click type extends from the back of the front teeth to the alveolar ridge. Speaker GS uses the tip and the blade of the tongue to contact an area on the roof of her mouth. There are variant productions of this click across speakers (e.g., speaker AO, who lacks upper teeth, makes anterior contact with the blade of his tongue in the dental area), but given the small speaker population it is not possible to determine whether such variation is dialectal, idiolectal or simply the result of differences in denture.

The linguogram and palatogram for the central alveolar click [!] are shown in Figure 2.

Figure 2: Linguogram (left) and palatogram (right) of the N|uu central alveolar click type (speaker GS) in the word [!aa] 'hartebeest'.

The central alveolar click [!] in N|uu is best characterized as an apical central alveolar, and not an alveo-palatal or post-alveolar click, like those found in isiZulu and isiXhosa (Sands 1991). The linguogram in this figure shows that speaker GS uses the tip of her tongue in producing this click. The palatogram shows that contact is on the alveolar ridge, with no contact between the tongue tip and the back of the upper front teeth. This is true of speakers GS, KE, AO, and AK, but speaker JK (who lacks all upper teeth) makes a laminal articulation in the alveolar/post-alveolar region.

The lateral click [‖] in N|uu has an alveolar place of articulation, as shown by the palatogram in Figure 3.

Figure 3: Linguogram (left) and palatogram (right) of the N|uu lateral alveolar click type (speaker GS) in the word [ᵍ‖aa] 'night'.

Anterior constrictions for lateral clicks have been reported in the literature to range from denti-alveolar to alveolar to post-alveolar in different languages. Differences have also been reported as to whether the lateral release is more to the front or back, and whether the constriction is apical, apico-laminal or laminal. Palatography does not provide us with evidence for the location of the lateral release in N|uu, and it is difficult to characterize the lateral click as either apical or laminal, in part because the anterior contact patterns vary across speakers: JK has consistently laminal articulations, as does GS in the photo in Figure 3, while KE's are consistently apical. Generally, [‖] contact patterns are broader than those for [!], yet less broad than those for [|].

The palatal click [ǂ] in N|uu is produced with a very long laminal anterior constriction from at, or just behind, the upper front teeth to the post-post-alveolar, or pre-palatal region, as shown in Figure 4.

Figure 4: Linguogram (left, speaker KE) and palatogram (right, speaker GS) of the N|uu palatal click type in the word [ǂɑ] 'someone'.

The linguogram in Figure 4 shows that the lingual contact covers an even broader area than the contact seen for the dental click in Figure 1. This broad contact pattern may be due to the sliding of the tongue from a laminal dental to a laminal palato-alveolar location during the production of the click. Unfortunately, static palatography does not provide information about the dynamic properties of the anterior release, and as noted by Ladefoged and Maddieson (1996), it is only the point of contact just prior to the release that determines the spectral properties of the click burst. EPG data from a single Khoekhoe speaker (Miller 2007b) shows that there is extreme anterior constriction movement during this click, with the last point of contact being narrow and laminal post-alveolar. Dynamic investigations of the anterior release would be needed to fully document the articulation of this click type in N|uu, but we expect that it may also be best characterized as laminal post-alveolar at the time of the anterior release. The palatal click [ǂ] is made with apico-laminal contact in Khoekhoe (Beach 1938; Miller 2007b) but without apical contact in !Xóõ (Traill 1985), G|ui (Nakagawa 2006) and N|uu. The lack of apical contact in [ǂ] in N|uu was documented independently by Doke (1936) who says it is made with the "upper part of the tongue behind the tip pressed firmly against the gum ridge behind the central upper teeth".

4.1.2 Bilabial lingual stops

The bilabial click ([⊙]) is one of the rarest consonants in the world. As a contrastive sound, it is only known to occur in N|uu, !Xóõ and ǂHoan, though it also occurred in other now-extinct Tuu languages, such as |Xam. Bilabial clicks are found as allophones of labio-velar stops in some West African languages (Ladefoged 1968).

Ladefoged and Maddieson (1996) note that these clicks are typically made with bilabial compression rather than labial puckering. This is generally true of N|uu bilabial clicks, which are made with compression during the closure phase, but rounding of the lips can occur during the release of the bilabial closure before rounded vowels, as shown in the pictures in Figure 5.

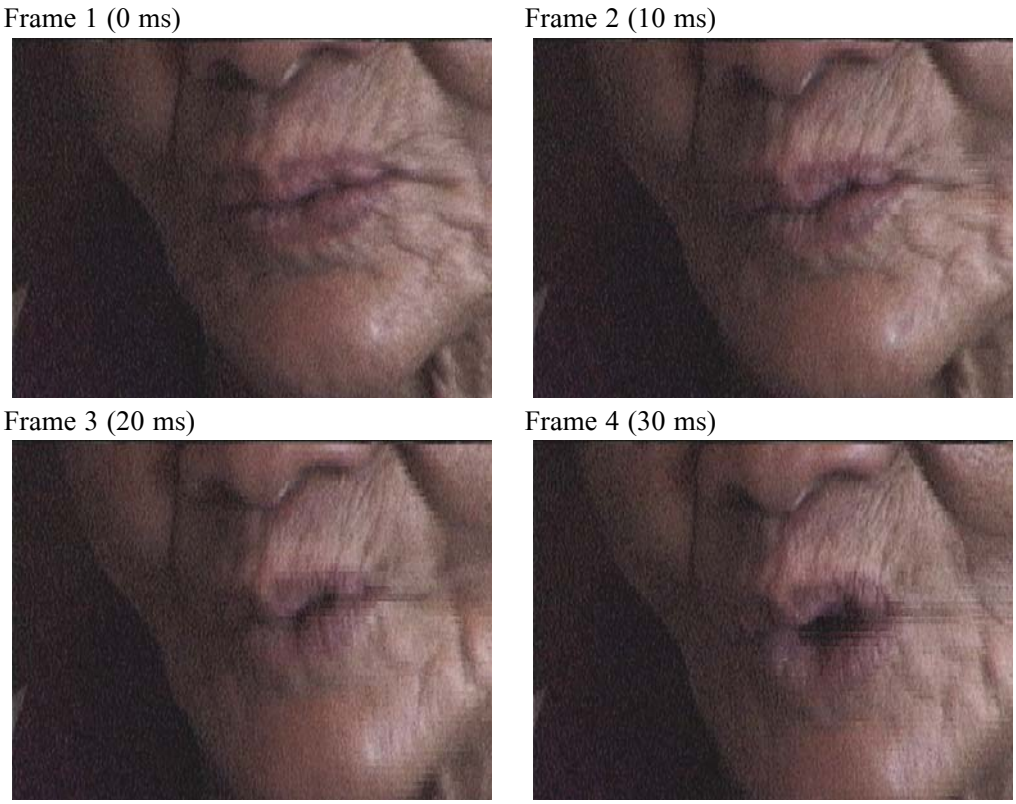

Figure 5: Video stills of the bilabial click in the word [ʘoe] 'meat' at 10 ms intervals. Frames 1-3 show lip compression and release, with slight puckering that begins in Frame 2. Frame 4 shows lip rounding of the following vowel (Speaker UR, Western N|uu).

There are also variant productions of the bilabial click that appear to be speaker-specific. Ladefoged and Maddieson (1996:251) note that in some productions "the lower lip may articulate against the upper teeth as the click is released, thus increasing the turbulent airflow associated with the release of the click." Speaker HK, one of the two speakers of the Eastern dialect, sometimes uses such a production. Figure 6 shows still images from video of a labio-dental click before an unrounded vowels. It is possible to indicate this variant with the dental diacritic ([ʘ̪]), but this transcription might also be the preferred way of indicating the variant of the bilabial click used by some !Xóõ speakers in which a dental closure is made in addition to a bilabial closure in producing the bilabial click (Traill 1985:103).

Frame 1 (0 ms) Frame 2 (10 ms) Frame 3 (20 ms)

Figure 6: Video stills of the anterior release of [⊙] produced with labio-dental friction in the word [⊙oe] 'meat' (Eastern N|uu) at 10 ms intervals, produced by Speaker HK (Frame 1 shows the lip compression of the anterior click closure, Frame 2 shows the release of the closure and Frame 3 shows the onset of the vowel).

4.1.3 Acoustics of lingual stop bursts

In this section, we describe the acoustic properties of bursts in the five N|uu lingual stops. The acoustic results seen here are largely in keeping with the results of Kagaya (1978), Sands (1991), Ladefoged and Traill (1994), Traill (1997), Ladefoged and Maddieson (1996) and Fulop, Ladefoged, Liu and Vossen (2003). In this section, we begin by discussing the patterns visible in representative waveforms and spectra, and in the next turn to a quantitative investigation of the center of gravity in bursts for three N|uu speakers. This allows us to give a detailed description of these bursts and to assess both inter- and intra-speaker variability.

In Figure 7, we provide waveforms of words that begin with each of the five lingual stops and Bark-scaled FFT spectra of their bursts.

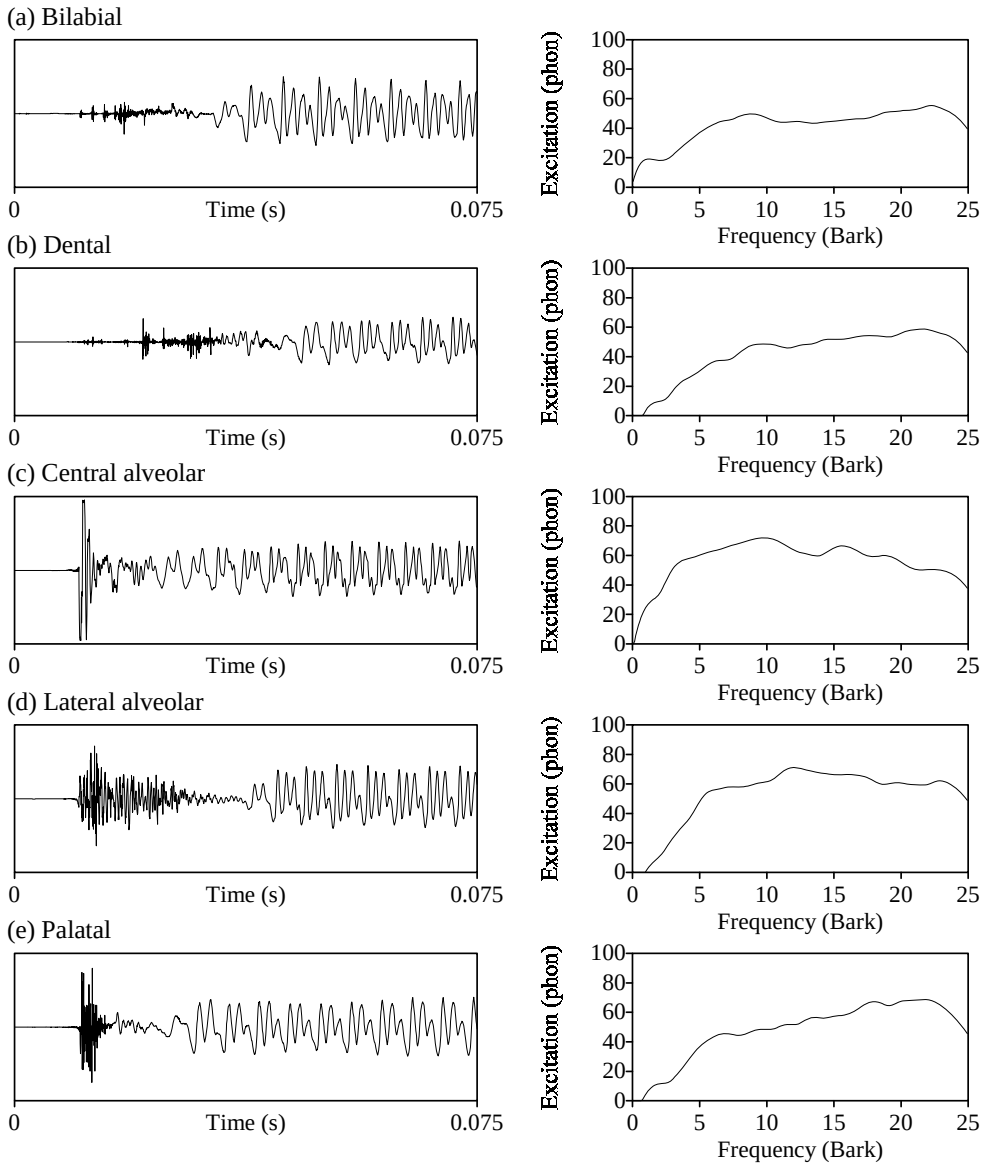

Figure 7: Representative waveforms and Bark-scaled FFT spectra of bursts (25 ms window) in words extracted from the frame sentence [na ka ___] 'I say ___' for the five N|uu lingual stops in the words: (a) [⊙oaχe] 'daughter', (b) [|aaχe] 'niece', (c) [!ama] 'kidney', (d) [‖aaχe] 'sister' and (e) [ǂausi] 'tsama melon' (Speaker KE).

These 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 in this figure 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 the noisy clicks are characterized by a generally flatter energy distribution. The differences in noisiness correlate with durational differences, so that noisy clicks are longer than abrupt ones. 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. 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).

Click bursts differ not only in abruptness, but also in their spectral properties, as illustrated in the Bark-scaled FFT spectra in Figure 7. We present Bark-scaled spectra in order to give a better sense of the auditory impression of the higher frequencies. Like the differences in abruptness, differences in energy distributions of N|uu 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. Ladefoged and Maddieson (1996:259) note that these two peaks are clear in the bilabial because the energy for the transient and the noise are concentrated in very different regions.

Finally, 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 4.3, and we maintain that it is the norm rather than the exception in click production.

4.1.4 Quantitative acoustics

In this section we provide quantitative data on the center of gravity of bursts in N|uu clicks and the velar and uvular pulmonic stops. In principle, quantitative analysis allows us to assess inter- and intra-speaker variability, but since we found little actual variability across these three speakers, we will present only the pooled results.

The center of gravity is also known as the first central moment of an acoustic spectrum (Forrest, Weismer, Milenkovic and Dougall 1988). Moments analysis treats spectra like probability distributions, and the first moment represents a spectrum's mean value. That is, it indicates where the balance of the entire spectrum lies and corresponds to the distinction between acute and grave discussed by Jakobson, Fant and Halle (1952). For pulmonic egressive consonants, it is a rough measure of place of articulation, since non-labial consonants with more front constrictions have higher spectral peaks, while consonants with more back constrictions have lower spectral peaks (see e.g., Johnson 2003:131, Figure 7.8). However, because the center of gravity alone provides only a gross estimate of spectral shape and because very different spectra can have similar centers of gravity, it alone is often insufficient to distinguish contrastive sounds (see e.g., Kochetov 2006; Miller and Zec 2003, forthcoming). Nonetheless, it provides a good first approximation and, as we shall see, it is useful in distinguishing the different N|uu click types.

Figure 8 provides boxplots for the center of gravity computed over the bursts of the five lingual stops and averaged across three speakers (GS, AK and KE).

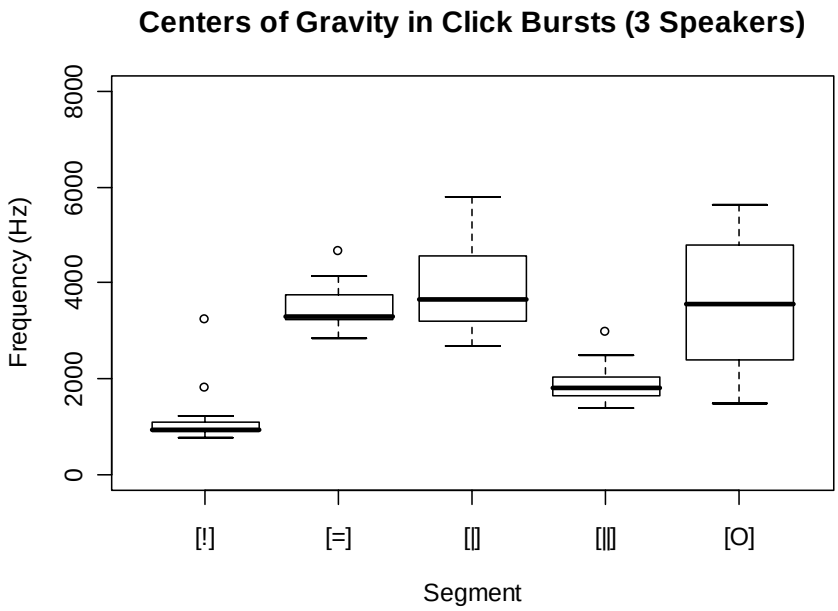

Figure 8: The center of gravity for the five lingual stop bursts, averaged across 3 female speakers (n = 21, boxes enclose 50% of values, horizontal lines show the mean, whiskers show 1.5 times the inter-quartile range and "[=]" and "[O]" are used for "[ǂ]" and "[⊙]", respectively).

These quantitative results reflect the qualitative generalizations mentioned above, namely that the central alveolar [!] and lateral alveolar [‖] clicks have more energy in the lower part of the spectrum, while the palatal ([ǂ]) and dental clicks ([|]) are characterized by more higher-frequency energy. We see that the values for the four coronal clicks are quite consistent, as indicated by their fairly narrow distributions. The distribution for the bilabial click is larger, but this is the result of inter- rather than intra-speaker variation. The mean center of gravity for Speaker KE is in the vicinity of 5000 Hz, while that for GS is near 3500 Hz and that for AK is around 2500 Hz, and these distributions are comparable to those for the other clicks. It is perhaps not surprising that this click is the one with the most variation, because it is the most diffuse (note the

flatter shape of the spectrum in Figure 7a) and because it has clearly separated peaks for the transient and noise contributions. We suspect that speakers vary with respect to the relative contributions of these two components. Because the spectrum is generally diffuse and the center of gravity is such a gross measure, small differences in these relative contributions can make the inter-speaker differences appear more significant than they actually are.

The center of gravity values for the four coronal clicks cannot be accounted for by the location of the anterior constriction alone. The central alveolar click, for instance, has a low center of gravity and an alveolar place of articulation, as we saw in section 4.1.1. The palatal click, on the other hand, has a higher center of gravity and a post-alveolar place of articulation. This is contrary to the generalization in pulmonic segments that further back constrictions lead to lower spectral peaks. The difference lies in the fact that the frequency distribution of a click burst is determined by cavity shape and volume, not merely front constriction location. We saw above in section 4.1.1 that different clicks have different tongue contact patterns, and that some are apical and some are laminal. We will see in section 4.3 that different clicks also have very different tongue shapes, including different posterior constrictions. These differences in the anterior and posterior constrictions lead to different cavity shapes and volumes, which together determine a burst's center of gravity. Basically, the more curved tongue shape found in the alveolar click results in a larger lingual cavity volume, while the flat tongue shape found in the palatal click results in a shallower cavity volume. We have not yet fully analyzed our ultrasound data for the noisy dental and lateral alveolar clicks, but our impressions concur with the center of gravity results to suggest that we will find a smaller, shallower volume with the former and a larger volume with the latter.

4.2 Click closures and releases

In this section we discuss the acoustic attributes of click closures and releases, which basically corresponds to the categories of *click efflux* or *click accompaniment.*

We follow Thomas-Vilakati (1999) and Miller-Ockhuizen (2003) in orienting our discussion temporally by focusing on the characteristics of click closures (4.2.1) and click releases (4.2.2), much as Abercrombie (1967) does in his discussion of pulmonic stops. This division is both phonetically appealing and phonologically important. Miller-Ockhuizen (2003) shows that patterning with respect to the Guttural OCP constraint in Ju|'hoansi depends only on the release portions of consonants, independent of their closures properties.

4.2.1 Click closures

Click closures in N|uu can be voiced or voiceless and nasalized or not nasalized. Figure 9 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. Note that the stronger boundary correlates with a longer closure duration, as well as differences in voicing that will be discussed below.

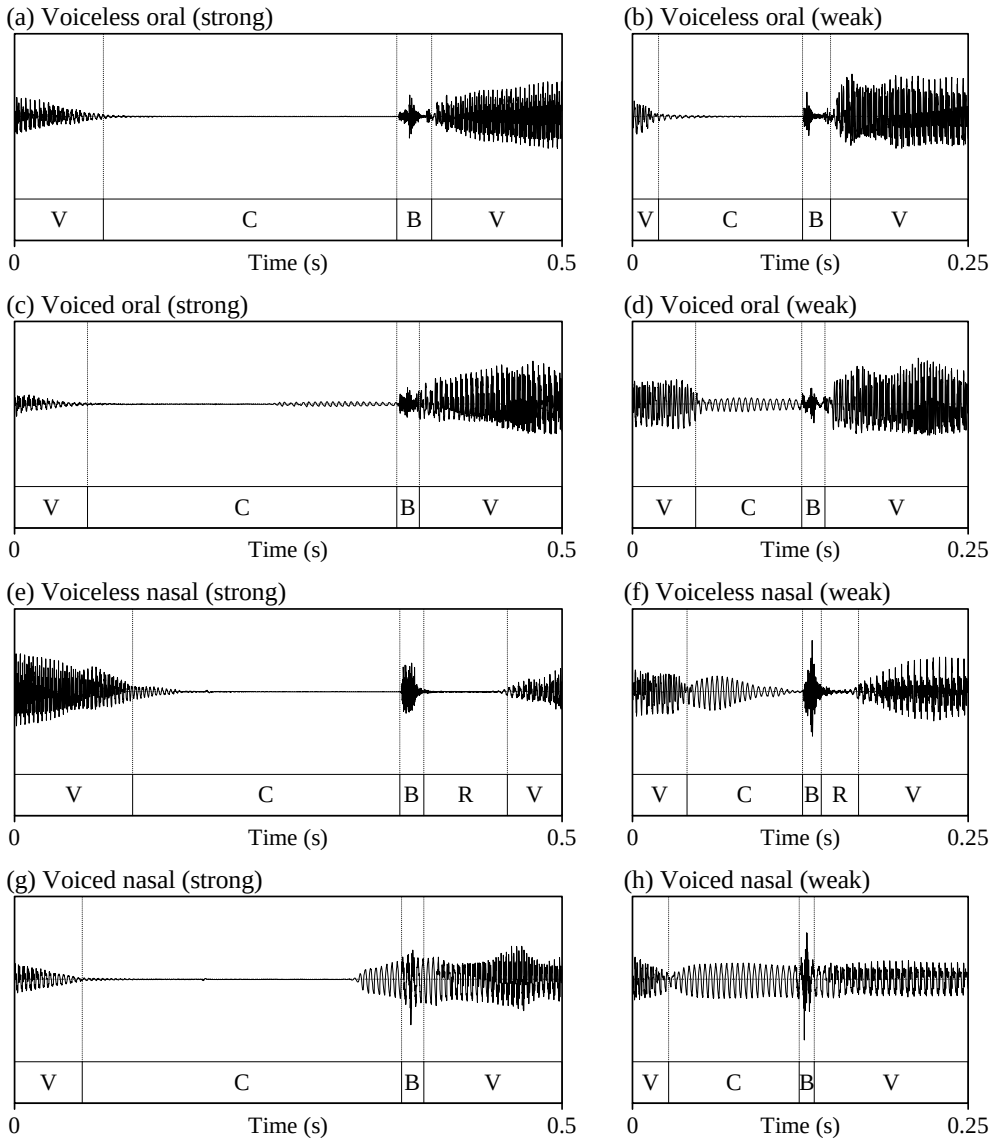

Figure 9: Waveforms of clicks with different types of closures excerpted from the frame sentences [na ka __] 'I say ___' (left, stronger prosodic boundary) and [na ka a ___] 'I say my [noun]'/'I say I [verb]' (right, weaker prosodic boundary): (a-b) [‖aaχe] 'sister', (c-d) [ᵍ‖aa] 'night', (e-f) [ᵑ̊‖ʰaasi] 'uterus' and (g-h) [ᵑ‖aa] 'stay'. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R) (Speaker GS).

The difference between voiced Figure 9(c-d) and voiceless Figure 9(a-b) clicks is directly parallel to that of voiced and voiceless pulmonic stops, 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, 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 9(c) has weak voicing that starts only half-way through the closure, while the voicing across the weaker prosodic boundary in Figure 9(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.

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. 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 9 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 9(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 9(f) is voiced. This type of voicing seems different from that in the voiced click in Figure 9(c-d), which is unsurprising given that a voiceless nasal closure in N|uu, as in Khoekhoe, is never independently contrastive.[6]

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

Voiceless nasal aspirated clicks (e.g., [ŋ̊!ʰ]) in N|uu are usually produced with at least some audible nasalization, but the voiceless nasal closure in clicks with a glottalized release (e.g., [ŋ̊!ˀ]) are much more variable across speakers, contexts and tokens. 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 Figure 10.

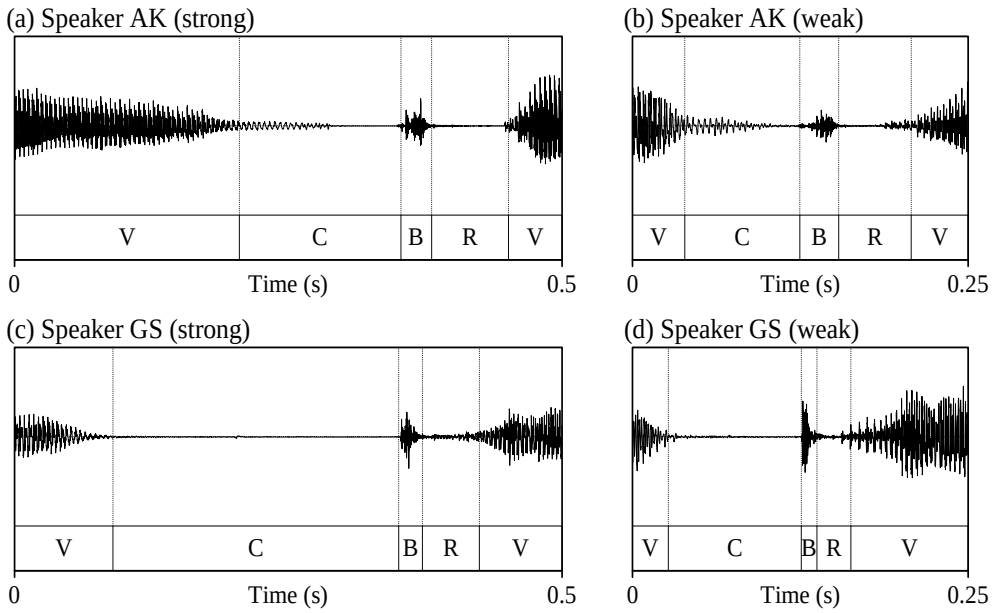


Figure 10: Waveforms illustrating variation in lingual stops with a glottalized release for two speakers, excerpted from the frame sentences [na ka __] 'I say ___' (left, stronger prosodic boundary) and [na ka a ___] 'I say I [verb]' (right, weaker prosodic boundary): [ŋ̊‖ˀaa] 'go through'. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R).

In Figure 10 we see tokens of glottalized clicks in the same two prosodic contexts from two different speakers. These tokens illustrate the range of variability found in our data in terms of the phonetic realization of closures in glottalized clicks. Voicing can be minimal or absent, as for Speaker GS, especially in the stronger

prosodic context, or it can be fairly strong, as for Speaker AK. It should be noted, however, that there is also considerable intra-speaker variability, and Speaker AK's closures are sometimes produced with little voicing. The release portions of these segments will be discussed in the following section.

4.2.2 Click releases

In this section, we summarize the distinct releases found in N|uu lingual, linguo-pulmonic and linguo-glottalic segments. We begin with the releases observed in lingual stops, which can be unaspirated, aspirated, glottalized or nasal aspirated. All releases in N|uu are voiceless. Waveforms illustrating these possibilities with the lateral alveolar click are provided in Figure 11.

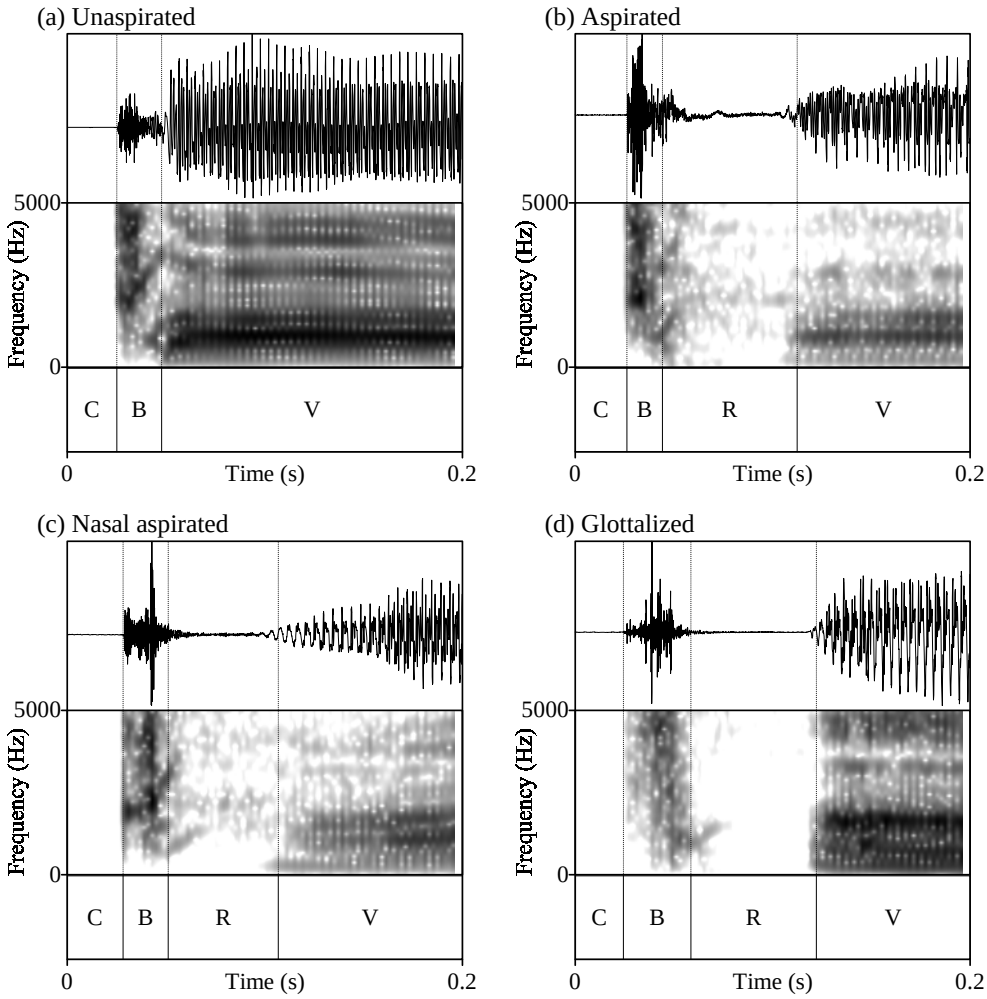


Figure 11: Four lingual stop release types in words extracted from the frame sentence [na ka ____] 'I say ___': (a) [‖aaχe] 'sister', (b) [‖ʰaa] 'break', (c) [ⁿ̥‖ʰaasi] 'uterus' and (d) [ⁿ̥|ˀaa] 'dead'. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R) (Speaker GS).

The plain release in Figure 11(a) and the aspirated release in Figure 11(b) look much like those we would see with pulmonic stops. The waveforms and spectrograms of the two aspirated releases in Figures 11(b) and 11(c) appear similar, but there is a clear auditory impression of nasality in segments like Figure 11(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 11(d) is exactly what we would expect of a 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 10(c-d) are examples of such onsets. While this observation is not surprising giving the strong cross-linguistic tendency for glottal stops to be realized with incomplete closures (Ladefoged and Maddieson 1996:75), it is not something we have observed in previous work on other Khoesan languages.

Our analysis of the segments in Figure 11(a-c) is much like those of previous authors, but our analysis of Figure 11(d) is subtly different from most. We follow Miller-Ockhuizein (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 positions, 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).

Figure 12 provides waveforms for the linguo-pulmonic (unaspirated stop, aspirated stop and fricative) and linguo-glottalic (ejected) click releases in N|uu.

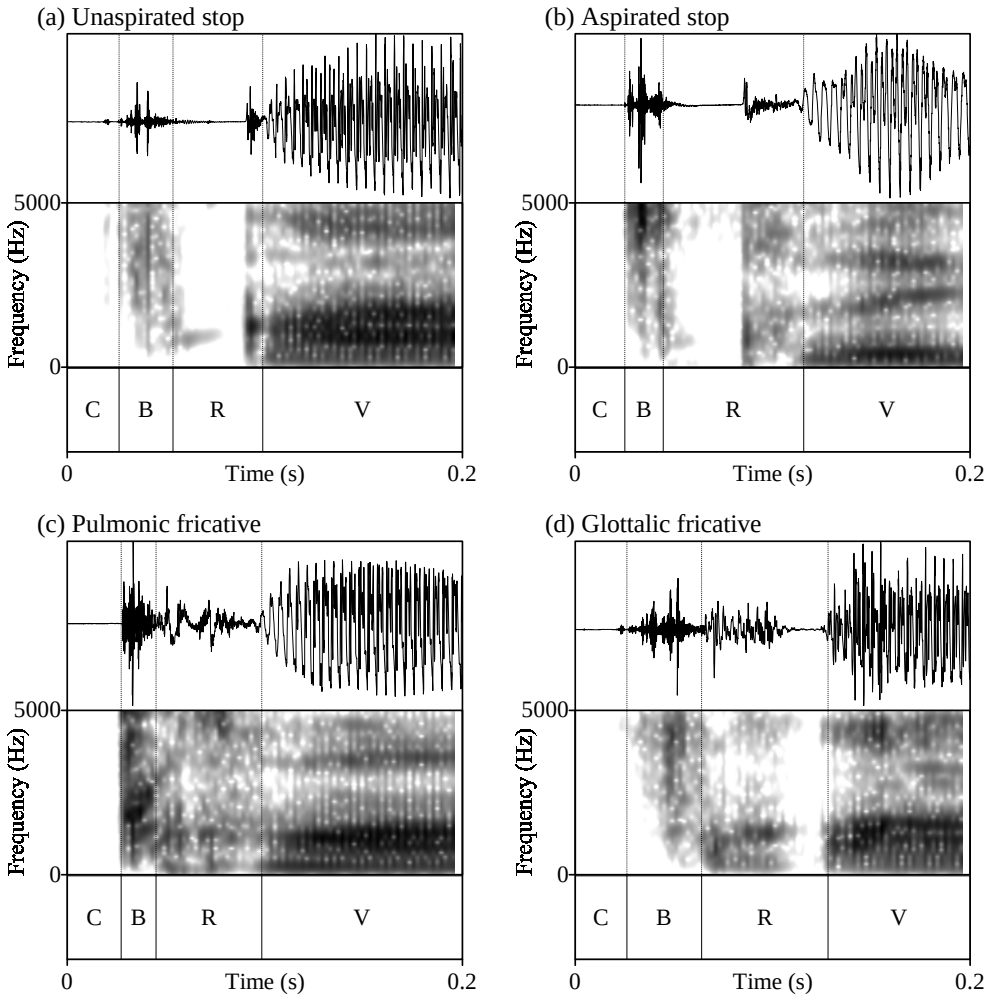


Figure 12: N|uu linguo-pulmonic and linguo-glottalic releases in words excerpted from the frame sentence [na ka ___] 'I say ___':, (a) [ǁqaa] 'shiny', (b) [ǁqʰəisi] 'bird', (c) [ǁχaaⁿ] 'sack' and (d) [ǁχ'aa] 'hand'. Labels indicate the locations of vowels (V), closures (C), bursts (B) and releases (R) (Speaker GS).

The three linguo-pulmonic clicks in Figure 12(a-c) differ in the phonation and manner of the pulmonic release. In Figure 12(a), the lingual stop is followed by an unaspirated pulmonic egressive release of the click's posterior constriction. In Figure 12(b), the release is also a pulmonic egressive stop, but here it is aspirated. In Figure 12(c) the pulmonic egressive release is a fricative, so that the whole segment is a

manner contour. Note that the difference between the aspirated release in Figure 11(b) and the fricated release in Figure 12(c) is clear in both the waveform and the spectrogram for these sounds. The fricated release in Figure 12(c) is characterized by a distinct 'scraping' sound, as would be expected of a uvular or uvulo-pharyngeal fricative. The ejected release of the linguo-glottalic click in Figure 12(d) looks and sounds like an ejected uvular fricative. As with the glottal stop release in Figure 11(d), there is generally an abrupt onset of the following vowel after this segment. While the releases in Figure 11(d) and Figure 12(d) both involve glottal closure, it is important to remember that the glottal closure in Figure 11(d) is one of phonation, while that in Figure 12(d) is associated with the glottalic airstream. We are not aware of a language outside of Khoesan that makes such a distinction.

Our analysis of the closures and releases in N|uu involves two parameters in the closures (voicing and nasalization), three types of phonation in the release (plain unaspirated, aspirated and glottalized) and three possibilities for the airstream (lingual, linguo-pulmonic and linguo-glottalic). These combine to give ten distinct ways for each click type to be produced in this language. Aspiration, for example, is found in both the simple and the contour clicks, and nasalization is associated with the nasal, voiceless nasal aspirated and glottalized clicks. Within a segment, different airstreams can only be sequenced to produce contours. We would not expect any language to have complex segments with two simultaneous airstream mechanisms, since the effect of at least one airstream would not be perceptible. We now turn to our evidence for the places of articulation associated with the different click types and airstreams.

4.3 Posterior constrictions and airstream contours

For the remainder of this section we will focus on the location of the posterior constriction in lingual and linguo-pulmonic stops. At least since Doke (1923), it has been supposed that the posterior constriction in most clicks is velar. Miller et al. (forthcoming) show that this is not the case in the central post-alveolar and palatal clicks of Khoekhoe and Miller, Brugman, Howell and Sands (2006) provide preliminary

results showing that this is not the case in N|uu. Our first goal is to show that the same is true 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. This is discussed in section 4.3.1.

Our second goal is to show that the clicks we transcribe as [⊙͡q, ͡|q, ͡!q, ͡ǂq, ͡‖q] contrast with [⊙, |, !, ‖, 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 !Xóõ[7], ǂHoan and G|ui, and in section 4.3.2 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 airstream associated with the posterior release.

4.3.1 Lingual stops

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

[7] There are apparent cognates that contain the segments such as [͡!qʰàa] 'water, rain' (!Xóõ) and [͡!qʰaa] 'water' (N|uu), as well as [͡ǂqʰùe] 'wind' (!Xóõ) and [͡ǂqʰoe] 'wind'(N|uu).

necessary for click production and that the position of the tongue root determines phonological patterning with respect to the Back Vowel Constraint (Traill 1985; Miller et al., forthcoming; Miller 2007a). For this reason, we will focus primarily on the action of the tongue root in the pharyngeal cavity.

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 between two parts of the oropharynx, which we call the upper pharynx and the mid pharynx, following Hess (1998).

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. 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 know from static palatography and from Traill's x-ray recordings of !Xóõ that the tongue tip is pointed upward in these clicks, but our traces do not show this posture.

Figure 13 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.

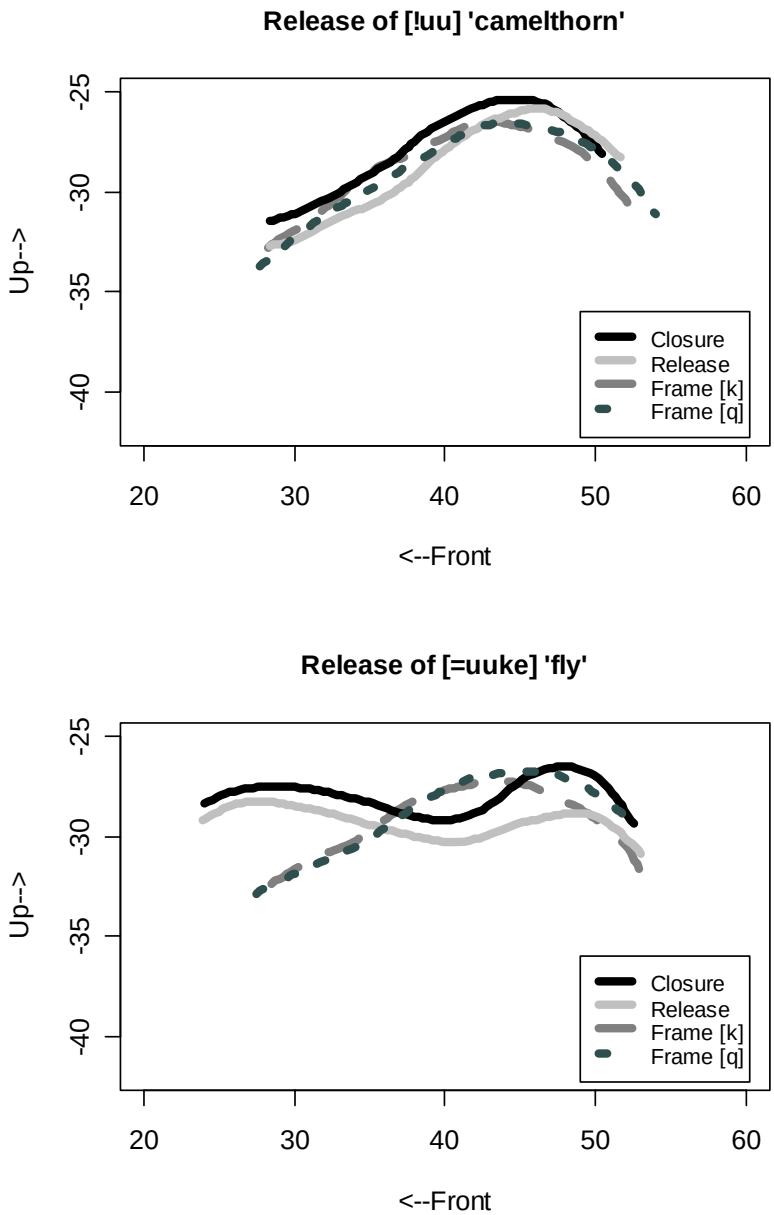


Figure 13: Tongue traces of the central alveolar [!] (top) and palatal [ǂ] (bottom) click types. Plots include traces associated with the closures and releases of the lingual stops, as well as with the closures of velar and uvular pulmonic stops in the frame sentence. (Note that " = " is used for "ǂ" in the plot).

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 that we find show a much more retracted upper and lower tongue root in [q] than [k]. It is for this reason that we call [!] an alveo-uvular segment in the consonant chart in Table 4.

Turning to the posterior constriction in the palatal click, we see that the upper tongue root is raised into the upper pharynx, hence the description palato-pharyngeal in Table 4. There cannot be a complete pharyngeal constriction because there is airflow during nasalized palatal clicks, but we see pronounced retraction in the videos. We know that the tongue root is raised and the tongue dorsum is retracted into the upper pharynx, presumably causing bunching. We surmise the raising of the 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 approximates the upper pharynx. We are not aware of pharyngeal pulmonic consonants with such high pharyngeal constrictions.

In addition to the clear differences in overall tongue shape, our ultrasound recordings also show 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 in a very curved manner, as we might expect from a 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. In the palatal click, on the

other hand, the two constrictions seem to lower more simultaneously, as is suggested from the successive frames traced in the bottom panel of Figure 13. The cavity between the constrictions is much shallower in this click. These differences in tongue shape and the resultant differences in cavity size explain the spectral differences discussed in sections 4.1.3 and 4.1.4.

Furthermore, our impression from viewing the ultrasound video is that the relationship between the anterior constriction location, the posterior constriction location and cavity volume are highly constrained by the tongue musculature. The tongues muscles are interconnected and the tongue can be divided into four main extrinsic muscles (Zemlin 1968; 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, as well as between laminal dental or palatal anterior constrictions and uvular posterior constrictions. 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 tongue root accomplished through the compatible hyoglossus muscle activity. 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. 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 et al. (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 et al., forthcoming). 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.

4.3.2 Linguo-pulmonic stops

Above, we saw waveforms and spectrograms for voiceless unaspirated lingual stops (Figure 11a) and linguo-pulmonic stops (Figure 12a). Figure 14 schematizes the durational differences between the different phases of the dental, palatal and central alveolar stops of these types.

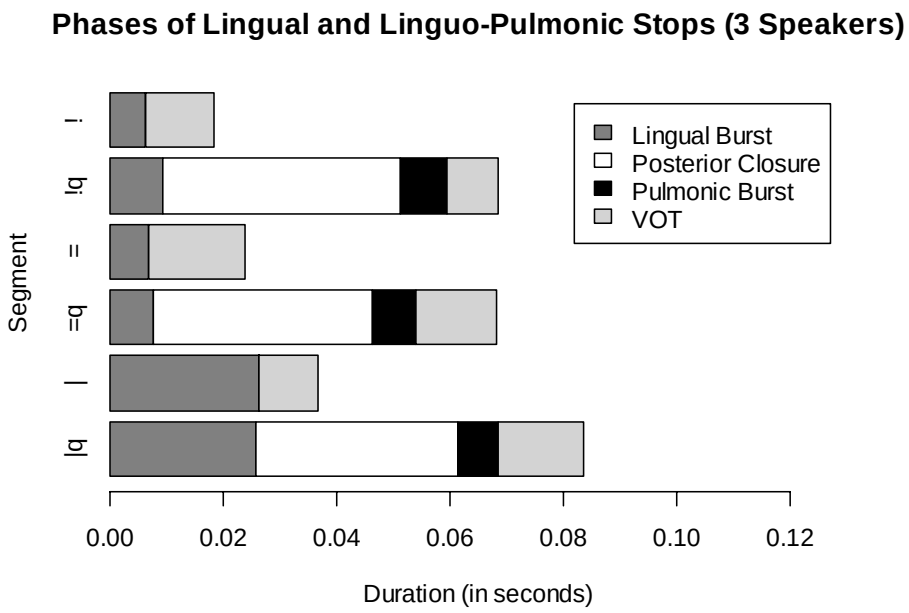


Figure 14: Durational phases of three pairs of lingual and linguo-pulmonic stops averaged across three female speakers (n = 21, note that " = " is used for "ǂ").

In this figure, we see that the durations of the lingual bursts and the voice onset times are comparable in the lingual and linguo-pulmonic segments. 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. While it is possible that this silence could be the result of a second posterior constriction, we see no positive evidence for an analysis that posits a posterior release, followed by a second closure and a second release. We also note that Traill (1985:125-6) reports comparable differences in his !Xóõ data. He observes that the voice onset time with [ǂ] is approximately 12 ms, while that with [ǂq] is closer to 40 ms. Significantly, he also observes that [ǂq] is characterized by an audible release, while [ǂ] is not. Despite Traill's subsequent analysis of the contrast as a difference in place of articulation, his acoustic results are perfectly compatible with our analysis. The same is true of such segments in G|ui (Nakagawa 1996a, 1996b, 2006) and ǂHoan (Bell and Collins 2001). There are no recordings or published spectral representations of clicks transcribed as uvular clicks in Khwe (Kilian-Hatz 2003).

As we have discussed, previous analyses of the !Xóõ inventory have argued that this 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) and Bell and Collins (2001) follow this analysis in their descriptions of G|ui and ǂHoan, respectively. If these segments really contrasted in posterior place of articulation, we would expect the bursts themselves to have different centers of gravity. Figure 15 shows that this is not the case in N|uu.

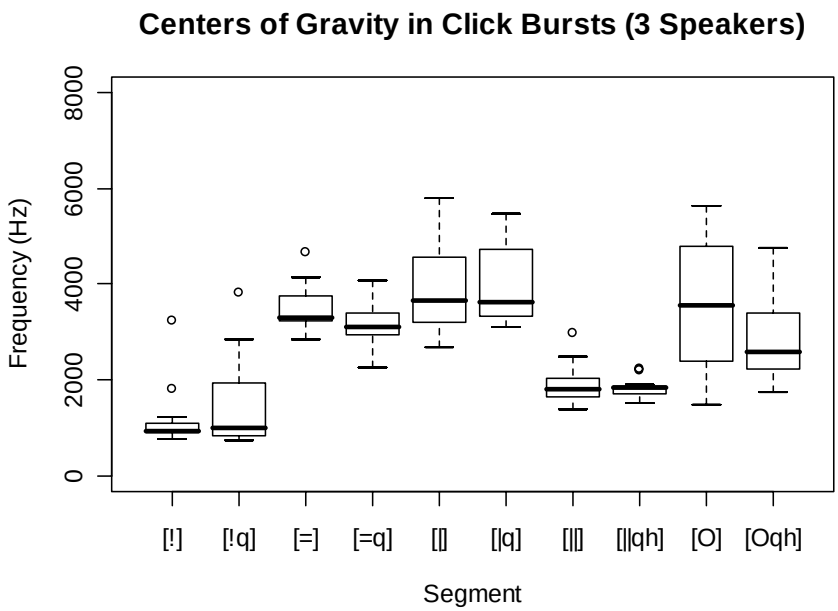


Figure 15: The centers of gravity for the lingual bursts in lingual and linguo-pulmonic segments, averaged across 3 female speakers (n = 21, boxes enclose 50% of values, horizontal lines show the mean, whiskers show 1.5 times the inter-quartile range and " = " and "O" are used for "ǂ" and "⊙", respectively)

Here we see side-by-side comparisons of the centers of gravity in the lingual bursts of lingual and linguo-pulmonic segments for all five click types. If the linguo-pulmonic segments differed in the place of the posterior, but not the anterior, constriction, this would create a larger cavity volume and a correspondingly lower center of gravity. It is clear, however, that the mean center of gravity values and ranges are highly similar for these pairs of segments, suggesting that the lingual cavity volume between the two constrictions must be roughly the same for both types of segments. We conclude from this that both the anterior and posterior constriction locations, as well as overall tongue shape, must be highly similar for the simple and contour segments of each type. We suspect that this is also the case for the other three languages with such segments.

Figure 16 provides center of gravity results for the pulmonic egressive bursts in the linguo-pulmonic clicks of each type, along with the pulmonic bursts for [k] and [q]. The results suggest that there are no large differences in the posterior release locations associated with the different click types. Furthermore, the centers of gravity associated with the click releases are clearly more similar to [q] than [k], as we would expect from previous descriptions.

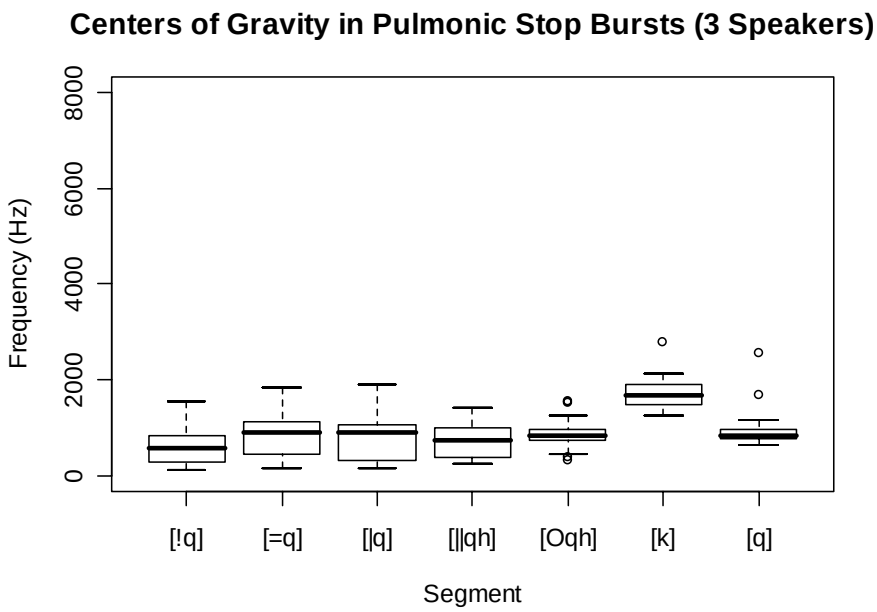
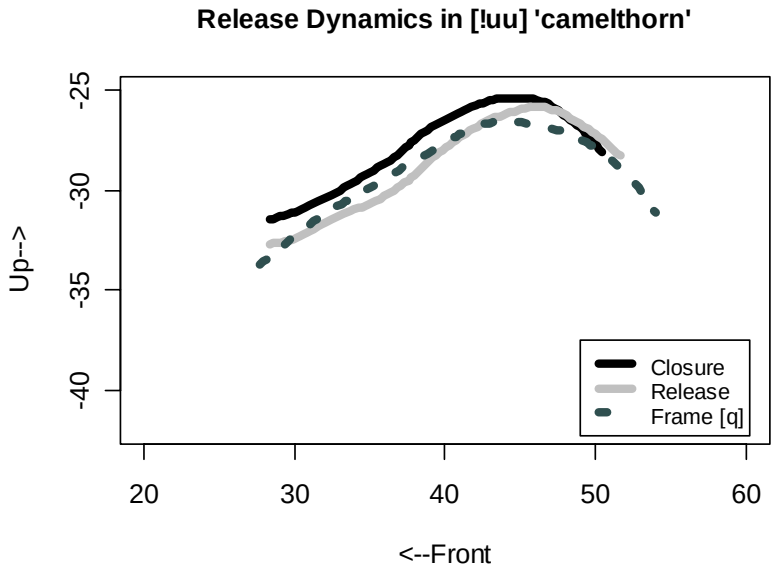


Figure 16: Center of gravity of the posterior burst in the five linguo-pulmonic stops, [k] and [q] for three female speakers. (n = 21, boxes enclose 50% of values, horizontal lines show the mean, whiskers show 1.5 times the inter-quartile range and " = " and "O" are used for "ǂ" and "⊙", respectively.)

We now turn to the articulatory evidence for our claim. In Figures 17 and 18, we provide tongue traces for the central alveolar and palatal lingual and linguo-pulmonic stops. The lingual stops have two traces, while the linguo-pulmonic stops have three. For the sake of clarity, these traces include traces of the uvular but not velar stops from the frame sentence.



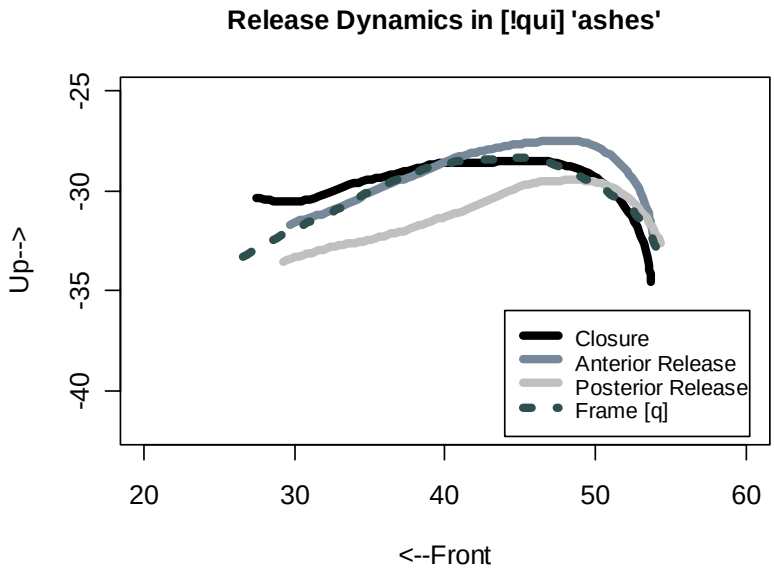
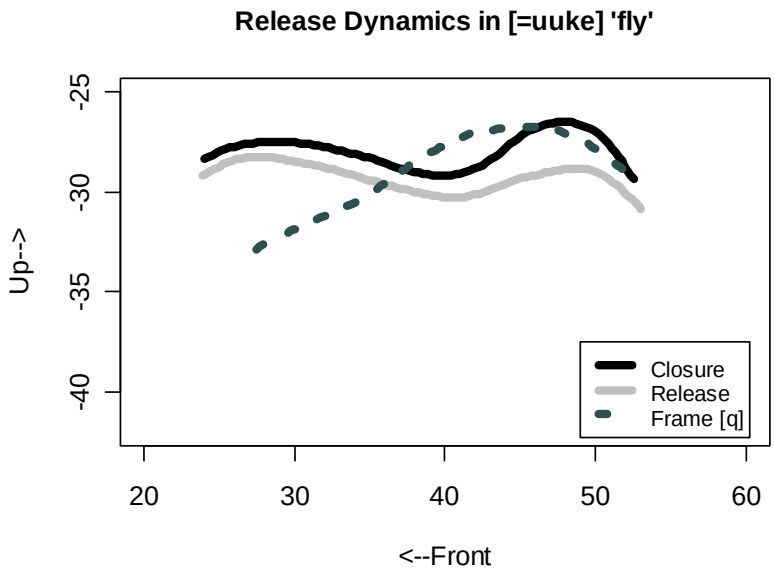


Figure 17: Tongue traces of central alveolar lingual [!] (top) and linguo-pulmonic ([!q]) (bottom) stops. Plots include traces associated with the closures and releases of the lingual stops, as well as with uvular pulmonic releases in the frame sentence.



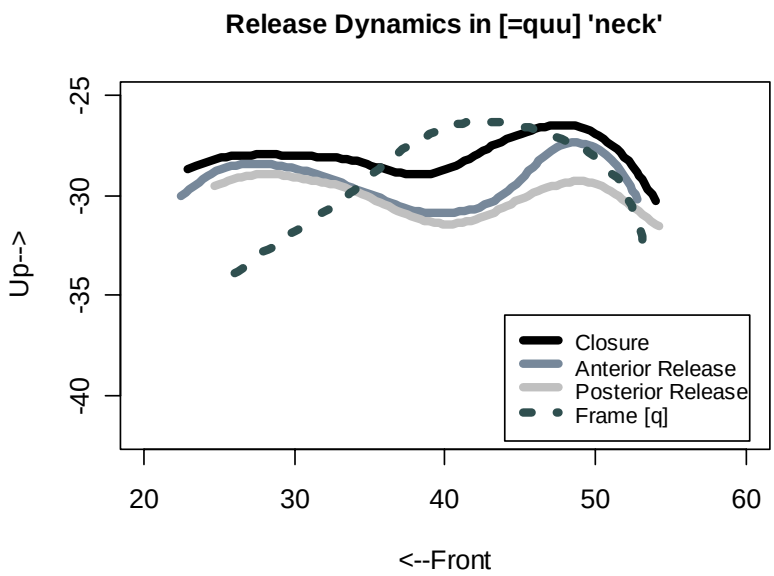


Figure 18: Tongue traces of palatal lingual [ǂ] (top) and linguo-pulmonic ([ǂ͡q] (bottom) stops. Plots include traces associated with the closures and releases of the lingual stops, as well as with uvular pulmonic releases in the frame sentence. (Note that " = " is used for "ǂ" in the plot).

The most striking aspect of Figures 17 and 18 is the similarity between the lingual and linguo-pulmonic segments. Comparing the central alveolar lingual (bottom) and linguo-pulmonic (top) stops in Figure 17, 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 18 have tongue root positions that are higher and further back than those in the velar and uvular stops. These patterns are consistent across all of the data we have looked at.

In the lower panel of Figure 17, the upper part of the tongue root appears to be higher 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 these stops are exactly like [q], or that they are exactly the same in all instances. We maintain this earlier convention because it is not obvious what IPA symbol could be used for the upper pharyngeal pulmonic portion of the stop that follows the palatal click. There are no IPA symbols for upper pharyngeal stops, or for pharyngeal stops for that matter, since they are considered impossible to produce. 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 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] (pp.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 these segments. 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 velar and uvular stops and similar stops found in languages such as Arabic. Of course, complete reanalysis of !Xóõ, as well as G|ui and ǂHoan 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.

5. Conclusions

This paper provides a complete sound inventory of 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 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 and airstream. Such categorization classifies segments in phonetically natural ways, using principles that are well established for non-click consonants. With this approach, we provide an analysis that obviates the 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 alternate 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. This is most readily explained as an airstream contour, analogous to contours in manner (affricates) and nasality (prenasalized stops). It is clear from previous descriptions of !Xóõ (Traill 1985), ǂHoan (Bell and Collins 2001) and G|ui (Nakagawa 2006) that this analysis will work for those languages as well. 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 and mechanisms.

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 et al. (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 [‖] clicks that the dental click will have an upper pharyngeal posterior constriction, much like the palatal, and that the lateral alveolar click will pattern with the central alveolar click in having a uvular posterior constriction. This is also suggested by our spectral data. 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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