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Clicks and their accompaniments

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A survey of the languages in which click sounds are known to occur shows that there are a large number of distinct ways of beginning a word with a click. All these sounds are described in articulatory terms, and the principal acoustic features exemplified. Arguments are presented for claiming that 105 distinct clicks have been observed, 83 of which actually occur in !Xóõ. It is suggested that some of these sounds are better considered to be sequences of a single click plus additional consonants, in which case there are 70 phonetically distinct known click segments, 55 of which occur in !Xóõ.

1. Introduction

This paper summarizes several decades of work on the production of clicks, using mainly new instrumental data to illustrate the wide range of phenomena involved. It attempts to provide a comprehensive survey of the types of clicks that have been observed in the world's languages. As such, it is part of the information required by linguists and others who are interested in determining the range of human phonetic capabilities.

The primary data that will be used are linguistic contrasts rather than physical measurements. We will describe the clicks that we have observed in individual languages, using data presented in tables to show that these are distinct sounds that are phonologically contrastive. We will illustrate these contrasts by reference to records of representative tokens that we consider to be typical, based simply on our observation of a number of speakers. The recordings of the data made in the field are usually not sufficiently well controlled to enable us to quantify the descriptions. After we have presented accounts of the linguistic contrasts within each of a number of languages, we will compare the sounds that occur in different languages. We will estimate whether the differences between sounds that occur only in different languages are comparable with those that distinguish sounds within a single language. If they are they will be regarded as distinct sounds that are potentially contrastive. On some occasions we have been able to conduct more rigorous experimental studies, and in these cases quantified results will be presented. The phonetic terminology used throughout is that of Ladefoged (1993).

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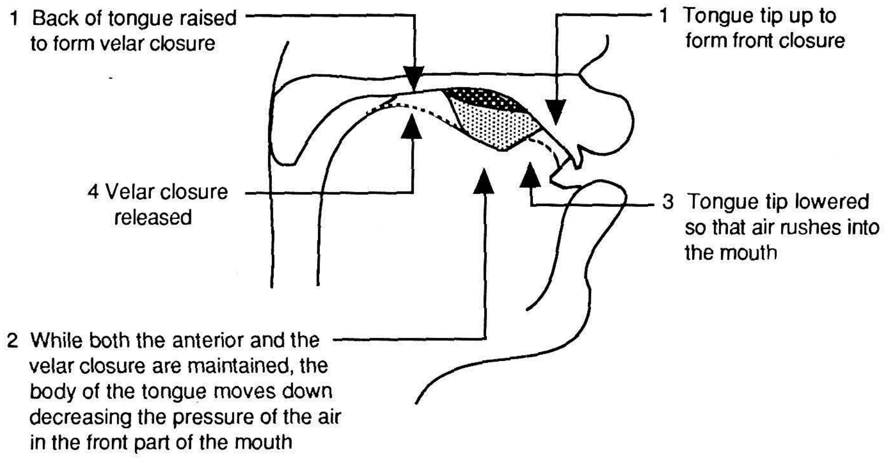


Figure 1. The articulation involved in an alveolar click in !Xóõ. The dark shaded area shows the cavity enclosed when the click articulation is formed. The light shaded area shows the cavity just before the release of the anterior closure. The dashed lines show the lowered tongue positions corresponding to steps 3 and 4.

Clicks are a regular part of the consonant systems of many of the languages spoken in Southern Africa. They are most common in the Khoisan languages such as !Xóõ, !Xũ and Nama, in which they are very frequent. Over 70% of the words in a !Xóõ dictionary (Traill, in press) begin with a click. They also occur, with a far lower frequency, in a number of Bantu languages, such as Zulu, Xhosa, Gciriku and Yei, in Dahalo, a Cushitic language of Kenya, and in Sandawe and Hadza, two languages spoken in Tanzania. Clicks have not been reported to be used in any languages outside Africa, except in Damin, the auxiliary language formerly used by Lardil speakers in Australia, which is constructed somewhat on the lines of a language game (Hale & Nash, 1987). Clicks are familiar as extralinguistic signals in many languages.

Clicks are made with the velaric airstream mechanism, which is always ingressive. It cannot be used for sounds other than stops and affricates. Figure 1 (based on x-rays of a !Xóõ speaker; in Traill, 1985) shows the sequence of events involved. (1) A body of air is enclosed usually by raising the tip or blade of the tongue to form a closure in the front of the mouth, and always by also raising the back of the tongue to make a velar or uvular closure on the soft palate. (2) The air in the cavity between the two closures is rarefied by the downard movement of the center of the tongue, both the back and the tip or blade of the tongue maintaining contact with the roof of the mouth all the time. (3) The tip, blade or side of the tongue moves down, releasing the forward closure so that air rushes into the mouth, producing a click sound. (4) The closure formed by the back of the tongue is released. The presence of this posterior closure leads to the important notion that every click has both a tip or blade (or lip) action determining the type of click, and also an accompanying velar or uvular articulation. Beach (1938) coined a pair of terms for these two aspects of the articulation of a click. He regards the first, the release of the anterior closure, as determining the click *influx*. From our point of view the click influx determines what we call the click type. The velar or uvular articulation (which we will call the click accompaniment) was in Beach's view the click *efflux*.

2. Articulatory properties of click types

We will regard any click as belonging to one or other of the five types: bilabial, dental, alveolar, palatal and lateral. We will note the differences in the articulation of these types, both between languages and between speakers within languages in the following discussion. Comparatively few languages use all five types of clicks. Dahalo and SiNdebele use only one (dental), Southern Sotho also uses only one, but in this case it is alveolar. Zulu, Xhosa and Sandawe use three (dental, alveolar and lateral). Nama and !Xũ use four (all except the bilabial). Only Southern Khoisan languages such as !Xóõ use five.

In the history of the study of these sounds there has been an enormous diversity in the articulatory descriptions. Some of the principal descriptive labels that have been used are summarized in Table I, in which it can readily be seen that different authors stress different aspects of the articulations. The confusion among descriptions of these types is such that we and Snyman (1975) give precisely the opposite names for [!] (our alveolar, his palatal), and [ǂ] (our palatal, his alveolar); other authors offer yet other names for these two sounds. Similarly, what we call dental, Maddieson (1984:297) calls alveolar, and our alveolars are his palato-alveolars. It is clear that many of the names can be considered only as approximate descriptive terms.

TABLE I. Some confusions among the articulatory phonetic classifications of the clicks [|, !, ǂ, ||]. The [ʘ] click is not included in this table as it is always described as bilabial by those authors who refer to it

Source	Language	|	!	ǂ	||
This paper	all	dental	alveolar	palatal	lateral
Beach (1938)	Nama	dental affricative	alveolar implosive	denti-alveolar implosive	alveolar lateral affricative
Bleek & Lloyd (1911)	|Xam	dental	cerebral	palatal	lateral
Doke (1937)	ǂKhomani	dental with friction	palato-alveolar instantaneous	alveolar instantaneous	lateral with friction
Köhler (1981)	Kxoe	dental	palatal rétroflexe	alvéolaire	latéral
Maddieson (1984)	Nama	dental	alveolar	palatal-(alveolar)	alveolar (lateral)
Maddieson (1984)	Zulu	alveolar	palatal-alveolar		alveolar lateral
Sagey (1986)	Khoisan	+coronal +anterior +distributed −lateral	+coronal −anterior −distributed −lateral	+coronal +anterior +distributed −lateral	+coronal −anterior −distributed +lateral
Snyman (1975)	Zhu|õasi	denti-alveolar	palatal	alveolar	lateral
Taljaard & Synman (1990)	Zulu	apico-lamino dental	apico-palatal palatal		apico-alveo-palatal

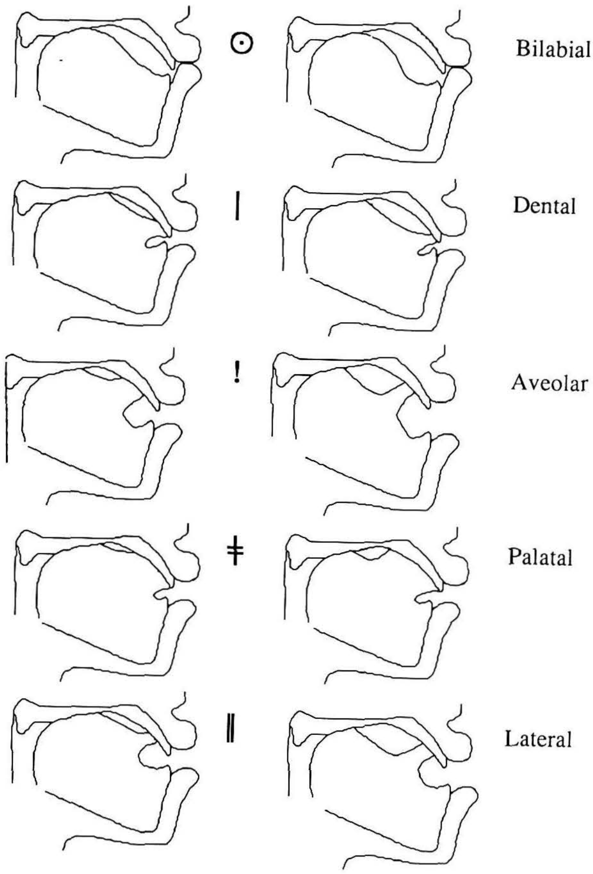


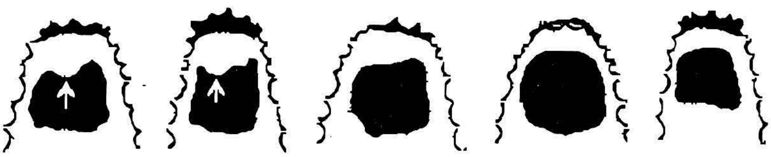
Figure 2. The positions of the vocal organs at the onset of the click closure (left column), and just before the release of the click closure (right) in the five click types of !Xóõ. Based on cineradiology data published in Traill (1985). Possible terms for the places of articulation are shown on the right.

The five possible types of click are illustrated in Fig. 2, which is based on cineradiology data (from Traill, 1985). In the original data the lips are visible only in the case of the bilabial click. Outlines of the lips have been added to each of the other clicks, with their positions based on those of the lower teeth, which are visible on the records of all the clicks. In each case the left-hand diagram shows the smallest cavity enclosed by the tongue, while the right-hand diagram indicates the position which occurred just before the anterior closure was released. The left-hand diagrams are fairly similar, except for the bilabial click. The most significant difference is that the anterior margin of the enclosed body of air is somewhat further from the front of the mouth for the palatal click. The major differences among these clicks are at the moment of release as indicated in the right-hand diagrams, each of which will be considered in turn. It is these points in the articulation that we will consider in most detail, noting particularly the location of the part of the anterior closure which is closest to the suction cavity.

The bilabial click, in the top row of Fig. 2, occurs only in Southern Khoisan languages. In most forms of this click the lips are together, but not rounded or protruded; the only exception is when there is labialization. The regular gesture is one of lip compression rather than the puckering of the lips normally associated with a kiss. In some productions the lower lip may articulate against the upper teeth, thus increasing the turbulent airflow associated with the release of the click.

The dental click (in the second row of Fig. 2) occurs in more languages than any other click. Both the tip and blade of the tongue are used to make the front closure. Louw (1977) suggests that some speakers use what he calls an apical articulation, but these articulations always involve both the tip and the blade of the tongue, and are what we would classify as laminal. Doke (1925) suggests that this click may be inter-dental in what is now called !Xũ; and we have ourselves observed some speakers of Sandawe and Hadza who protrude the tip of the tongue between the teeth. When the click is formed, the front closure may extend as far back as the post-alveolar region, so that it might seem preferable to call these denti-alveolar or even denti-palatal clicks. But the crucial point in the description of a click is the location of the closure at the moment of release, not the location of the closure when the suction is being produced. In the clicks that are being classified as dental, the closure at the time of the release always involves at least part of the blade of the tongue, and is usually on the teeth and the anterior part of the alevolar ridge, making them clearly laminal dental or laminal dentialveolar. These clicks are also affricated.

The third row in Fig. 2 shows the articulation for the click transcribed as [!]. Clicks of this type contrast with the dental clicks in that they are always produced with a more abrupt, non-affricated, articulation. But their articulation may be somewhat varied, resulting in their being given various names. Traill (1985) prefers the term post-dental on the grounds that most of the considerable number of speakers of Khoisan languages that he has examined have smoothly sloping palates without an alveolar ridge. This is not true, however, of the speakers of the East African click languages. We have made dental impressions of only five of these speakers, but all of them had far more pronounced alveolar ridges than any of the speakers in Traill (1985). An alternative would be to call these sounds apical clicks on the grounds that by far the majority of clicks of the [!] type are made with the tip of the tongue contacting the roof of the mouth at the moment of release of the closure. But again this is not true for all speakers; palatograms and accompanying linguograms (Maddison, Ladefoged & Sands 1992) show that some speakers of Hadza and Sandawe have a laminal articulation in which the tip of the tongue never touches the roof of the mouth. The situation is further confused by the fact that there is even a sublaminal variety (an extreme form of apicality) reported in some languages. Doke (1925:148) describes a sublaminal retroflex click in !Xũ although other investigators (Snyman, 1975, 1978, 1980; Köhler, 1981; Traill, 1991*a*) working on this language and closely related dialects do not note this possibility. Doke (1925) implies that the retroflex click contrasts with the alveolar click, but as Traill (1991*a*) notes, Synman consistently transcribes the words that Doke has with a retroflex click as simply containing the [!] click. It seems mostly likely that some of Doke's speakers used a retroflex click, but there is no contrast between this sound and a [!] click. Retroflex clicks, however, may be the favoured form of pronunciation of [!] in some languages. The noisy articulation of [!] by ||Gana speakers is auditorily similar to Doke's so-called retroflex click.



(1) (2) (3) (4) (5)

Figure 3. Palatograms of [!] by five speakers of !Xóõ (based on Traill, 1985:103).

Further evidence for retroflex articulations of [!] by some speakers comes from data on five speakers of !Xóõ. The palatograms in Traill (1985:103), which show a single articulation of a word containing initial [!] produced by five different speakers, have been re-drawn and shown here in Fig. 3. Note the inverted curve for the first two speakers (marked by the arrow). The contact in the center of the mouth is further back than at the sides. This kind of contact area is produced by the tip of the tongue curling back as it touches the roof of the mouth, in a sublaminal articulation. Similar contact areas have been found in studies of the retroflex consonants in Malayalam (Dart, 1991). The other three speakers of !Xóõ in Fig. 3 do not use this kind of articulation. Another example of a retroflex articulation of [!], this time by a Xhosa speaker, is demonstrated in a palatogram in Beach (1938; reproduced in Sands, 1991).

The two speakers of Sandawe for whom there are palatographic records do not have a sublaminal articulation. Nevertheless we have observed Sandawe speakers who have a sublaminal articulation. Some of these speakers have a retroflex click in which the underside of the tongue slides off the roof of the mouth and goes on to produce a percussive sound as it hits the floor of the mouth. This version of the [!] click is thus similar to the sound sometimes made by speakers of non-click languages trying to imitate the sound of a trotting horse. We do not have exact figures on the frequency of the production of [!] with this added percussive sound in Sandawe, but we estimate that 10–20% of the many Sandawe speakers that we have observed, make the sound in this way. Sands (1991) and Traill (1992*b*) have noted that writers on clicks have described the [!] click in a large number of different ways. In the preceding paragraphs we noted that for some speakers in some languages this click may involve a laminal articulation, whereas for others it is apical or sublaminal. We suspect that the laminal articulation of [!] can occur only in languages that do not have a contrasting palatal click [ǂ] of the type we will discuss below. Except for Traill's data on !Xóõ, we do not have any data (cineradiology or dynamic palatography) which show the place of articulation on the roof of the mouth at the moment of the release of the click. Static palatography does not help in this respect, although the linguagraphic part of such data may be useful for distinguishing between apical and laminal articulations. Consisering all the varieties of [!] clicks that have been observed, many of them being differences among individual speakers of the same language, we think it best to use the term alveolar to describe these clicks, noting, however, that it should not be interpreted too specifically. We should also note that in each of the languages we have investigated with a [!] click, at least some speakers make this sound with an apical (or sublaminal) contact in the alveolar region. In the Khoisan languages of Southern Africa it is always made in this way, and for these languages [!] can be considered simply as an apical click.

The [ǂ] click shown in the fourth row of Fig. 2 has been called denti-alveolar (Beach, 1938). This seems to us to be a complete misnomer, and we will refer to it as palatal. It is true that the tip and blade of the tongue are in contact with the teeth and alveolar ridge, but the forward edge of the click cavity is much further back; and this is the relevant factor. We disagree with Beach in his rejection of the term palatal, which was the term used by earlier writers on these languages. Traill's cineradiology data also demonstrate how the location of the click cavity alters during the production of this click. Figure 2 shows that the contact made by the blade of the tongue moved further back while the suction was being developed. At the moment of the release of the click, there is no doubt that [ǂ] should be described as a palatal sound.

The lateral click in the last row of Fig. 2 is also somewhat varied in its place of articulation. The significant aspect of this click is, of course, the lateral release, which is usually made by moving one side of the tongue at the level of the molar teeth. There are no reports of a retroflex or sublaminal version of this click. In the Southern African languages the central closure is usually apical alveolar, and the lateral click [||] has a similar front closure to that in the [!] click; but in Sandawe and Hadza the articulation is similar to that in the palatal lateral ejective [cʎ̥'], which these languages also have. Indeed, the Sandawe lateral click [||] might well be regarded as a lateral version of the [ǂ] click, rather than of the [!] click.

The anterior articulators move at different rates in these clicks. The clicks in the second and fifth rows of Fig. 2 have comparatively large cavities at the time of release. In all the languages that we have heard these dental and lateral clicks are affricated, whereas the alveolar and palatal clicks in the third and fourth rows are sharply released. The bilabial click is also affricated, so it appears that all the clicks with a large rarefaction cavity at the time of release are longer and noisier. A similar point has been made by Kagaya (1978) for the four oral clicks in Naron.

We follow Traill (1985) in emphasizing that, for languages that have both alveolar and palatal clicks, the major articulatory distinctions among [|, !, ||, ǂ] are not in the place of articulation on the roof of the mouth, but in the part of the tongue used. In these languages, two of the clicks, [!, ||], are apical and two, [|, ǂ], are laminal. The distinction between the two apical clicks is that [!] is central and [||] lateral. The tongue tip contact on the roof of the mouth can be anywhere from the dental to the post-alveolar region. There is a distinction in traditional place of articulation terms between the two laminal clicks, [|, ǂ]. The laminal closure for [|] is on the teeth and the teeth ridge (in so far as Khoisan speakers can be said to have an alveolar ridge; as we have noted most have very flat palates). The closure for the other laminal click, [ǂ], always extends further back into the palatal region. In coming to these conclusions, Traill (1985) was discussing a particular language, !Xóõ, but his findings seem equally applicable to the other click languages that have [||, !, |, ǂ]. Many of the descriptions of clicks in these languages are inadequate because they do not pay sufficient attention to the apical–laminal distinction. In languages with only three clicks there may be more variety in the articulation of the [!] click, as is evident from our records of Sandawe, in which some speakers have an apical or sublaminal variety of [!], and some a laminal variety.

3. Acoustic properties of clicks

The answers to many of the problems encountered in the articulatory description of clicks (such as the disagreement about their precise articulation) become clearer when we consider their acoustic properties. These acoustic properties not only provide essential additional information about the phonetic description of clicks but they also clarify the phonetic relationship between clicks and non-click consonants.

In the past there have been few attempts to describe clicks from an acoustic perspective. The most important are Jakobson's (1968) study of Zulu, Nama and Korana, Kagaya's (1978) study of Naron, and Sands' (1991) study of Xhosa. These authors have described the click types in terms of the general shape of their acoustic spectra and whether or not they are associated with noise (affricated). We will consider the spectra of clicks shortly, but the most convenient way to introduce a discussion about the acoustic properties of clicks is to consider the differences in the

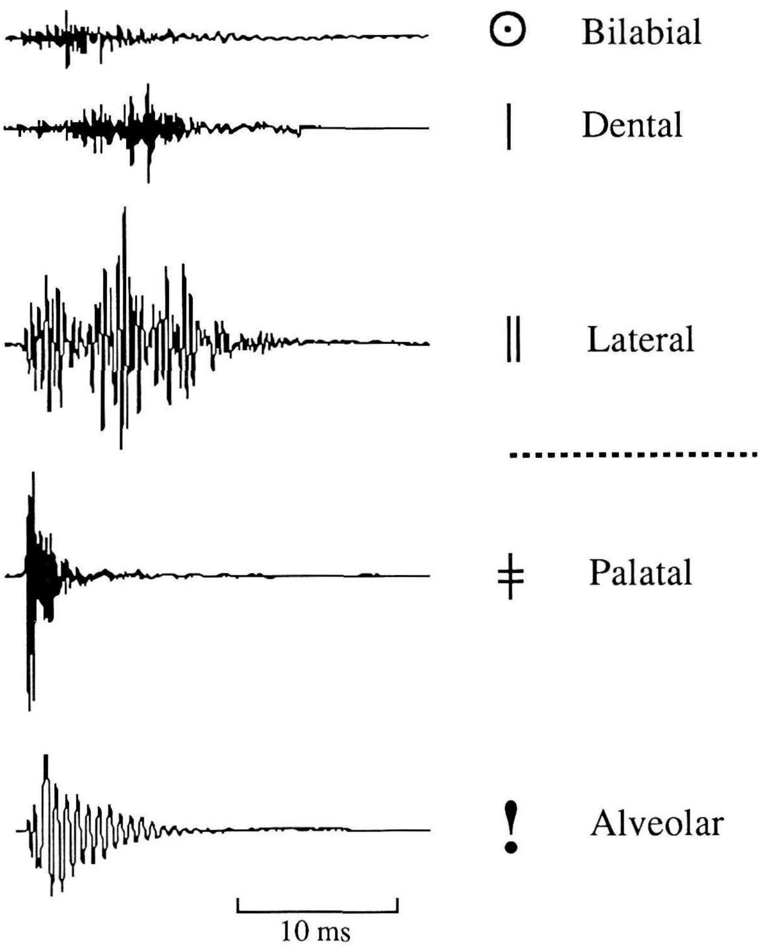


Figure 4. Waveforms of the noise bursts for the five !Xóõ clicks. The waveforms in the lower part of the figure (below the dashed line) are dominated by the transient response, those in the upper part have considerable turbulent noise after the release.

waveforms, shown in Fig. 4. We will concentrate on the acoustic structure of the waveform that occurs at the release of the anterior closure. This waveform is determined by the place and manner of the click release, and by the cavity and walls of the vocal tract anterior to the posterior closure. The relevant acoustics of the release of the posterior closure will not be discussed here. They are similar to the releases that occur in other velar and uvular consonants.

There are obvious differences among the waveforms in their duration and noisiness. Clicks, like other stops, can be considered to have two acoustic components; a transient which occurs when the articulators come apart, and a noise (often called the burst) associated with turbulent flow between the articulators. The transient is due to the rapid rate of change of vocal tract shape; it produces a wave that is like an impulse response of the vocal tract cavity at the time. The wave forms of the alveolar and palatal clicks (in the lower part of the figure) are dominated by the transient response; they are not accompanied by significant amounts of turbulent noise after the release. The bilabial, dental and lateral clicks (in the upper part of the figure) are longer and noiser. These differences correspond to the clear auditory differences between these two classes; the abruptly released clicks provide an intense but brief stimulation of the auditory nerve, whereas the noisy clicks do not. This makes the clicks [!, ǂ] more like the plan stops [t, k] whereas the noisy clicks [ʘ, |, ||] are more like the affricates [pɸ, ts, kx]. In the noisy clicks the tongue (for the dental and lateral clicks) and the lips (for the bilabial click) move more slowly when the front closure is broken and the negative pressure is equalized. In the abrupt (palatal and alveolar) clicks, the front of the tongue moves very fast when the anterior closure is broken, so that the impulse response of the chamber is accompanied by almost no noise. The duration of the turbulent airflow visible in the waveform is given in Table II. These measurements support the notion that [ʘ, |, ||] are related to the class of affricated stops, and [!, ǂ] to the non-affricated stops.

A feature that can also be seen in Fig. 4 is the crescendo and decrescendo of the noise. For the noisy clicks, after the anterior closure is released, the noise increases in intensity until it reaches a maximum, after which the noise decreases in intensity. This gives a measure of the speed with which the anterior part of the tongue or the lower lip moves away from its point of articulation. For the noisy clicks this is relatively slow, so that the duration of the fricative portion is about 30 ms; for the abrupt clicks the duration of this portion is about 6 ms. These duration differences are reflected in the measurements summarized in Table II, which also shows the time taken for each of the click noise bursts to reach maximum amplitude. The abrupt clicks do so within about 1.5 ms of release, but the affricated clicks reach their peak amplitude much later after the release.

Another acoustic feature of the abruptly released clicks [!, ǂ] visible in the

TABLE II. Mean durations (ms) of the noise bursts for clicks, and of the rise time until peak intensity. The figures are based on 10 tokens of each click type for four speakers

	ʘ	|	||	!	ǂ
Duration	31.6	30.3	28.5	12.0	6.6
Rise time	22.9	27.3	19.4	1.9	1.2

waveforms are the damped oscillations, initiated by the transient energy. The noisy clicks have a more random waveform. The waveform of the alveolar click has damped oscillations with a frequency of about 1200 Hz. The palatal click has less clearly visible damped oscillations, with a frequency over 3000 Hz, reflecting the fact that the cavity for the palatal click is smaller than that for the alveolar, as may be seen in Fig. 2.

The best way to discuss the differences in frequency is to refer to the spectrum for each click. Averages of four speakers each producing three tokens of each click type followed by the vowel [a] (left of the figure) and the vowel [u] (right of the figure) are given in Fig. 5. We have used spectra in which the frequencies and amplitudes have been transformed in accordance with the characteristics of the human auditory system. The spectral frequencies are displayed on a Bark scale, and the amplitudes have been convolved with an appropriate function so as to reflect the ear's perception of differences in loudness as described by Johnson (1990). We will refer to curves of this kind as auditory spectra, although, strictly speaking, they are acoustic data and not data derived from some set of listeners' responses. We prefer to use auditory spectra of this kind, as averaging untransformed acoustic data across tokens and speakers yields spectra that are more difficult to interpret. The auditory transformations foreground the major characteristics of the spectrum and therefore provide a less ambiguous representation that more closely reflects the way in which the listener perceives these sounds.

Clicks can be divided into three classes, dependent on the general distribution of energy within the auditory spectrum. For these speakers, the dividing point is about 14 Bark (about 2.5 kHz). The dental and palatal clicks in rows (2) and (3) have more energy above this frequency, and the alveolar and lateral clicks in rows (4) and (5) have more below it. The bilabial click in row (1) will be discussed separately. The dental and palatal spectra both have a peak at around 18 Bark (4 kHz) when before [a]; before [u] this peak is somewhat lower (distinctly so in the case of the palatal click). There is also a less intense peak in the spectra of palatal clicks at about 10 Bark (1.2 kHz) which is 8–10 dB less than the main peak and is weaker when [a] follows than when [u] follows. However perception tests reported in Traill (1992*c*) show that this secondary peak does not affect the percept of this click as essentially a higher frequency sound.

The alveolar click has an intense peak at 10 Bark (1.27 kHz) and a secondary peak at an even lower frequency when [a] follows and a single peak at about 7 Bark (0.8 kHz) when [u] follows, making it the click with the lowest frequency concentration of energy. The lateral has a sharp peak at 12 Bark (1.74 kHz) when [a] follows and a clear one at 8 Bark (0.9 kHz.) when [u] follows. The peak in the lateral auditory spectrum at 15 Bark (2.7 kHz) is about 4 dB weaker and, as shown in Traill (1992*c*), does not affect the auditory percept of this click as having most of its energy in the lower part of the auditory spectrum.

The spectra of the bilabial click are partly reminiscent of those for the dental click, with a high frequency peak at 17 Bark (0.9–1.5 Hz). There are two regions of spectral energy because the bilabial click is the only click in which the initial transient and the following noise burst are in different regions. The spectra in Fig. 5 show the frequencies present in both these events. Much of the low frequency energy in the bilabial click arises from the transient produced by the rapid opening of the lips. The higher frequency energy is the result of the turbulent flow between

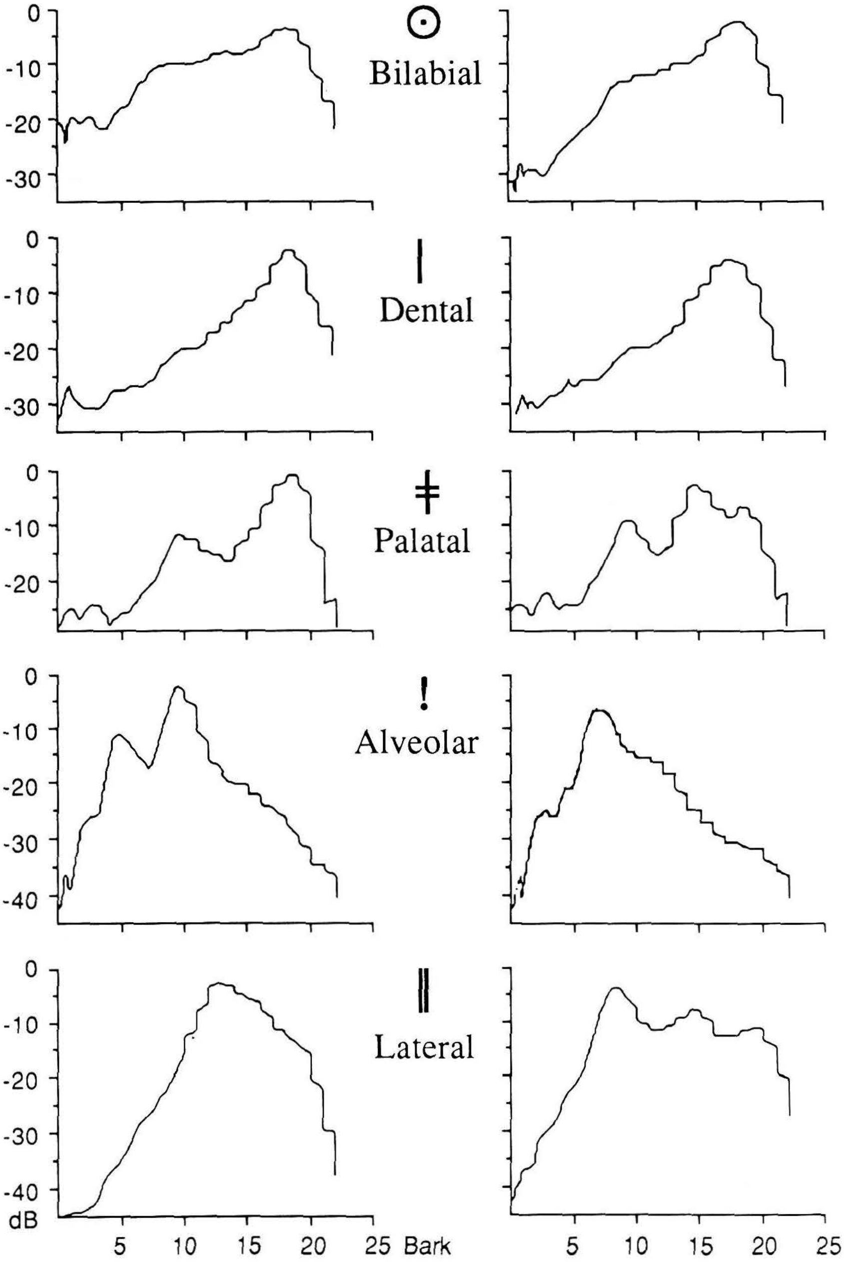


Figure 5. Mean auditory spectra of four speakers each producing three tokens of each click type followed by the vowel [a] (left of the figure) and the vowel [u] (right of the figure).

the lips and the teeth which occurs later. The tests reported in Traill (forthcoming) show that the perception of this click in fact depends simply on the lower frequencies. Spectra which have been low-pass filtered at 15 Bark result in stimuli that are always perceived as the bilabial click. When the same spectra are high pass filtered at 15 Bark, they are perceived as the dental click.

We should point out at this stage that the spectra give a misleading representation of differences in the relative amplitude of the various clicks. In these spectra all the clicks are normalized to the peak amplitude of the click regardless of whether the relative intensity of one click differs from that of another click. Thus the large difference in amplitude between the bilabial and dental click is not apparent. In fact, the bilabial click has the weakest intensity of all the clicks, and this is just as important a distinguishing feature as is its lower frequency components. Thus the perceptual difference between the bilabial and dental clicks is large.

It has been customary (Jakobson, Fant & Halle, 1951) to label spectra with a higher frequency emphasis as acute, and spectra with a lower frequency emphasis as grave. By using these terms for clicks we can see that the acute clicks [ǀ, ǂ] are acoustically related to other acute consonants like [t, s] and the grave clicks [ʘ, ǁ, !] are acoustically related to other grave consonants like [p, k].

Having noted that the click spectra can be divided into those that are grave and those that are acute, we should also note that the spectra in Fig. 5 are either dominanted by a relatively wide frequency region or have their acoustic energy in a narrower range. Thus, bilabial clicks do not rely on as narrow a focus of energy as the others do. Again, this is a relative distinction, because there are clear differences among the more peaked clicks. Sounds with the acoustic feature of the later class, viz. [ǂ, ǁ, !, ǀ], may be classified as compact, whereas bilabial clicks may be termed diffuse sounds. We can summarize these features, together with the noisiness attribute which we discussed above, as shown in Table III. The noisiness attribute might be considered as equivalent to delayed release or gradual (as opposed to abrupt) onset in other feature systems.

The acoustic properties that distinguish the different types of clicks have been exemplified from !Xóõ, but these features apply equally to the clicks of other languages. While there may be a greater range of individual variation in the pronunciation of a click in a language with only three click types as opposed to one with five click types, the main acoustic features identified above can be used to describe clicks in all languages.

Finally, in our consideration of the acoustics of clicks, we must emphasize the importance of their intensity. Clicks stand out from the sounds around them. This is partly due to their usually being preceded by silence or low level voicing, and often followed by a voiceless accompaniment. But it is more because many of the clicks contain a great deal of energy compared with the surrounding sounds. As the

TABLE III. Summary of three acoustic features of clicks

	ʘ	ǀ	ǁ	ǂ	!
Grave	+	−	+	−	+
Compact	−	+	+	+	+
Noisy	+	+	+	−	−

illustrations in the later part of this paper will show, they often have a peak-to-peak voltage ratio that is more than twice that of the following vowel, meaning that they have at least 6 dB greater intensity. (It may be helpful to remember that if one sound is 5 dB greater than another, and has approximately the same frequency components, then it sounds about twice as loud as the other.) This is an important acoustic feature that distinguishes clicks from other consonants. The clicks [|, !, ||, ǂ] are nearly always more intense than the following vowel. Only the bilabial click normally has much less intensity than the following vowel; but it is, nevertheless, at least as intense as [s], the strongest of the other voiceless consonants.

As a class clicks are probably the most salient consonants found in a human language. It is therefore of interest to compare the perceptual salience of clicks with other consonants that have been assumed to be perceptually optimal. Figure 6 shows how clicks and non-clicks are perceived under various conditions of noise masking. In this experiment, syllables of the form CV with C = [ʘ, ǂ, ||, !, |, p, t, k, q, t^h, k^h, q^h, ts^h, ts', t', q', s, x, m, n] and V = [a] were played over headphones to 10 !Xóõ listeners whose hearing had been tested and found to be normal. The stimuli were masked by various levels of white noise at decreasing intensities and the listener was asked to repeat what had been said. Responses were transcribed phonetically, and then scored as correct or incorrect.

Figure 6 shows that clicks are easier to identify than non-click consonants. Furthermore, an investigation of the perceptual confusions in this experiment showed that clicks are virtually never confused with non-click consonants. They thus form a robust and perceptually salient class.

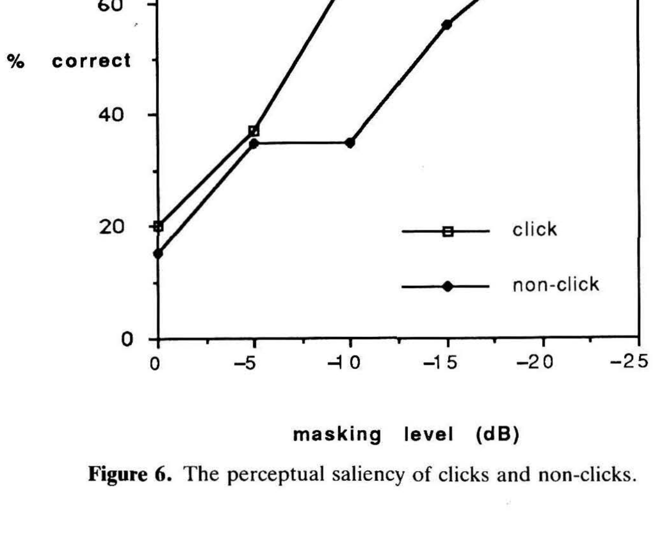


Figure 6. The perceptual saliency of clicks and non-clicks.

4. Click accompaniments

Clicks must involve two closures. So far we have been discussing only the sound that is caused by the release of the anterior closure, the so-called influx. We will now consider the range of sounds associated with the posterior closure and with the laryngeal and oro-nasal settings during clicks. These variations are called the accompaniments or, in older terminology, the "effluxes" of the clicks. It should be emphasized that they are a necessary part of any click. There cannot be a click without an accompaniment of some kind, and our transcriptions of clicks will always include a way of symbolizing this part of the sound. The posterior closure is usually in the velar region, so that most clicks include a velar plosive [k] or [ɡ] or a velar nasal [ŋ] as one of their attributes.

There are three types of variations in the accompaniments of clicks: (1) those associated with activities of the larynx; (2) those associated with the oro-nasal process; and (3) those associated with the place and manner of release of the back closure. Nguni languages such as Zulu and Xhosa use only the first two of these possibilities. The Khoisan languages use all three.

We will begin a more detailed study of click accompaniments by considering data from Xhosa, in which there are five different accompaniments for each click. These clicks may be accompanied by a voiceless, or an aspirated, or what we will call a murmured velar plosive [k, k^h, ɡ̤]; in addition there may be a voiced velar nasal [ŋ], or a murmured velar nasal [ŋ̤]. Xhosa clicks have one of three possible anterior releases, dental, alveolar or lateral. Accordingly this language has 15 contrasting clicks as shown in Table IV.

We can see a number of points about these different accompaniments by considering the waveforms for the alveolar clicks, which are shown in Fig. 7. The voiceless click in the top row has a small amount of aspiration; but it is clearly distinct from the aspirated click in the second row, which has a Voice Onset Time (VOT) of about 125 ms. The click in the third row may be called murmured, and transcribed with a voiced velar symbol with a dieresis under it; but Fig. 7 shows that in the velar plosive accompaniment in the third row there is no breathy voice during the closure. The murmured clicks in Xhosa (and in the neighboring languages such as Zulu) are part of the set of depressor consonants, which are marked by the lowering of the tone on the following vowel (Traill, Khumalo & Fridjhon, 1987). The murmur in these depressor consonants in Bantu languages such as Zulu and

TABLE IV. Contrasting clicks in Xhosa

<table>
<tr><th></th><th>Dental</th><th>Alveolar</th><th>Lateral</th></tr>
<tr><td>Voiceless</td><td>ukúk|ola
"to grind fine"</td><td>ukúk!oɓa
"to break stones"</td><td>úk||olo
"peace"</td></tr>
<tr><td>Aspirated</td><td>úkuk|ʰóla
"to pick up"</td><td>ukúk!ʰola
"perfume"</td><td>ukúk||ʰoɓa
"to arm oneself"</td></tr>
<tr><td>Murmured</td><td>úkuɡ̤|ôɓa
"to be joyful"</td><td>úkuɡ̤!oba
"to scoop"</td><td>ukúɡ̤||oba
"to stir up mud"</td></tr>
<tr><td>Nasal</td><td>ukúŋ|oma
"to admire"</td><td>ukúŋ!ola
"to climb up"</td><td>ukúŋ||iɓa
"to put on clothes"</td></tr>
<tr><td>Murmured nasal</td><td>ukúŋ̤|ola
"to be dirty"</td><td>ukúŋ̤!ala
"to go straight"</td><td>ukúŋ̤||oŋ̤||a
"to lie on back knees up"</td></tr>
</table>

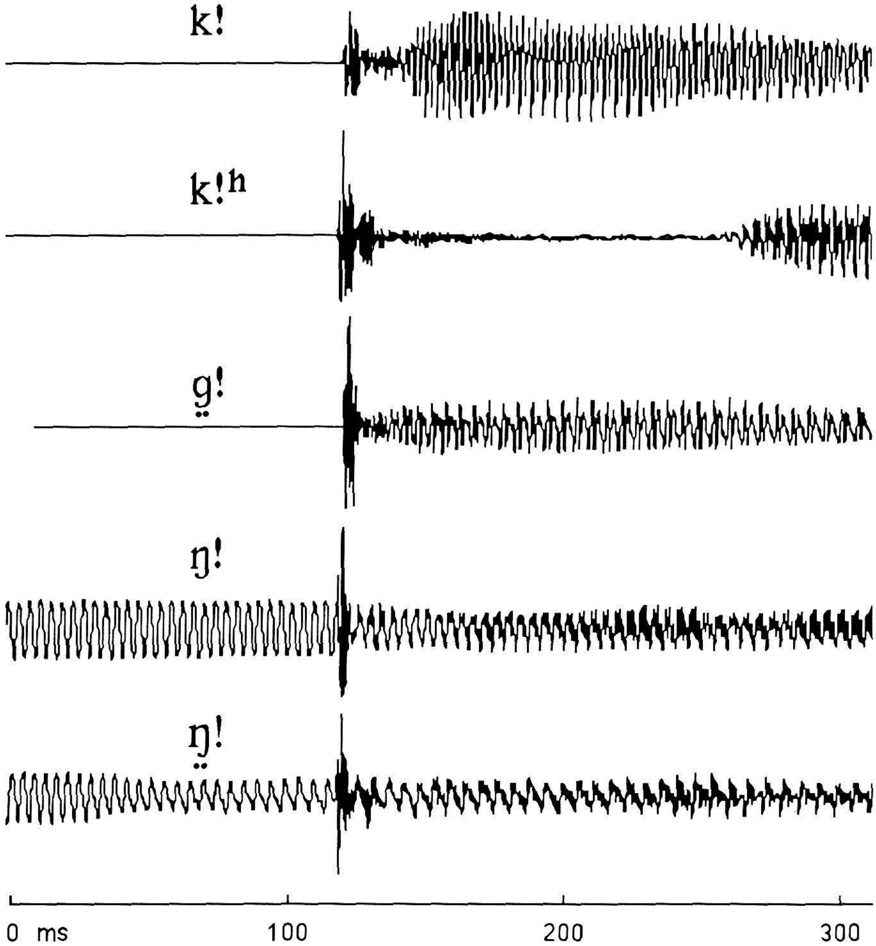


Figure 7. Waveforms of the five click accommpaniments for Xhosa alveolar clicks.

Xhosa is not accompanied by strong breathy voice during the release of the closure as it is in languages such as Hindi or Marathi. The clicks in the fourth row occur almost at the end of the accompanying velar nasal, as do the clicks in the fifth row. The clicks in these two rows are distinguished by the fact that the murmured nasal in the fifth row is a depressor consonant, lowering the tone. Unlike the situation in the case of the accompanying velar stop in the third row, in this case there is sufficient transglottal pressure difference to keep the vocal cords vibrating throughout the click and the following vowel. The breathy voice vibrations are evident in the waveform, which has a lower fundamental frequency. Again the breathiness is not as strong as it is in the murmured nasals in, for example, Marathi.

There are additional click accompaniments in the Khoisan languages. Nama has clicks accompanied by a glottal stop and clicks with what is traditionally called delayed aspiration, which will be discussed below. As it also has three of the possiblities mentioned so far—the nasal, voiceless unaspirated and aspirated accompaniments—there are five different forms of each of the anterior releases.

TABLE V. Contrasting clicks in Nama. All these words have a high tone

	Dental	Alveolar	Palatal	Lateral
Voiceless unaspirated	k|oa "put into"	k!oas "hollow"	kǂais "calling"	kǁaros "writing"
Voiceless aspirated	k|ʰo "play music"	k!ʰoas "belt"	kǂʰaris "small one"	kǁʰaos "strike"
Delayed aspiration	ŋ̊|ʰo "push into"	ŋ̊!ʰoas "narrating"	ŋ̊ǂʰais "baboon's arse"	ŋ̊ǁʰaos "special cooking place"
Voiced nasal	ŋ|o "measure"	ŋ!oras "pluck maize"	ŋǂais "turtledove"	ŋǁaes "pointing"
Glottal closure	k|ʔoa "sound"	k!ʔoas "meeting"	kǂʔais "gold"	kǁʔaos "reject a present"

Nama has four types of anterior release (the three in Xhosa and a palatal type), so that there are 20 distinct clicks as shown in Table V. Ladefoged & Traill (1984) have given a full account of these Nama clicks.

We need not comment further on the clicks in the first two and fourth rows, which have similar accompaniments to those in Xhosa. The third row contains clicks with so-called delayed aspiration. The voicing delay for these clicks is similar to that of the clicks in the second row, which contain audible aspiration immediately after the release of the velar closure. The clicks in the third row do not have an audible velar release, because the pressure that might have been built up behind the velar closure has been vented through the nose. Instead of having an aspirated velar stop [kʰ] as an accompaniment (as is the case in the second row) the clicks in the third row are accompanied by a voiceless velar nasal [ŋ̊]. Aerodynamic records of these clicks have been given in Ladefoged & Traill (1984). We will provide further documentation on the airstream mechanisms involved in our discussion of the clicks of !Xóõ below.

The clicks in the last row are accompanied by a glottal stop. During the glottal closure there is (naturally) no increase in pharyngeal pressure. However, aerodynamic records show that at the release of the click there is some nasal airflow, indicating that the velum is clearly lowered at this time. The voiceless nasal release was first noted by Beach (1938). It is possible that it is caused by a raising of the closed larynx while the velum is down. Clicks of this type do not occur as phonological contrasts in Xhosa or other Ngumi languages, but Lanham (1964) notes that the voiceless unaspirated stop in Xhosa may be followed by a glottal stop.

We have so far discussed seven ways (five in Xhosa and two others in Nama) in which the posterior component (the accompaniment) of a click can be varied. Several additional accompaniments occur in !Xóõ. Words illustrating the complete set of !Xóõ clicks (including some sequences of clicks and other consonants) are give in Table VI. As we have noted, !Xóõ has five types of click articulation; there are bilabial, dental, alveolar, lateral and palatal clicks. Each click has one of 17 possible accompaniments, which are exemplified in the table.

Waveforms for the alveolar click series are shown in Figs 8 and 10. These words were recorded at Lokalane in the Kalahari Desert, in a free field, about a kilometer away from the settlement. The slight background noise which is evident during

TABLE VI. Clicks and clusters involving clicks in !Xóõ

	Bilabial	Dental	Alveolar	Lateral	Palatal
(1)	gʘòõ (type of worm)	g|áã "work"	g!àã "accompany"	g‖àã "beg"	g‡àa "exploit"
(2)	kʘôõ "dream"	k|à "move off"	k!àã "wait for"	k‖āã "poison"	k‡àã "bone"
(3)	kʘʰoũ "ill fitting"	k|ʰáa "be smooth"	k!ʰà "water"	k‖ʰàã "other"	k‡ʰàa "stamp flat"
(4)	ɢʘòo "be split"	ɢ|áa "spread out"	ɢ!á̠ã "brains"	ɢ‖àa "light up"	ɢ‡àa "depress"
(5)	qʘóu "wild cat"	q|àa "rub with hand"	q!ā̠ę "hunt"	q‖áã "thigh"	q‡âa "conceal"
(6)	ŋʘò̠õ "louse"	ŋ|āa "see you"	ŋ!āã "one's peer"	ŋ‖áã "grewia berry"	ŋ‡àa "peer into"
(7)	ŋ̊ʘâˀã "be close together"	ŋ̊|ûˀi "be careful"	ŋ̊!âˀm "evade an attack"	ŋ̊‖âˀm "be damp"	ŋ̊‡ûˀã "be out of reach"
(8)	ˀŋʘâje "tree"	ˀŋ|àa "to suit"	ˀŋ!à̠n "lie horizontal"	ˀŋ‖àhã "amount"	ˀŋ‡âũ "right side"
(9)	ŋ̊ʘʰòõ "smeared with dirt"	ŋ̊|ʰáa "look for spoor"	ŋ̊!ʰài "fall"	ŋ̊‖ʰáa "carry"	ŋ̊‡àã "ahead"
(10)	kʘˣóõ "walk slowly"	k|ˣâã "dance"	k!ˣáa "go a distance"	k‖ˣàa "scrape"	k‡ˣáa "mind out"
(11)	gʘkˣàna "make fire with sticks"	g|kˣáã "splatter water"	g!kˣàn "soften"	g‖kˣ áˀn "calf muscle"	g‡kˣáˀã "sneeze"
(12)	kʘ'q'óm "delicious"	k|'q'àa "hand"	k!'q'áa "spread out"	k‖'q'âã "grass"	k‡'q'àũ "neck"
(13)	gʘq'óõ "fly"	g|q'àã "chase"	g!q'áã "cry incessantly"	g‖q'áã "tumor"	g‡q'àa "ground to powder"
(14)	gʘhòõ "sp. bush"	g|hâa "stale meat"	g!hàa "thorns"	g‖hàã "bone arrow tip"	g‡háa "cut"
(15)	kʘˀòo "be stiff"	k|ˀ âa "die"	k!ˀáã "be seated" [pl.]	k‖ˀ àa "not to be"	k‡ˀāa "shoot you"
(16)	qʘ'ûm "close mouth"	q|'án "small" [pl.]	q!'àma "stickgrass"	q‖'úɲa "turn one's back"	q‡'àn "lay down" [pl.]
(17)	—	ɢ|hàô "put into"	ɢ!hâɲa "grey haired"	ɢ‖hâẽ "remove thorn with foot"	—

voiceless closures is the unavoidable sound of the wind in the trees. In order to get visually comparable waveforms we used representative utterances made by one speaker in a single recording. In one case (No. 8) this recording is somewhat atypical (judged simply on the basis of our listening to a large number of occurrences of this sound from many speakers), and we have supplemented Fig. 8 by another token reproduced in Fig. 9. With that exception, all the waveforms shown here are judged to be similar to those in other, less perfect, recordings, in which speakers coughed, sneezed and moved around, while cocks crowed and babies cried in the background. As we noted earlier, this kind of research cannot be easily quantified.

We should note here that Khoisan linguists are not agreed on the most appropriate way of symbolizing click accompaniments (Köhler, Ladefoged, Synman, Traill & Vossen, 1988). The symbols used in Table VI (and in all similar tables in this paper) are an attempt at a systematic approach in accordance with the principles of the International Phonetic Association (IPA, 1989). Every click involves a posterior closure, which is symbolized first, together with whatever voicing and nasality also occurs. It may be voiced or voiceless or murmured, oral or nasal, and velar or uvular. Accordingly, before each click symbol there must be another symbol; we have observed the following possibilities: [k, g, g̤, ŋ, ŋ̤, ŋ̊, ʔŋ, q, g]. The click itself is symbolized using the IPA (1989) approved symbols. Different releases of the posterior closure are noted when necessary by an additional symbol after the symbol for the click. Possibilities include aspiration [ʰ], affrication [ˣ], and a glottal release either in the form of a glottal stop [ˀ], or with a glottalic airstream mechanism forming an ejective [ʼ].

We have not yet discussed the first accompaniment listed in Table VI, a voiced velar plosive, because it does not occur in Nama or Xhosa. But it occurs in !Xóõ and in many other Khoisan languages. As may be seen from the waveform in the top row of Fig. 8, there is a noticeable period of voicing before the release of the click. As often happens in fully voiced velar stops, regular voicing for the vowel does not begin for 10–20 ms after the release of the accompanying velar closure. The click shown in line (2) of Fig. 8 has the voiceless unaspirated accompaniment; it is the same as the click in Nama which we have already discussed. This voiceless unaspirated click has a vowel onset very similar to that in the voiced click above it, but it has no voicing during the closure. The !Xóõ voiceless aspirated click in line (3) is also similar to that found in Nama. The duration of the aspiration is fairly extensive, well over 100 ms in this example.

The clicks in lines (4) and (5) have uvular accompaniments. In these clicks, the back of the tongue is in the uvular region at the time of release of the posterior closure. Clicks with this type of release are found in only a very few languages such as !Xóõ and ||Ani (Vossen, 1986). We have followed a convention of regarding a velar accompaniment as the unmarked case, and have usually referred to the clicks we have been considering as, e.g., voiced, rather than voiced velar. When there is a uvular accompaniment it will be specifically mentioned. The voiced uvular plosive accompaniment (4) and the voiceless unaspirated uvular plosive accompaniment (5) are the direct counterparts of the velar accompaniments (1) and (2). However, there is less voicing for the voiced uvular, and slightly more aspiration for the voiceless unaspirated uvular. The release of the uvular closure also occurs slightly later with reference to the release of the anterior click closure. Traill (1985:126) notes that the

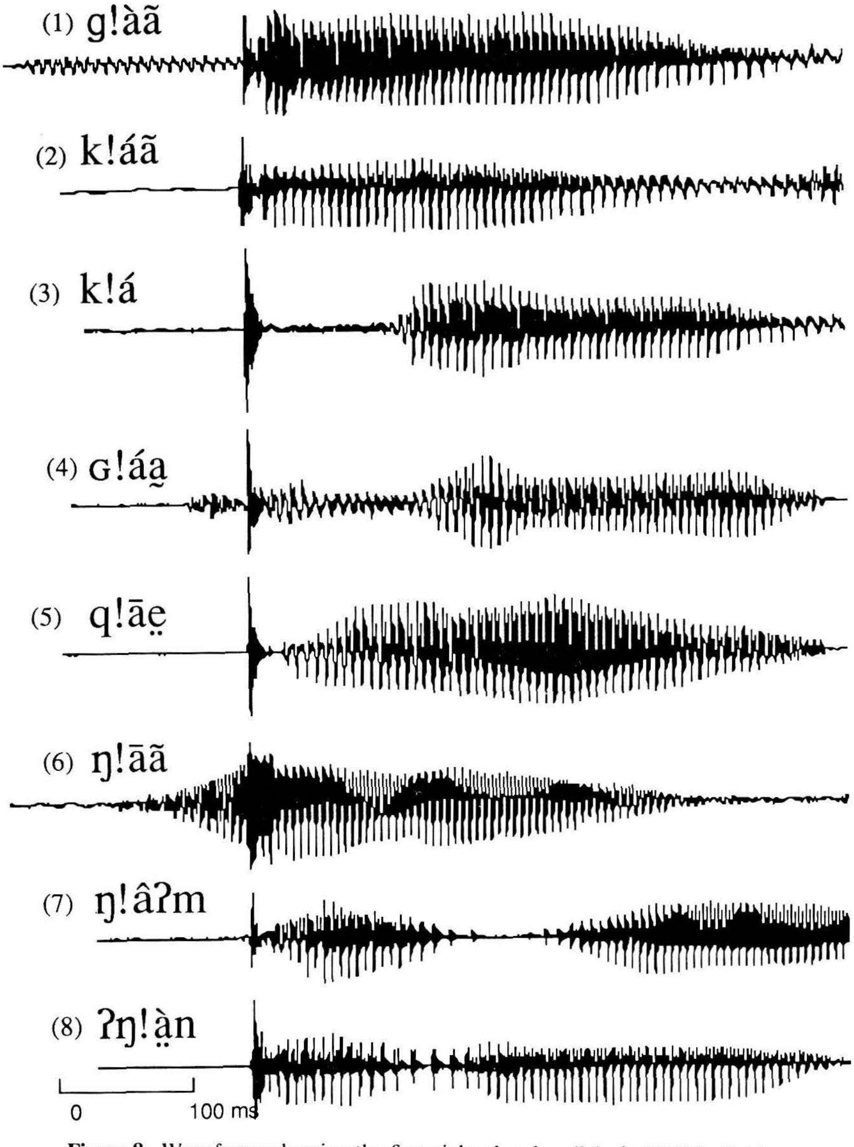


Figure 8. Waveforms showing the first eight alveolar clicks in !Xóõ in Table VI.

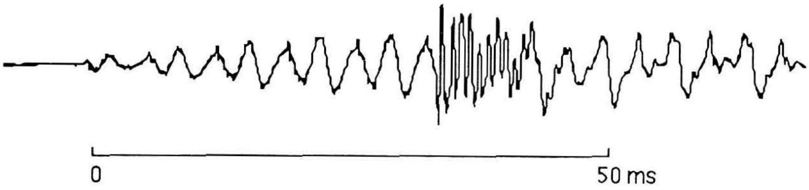


Figure 9. The waveform of a pre-glottalized nasal and the first few periods of the vowel in [ˀŋ!àn]. The time scale has been expanded so that the individual periods can be seen more easily.

velar release is so soon after the click that it is not audible, but the uvular release is a separate event. Perhaps because it is difficult to sustain voicing throughout a uvular stop, voiced-clicks of the form [ɢ!] are often prenasalized and might be transcribed as [ɴɢ!]. In some tokens, by the time of the release of the click there is no voicing, and it is not until about 30 ms later that vocal cord vibrations can be seen. Ladefoged & Traill (1984) transcribed clicks of this form as [ɴ!ɢ], noting, however, that the nasalization can be very short and that this click may be regarded as the voiced counterpart of [q!].

!Xóõ has the voiced velar nasal (in row 6) that we have discussed above in relation to Nama, and also two other nasal accompaniments in rows (7) and (8) in Fig. 8. Row (7) shows a voiceless velar nasal accompaniment in which there is a strong nasal airflow. Spectrograms show that in this sound the release of the anterior closure (the click) occurs towards the end of the voiceless nasal, about 20 ms before the voicing commences.

A glottalized nasal accompaniment is exemplified by the word in row (8). The preglottalized nasal is not evident in the particular token shown in Fig. 8. (As we have noted, all the examples in this figure are taken from a single recording of one speaker, resulting in this one not being as typical as we would have wished.) The glottalization can be seen in another token of the same word shown in Fig. 9. The preglottalized nasal is usually very short (about 50 ms) with the click burst occurring near the middle of the nasal. The irregularities in the first three or four glottal pulses are evident in the waveform in Fig. 9, which is shown on a slightly expanded scale. In this case the click occurs about 30 ms into the nasal, and the waveform for the vowel appears as soon as the high frequencies associated with the click can no longer be seen. The remaining click accompaniments in !Xóõ are shown in Fig. 10. Row (9) shows the voiceless velar nasal—the delayed aspiration—which is also found in Nama. In the delayed aspirated click, after the release of the anterior closure there is a long period of voicelessness (about 250 ms in the citation forms such as those in the figure), in the latter part of which weak aspiration may become more evident. Ladefoged & Traill (1984) note that the clicks with delayed aspiration in !Xóõ are very similar to those in Nama, but they could not hear a voiceless velar nasal in citation forms; it is also not visible on the waveforms or in spectrograms of these sounds. The !Xóõ sounds also differ from the corresponding sounds in Nama, in that the !Xóõ nasal remains voiceless even when the click is preceded by a vowel.

The puzzle of what goes on in the silent 250 ms after the click has now been explained by Traill (1991*b*). He has shown that the velum is lowered so that the pressure behind the velar closure can be vented through the nose. But, unlike the similar Nama sound, there may be no audible voiceless velar nasal because there is no egressive airflow. Instead of a passive venting of the pressure behind the velar closure, there is an active pulmonic ingressive airstream mechanism, drawing air inwards. This !Xóõ click is probably unique among the sounds of the world's languages in that, even in the middle of a sentence, it may have ingressive pulmonic airflow. [It has been claimed by Fuller (1990) that ingressive pulmonic phones occur in Tsou, but this claim has been disputed by Ladefoged (forthcoming).]

Row (10) illustrates the voiceless velar affricate accompaniment. This click contrasts with the voiceless aspirated click in row (3) of Fig. 8 in that the velar release is much more fricative. This can be demonstrated by data in which there are accompanying records of the pressure of the air in the pharynx. These records were made in the

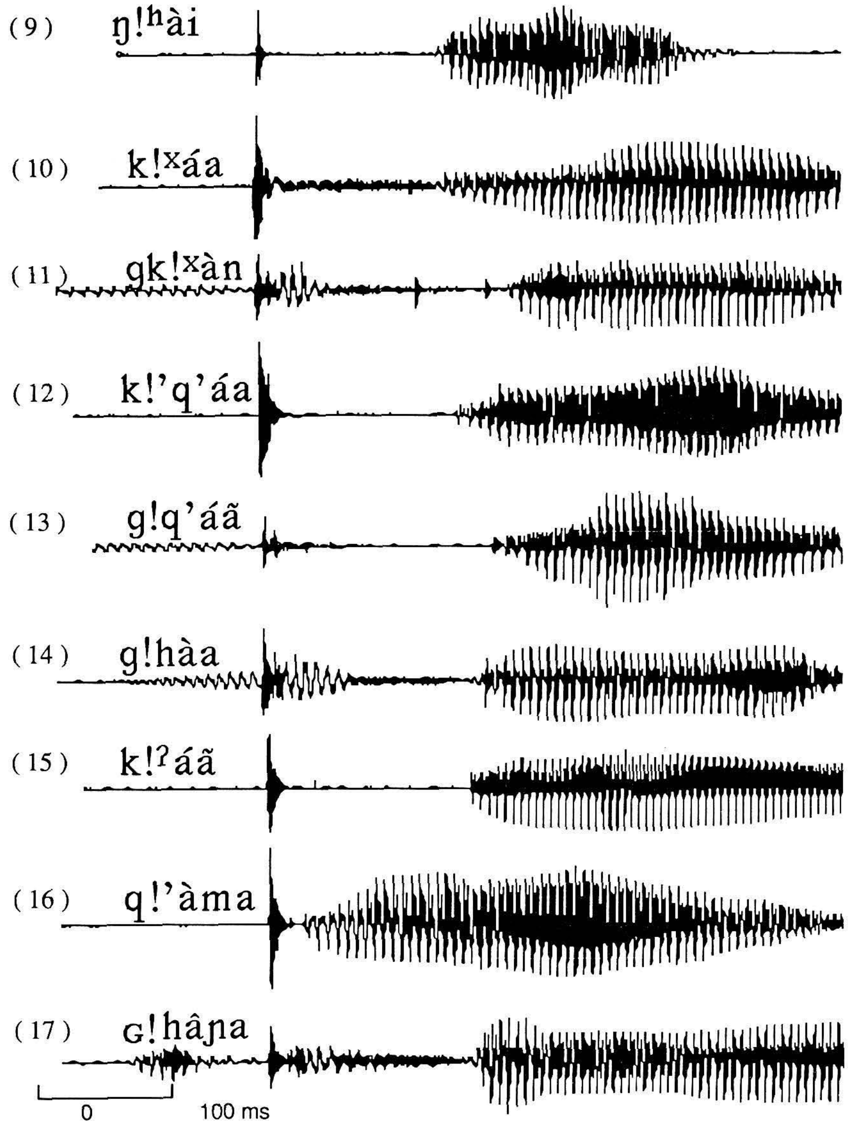


Figure 10. Waveforms showing the last nine alveolar clicks in !Xóõ in Table VI.

Kalahari Desert, using techniques described by Ladefoged & Traill (1984), except that the pressure signal has been demodulated so as to produce data as in Fig. 11. It may be seen that in the accompaniment with a fricative constriction, the pressure behind the posterior closure may remain comparatively high for more than 140 ms after the click.

As argued by Traill (1992*a*), the clicks in the next few rows are best regarded as sequences of consonants. The click in row (11) has voicing during the closure and for two or three periods after the release of the click. Other tokens of this click are more like those in Fig. 12, which shows a dental click which can be transcribed as

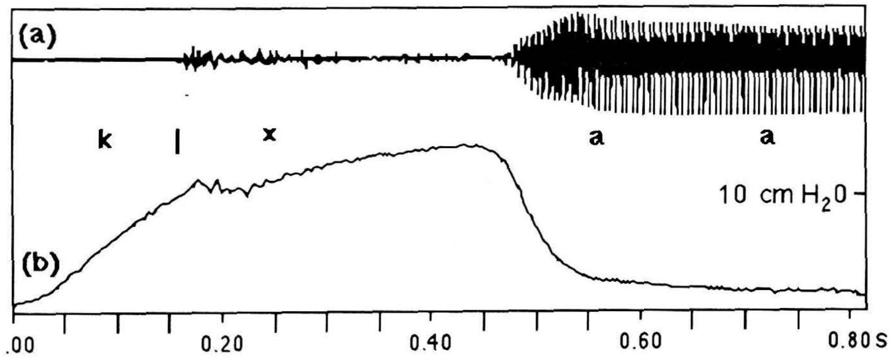


Figure 11. Audio (a) and pharyngeal pressure (b) in a dental click with a voiceless velar affricate accompaniment.

[g|kx]. Both in the dental click in Fig. 12 and in the corresponding alveolar click [g!kx] in Fig. 10 there is ample evidence of friction. After the release of the click there is a considerable pressure build up during [k], followed by a fricative portion [x]. Clicks such as those in row (11) are sequences involving a voiced click with an accompaniment as in row (1), followed by a voiceless velar affricate. Sometimes the velar closure is not maintained after the anterior click release, and there is a click with a voiced (velar) accompaniment, followed by a voiceless velar fricative, so that the sequence is [g̥x] rather than [g|kx].

The click in row (12) is even more complex. In this particular dialect of !Xóõ, it consists of a voiceless velar ejective released just after the release of the click, followed by the immediate formation of a uvular closure for an ejective that is released just before the vowel. This sequence can be more easily understood by reference to the dental example in Fig. 13. As can be seen, the pressure builds up towards the end of the closure for the click with an increasing rate in a way that is typical of a glottalic rather than a plumonic airstream mechanism. Then the releases of the click and of the velar closure occur in close succession. They are followed by the immediate formation of another closure and a continued glottalic airstream mechanism, this time for a uvular ejective.

Row (13) illustrates the voiced counterpart of this sequence. It consists of a voiced click followed by a uvular ejective. Similar articulations occur in the dental click

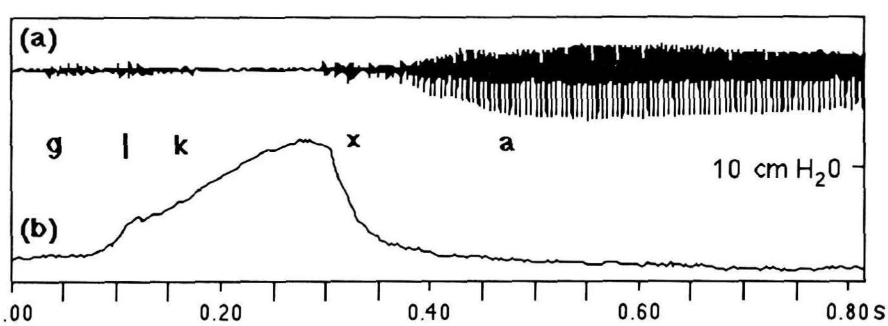


Figure 12. Audio (a) and pharyngeal pressure (b) in a voiced dental click followed by a voiceless velar affricate.

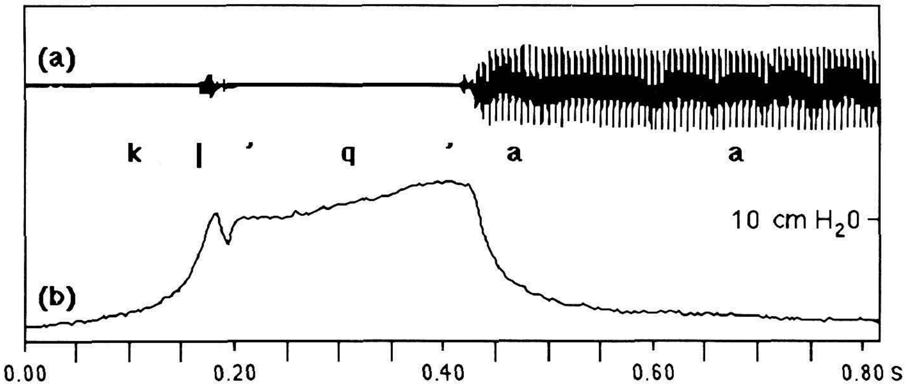


Figure 13. Audio (a) and pharyngeal pressure (b) in a voiceless dental click with an ejective accompaniment, followed by a uvular ejective.

[g|q’] shown in Fig. 14. During the click closure there is very little build up of pharyngeal pressure (as is normal in a voiced click), but afterwards there is a large increase in the pharyngeal pressure, which goes up to 20 cm H_2O. The uvular ejective is released immediately before the onset of the vowel. The timing of the articulations of clicks of types (13) and (12) makes it quite clear that these are sequences of a voiced or a voiceless click followed by a uvular ejective rather than unitary segments. This notion is further supported by the fact that !Xóõ has a uvular ejective in its consonant inventory making these sequences more plausible. A similar point has been made recently by Traill (1992*b*) on phonological as well as phonetic grounds.

The accompaniments in both rows (12) and (13) are pronounced with more velar friction in other dialects of !Xóõ. Instead of the sequence of two ejectives [k|’q’] illustrated in Fig. 14, there is a single ejective affricate with a less uvular quality, more appropriately transcribed as [k!^{x}’]; and instead of the prevoiced version [g|q’], there is a sequence that could be transcribed [gk!^{x}’]. These more affricated dialectal pronunciations correspond to the standard pronunciation in Zhu|hõasi, as will be illustrated later.

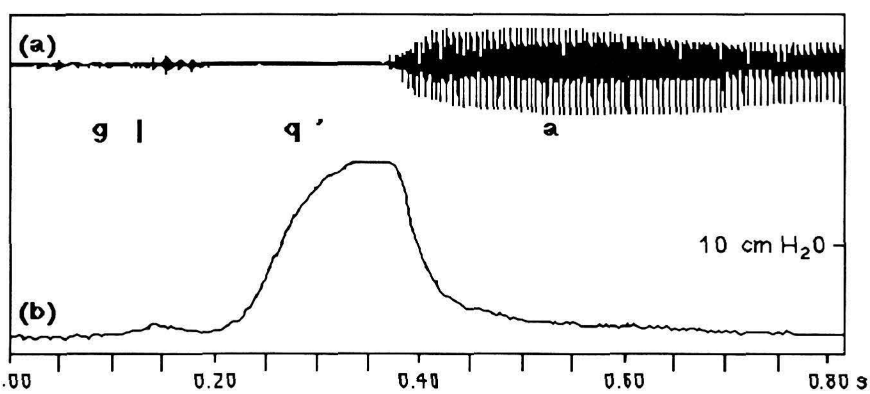


Figure 14. Audio (a) and pharyngeal pressure (b) in a voiced dental click followed by a uvular ejective.

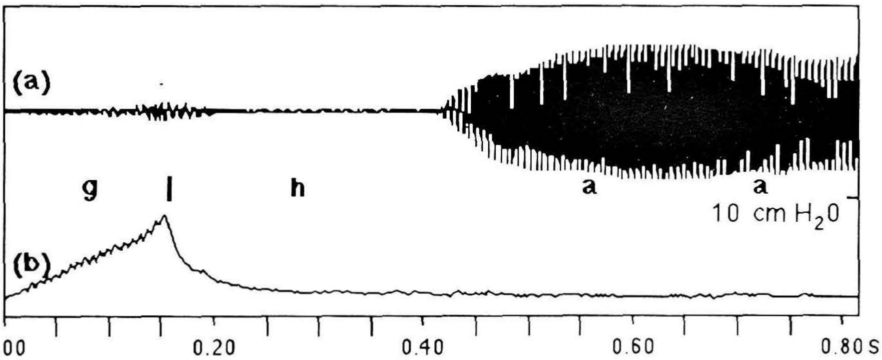


Figure 15. Audio (a) and pharyngeal pressure (b) in a voiced dental click followed by aspiration.

Row (14) in Fig. 11 illustrates the click [g!h]. In this alveolar click there is voicing throughout the closure, and for a few periods after the release of the click. It is this continuation of the voicing that prevents a salient voiced velar release. Pharyngeal pressure records of a dental click of this kind are shown in Fig. 15. Again the voicing is apparent right through the closure. After the click the pharyngeal pressure drops rapidly, and there is little evidence of friction during the interval before the voicing for the vowel begins. There seems to be some variability in the way that this sound is produced. Traill (1985:148) regarded it as a voiced click accompanied by delayed aspiration, but it now appears that the aspiration may have the more rapid acceleration found with [k|^h], rather than the more slowly rising aspiration that occurs in delayed aspiration. Trail also notes that he did not have any evidence of nasal venting. We will consider clicks of this type as generally sequences, involving a voiced click of type (1), followed by aspiration, as shown by the sequence of symbols [g|] and [h]. But on occasions when the voicing ceases before the release of the click, the conditions will be right for a voiceless velar aspirated release, and we may regard it as a sequence of the form [gk|^h].

Row (15) illustrates the click with an accompanying glottal stop in !Xóõ. As we have seen, there is a similar click in Nama. The glottal closure is formed during the velar closure for the click, and is released considerably later. The velar release is not audible, as it occurs during the glottal closure, without any pressure build up. Our pharyngeal pressure records for both Nama and !Xóõ show that the air pressure in the pharynx does not increase during clicks of the type shown in (15), so this is not an ejective accompaniment. As the example in Fig. 10 shows, the delay before the onset of voicing is very similar to that in (9), the delayed aspiration, but the onset of the following vowel is different. The VOT is also very similar in (10), the voiceless velar affricated click, [k!^{k}], in which the interval between the release of the posterior closure and the vowel is accompanied by considerable velar friction.

The click in (16) is the uvular counterpart to (15), the voiceless velar plus glottal stop; but whereas the velar plus glottal stop does not involve an upward movement of the larynx, in the case of the uvular plus glottal stop accompaniment there is an upward movement of the larynx, making this an ejective accompaniment. As can be seen in Fig. 16, which shows a comparable dental click, the uvular plus glottal closure accompaniment has an increase in the pharyngeal pressure both during and,

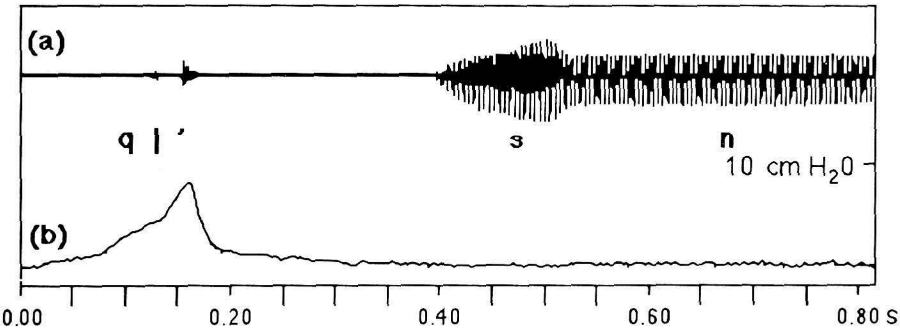


Figure 16. Audio (a) and pharyngeal pressure (b) in a dental click with a uvular ejective accompaniment.

more sharply, after the release of the anterior click closure. There is a noticeable burst when the uvular closure is released about 15–20 ms after the release of the click, which is perceptible as a separate event. In the case of the dental click in Fig. 16, the ejective release is followed by a period of comparable length to the VOT in (15) before the glottal stop is released and voicing commences. The token illustrated in Fig. 10 has a far shorter VOT.

The final row in Table VI and Fig. 10 is the uvular counterpart to (14); it consists of a voiced uvular plosive accompaniment, followed by aspiration. As can be seen in Table VI, only three of the five clicks have been found with this possibility. The voicing during the click closure ceases just before the release of the anterior closure. It is followed by strong voiceless aspiration which may have accompanying velar friction.

Zhu|hõasi, which is a dialect of !Xũ, is another Khoisan language for which there is a considerable amount of published data (Snyman, 1970, 1975, 1978, 1980). In this paper we will use data from our own field recordings, which are comparable to those we have for !Xóõ. This language has a slightly smaller number of clicks than !Xóõ. It does not have bilabial clicks, and also has fewer click accompaniments. Examples of contrasts involving the alveolar click are shown in Table VII and in Figs 17 and 18.

Most of the clicks illustrated in Fig. 17 are similar to those in !Xóõ, and need little further discussion. The main differences are in VOT, with the Zhu|hõasi examples having more voicing and less aspiration. In addition, unlike the situation in !Xóõ, the VOT is much greater for the delayed aspiration in (5) than it is for either the aspirated click in (3) or the glottal stop accompaniment in (6). We do not know if these differences in timing reflect real differences between the two languages or if they are simply due to a difference in the rate of speech or to the particular speakers that were recorded on the different occasions.

Figure 18 shows the remaining Zhu|hõasi clicks in Table VII. Again they are largely similar to the corresponding clicks in !Xóõ, except for differences in timing, which may be due to the individual circumstances of the recordings. However, this is not always the case. In (7) there is a click in Zhu|hõasi that we transcribe as [g!ˠ]. There is a similar click in !Xóõ in (11) of Fig. 10; we transcribed the !Xóõ click as [g|ˣ], a voiced click followed by a voiceless velar affricate, noting at the time that there may be no velar closure after the antierior closure has been released, so that

TABLE VII. Contrasting alveolar clicks in Zhu|hõasi. Tones are transcribed [à] low, [ā] mid and [á] high. Zhu|hõasi also has an extra high tone which does not occur in these examples

(1)	g!à	"rain"
(2)	k!ábí	"roll up a blanket"
(3)	k!^{h}ání	"palm tree"
(4)	ŋ!àmà	"road"
(5)	ŋ̊!^{h}ānà	"walking stick"
(6)	k̊!ʔàbú	"rifle"
(7)	g!^{ɣ}àré	"cut open an animal"
(8)	k!^{x}árá	"cough up from throat"
(9)	k!^{x}'àm	"tighten a bow string"
(10)	g!hání	"tie"
(11)	gk!^{x}'àrú	"leopard"
(12)	ŋŋ̥!^{h}àm	"spider"

this may be [g!k^{x}] or [g!x]. In Zhu|hõasi this click is not only always fricative, but is also usually (but not always) voiced throughout. We do not know of any language that contrasts the !Xóõ clicks [g!k^{x}] or [g!x] with the typical Zhu|hõasi click [g!^{ɣ}], although one might be considered a sequence of a voiced click followed by a voiceless velar affricate or fricative, and the other a voiced click with a velar frictive accompaniment. Another difference between the dialect of !Xóõ represented in Fig. 10 and Zhu|hõasi is that the former has clicks such as [k!'q'] and [g!q'], whereas Zhu|hõasi has clicks such as [k!x'] and [g!kx'], illustrated in rows (9) and (11) in Fig. 18. We noted above that in other dialects of !Xóõ the clicks [k!x'] and [g!kx'] occurred instead of [k!'q'] and [g!q']. No language that we know of contrasts clicks of the form [k!'q'] and [k!kx'] or the voiced counterparts [g!q'] and [g!kx']. We should also note a sequence that does not occur in !Xóõ, but does occur in Zhu|hõasi, as exemplified in (12), a voiced velar nasal and voiceless aspirated velar nasal. This is another example of the complex voicing clusters that occur in these languages.

We are now in a position to try to summarize the complete range of click accompaniments. The number of possible accompaniments is fairly considerable, as can be seen from Table VIII, which lists symbols and a short description for 23 accompaniments, together with one or more languages in which each occurs. As we have noted, some of these accompaniments might be better regarded as involving sequences of consonants. Khoisan languages have no constraint forbidding voiced and voiceless sequences of obstruents within a single cluster. All these sequences are included here so as to give a more complete overview of possible sounds involving clicks.

There are problems in trying to draw up a list such as that in Table VIII, in that it is not easy to say when two sounds in different languages should be regarded as phonetically the same. This is an issue that has plagued phoneticians for many years. It is at the heart of the IPA's difficulty in trying to decide which symbols need to be represented on its chart (Ladefoged, 1990). If two sounds contrast phonologically in a single language, of course they must have distinct phonetic qualities. But if two seemingly different sounds never occur in the same language, how can one decide whether they are indeed different?

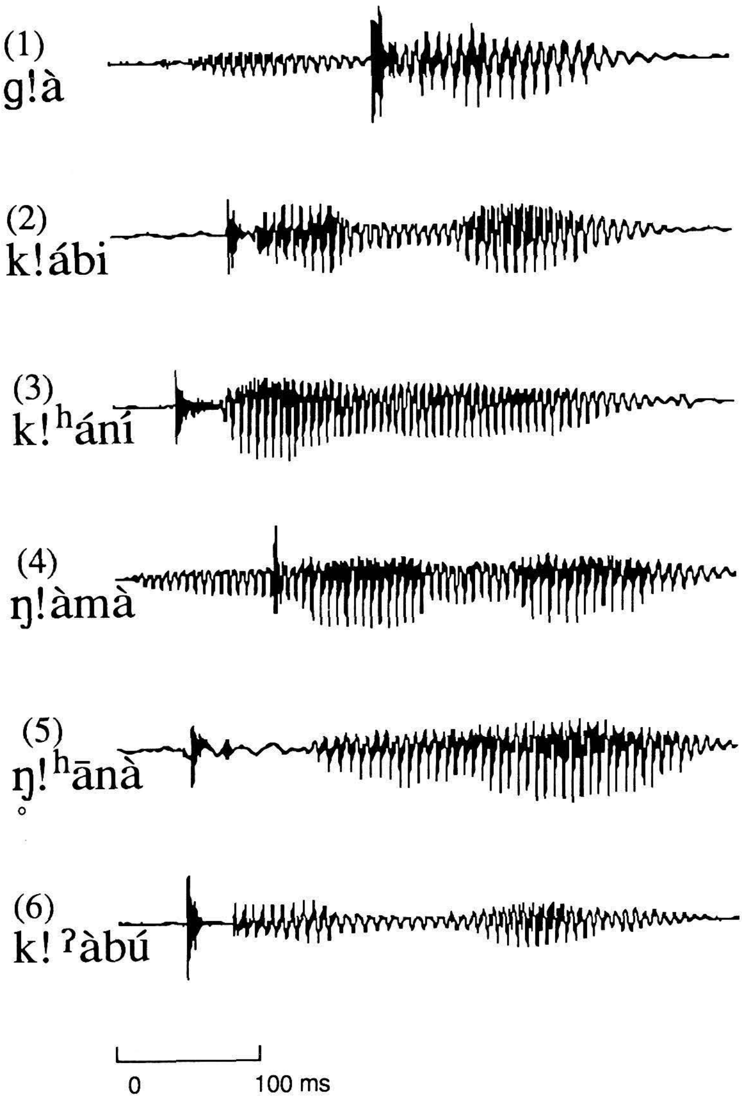


Figure 17. Waveforms of the first six Zhu|hõasi alveolar clicks in Table VII.

The first six items in Table VIII present no problems in this respect, but it is worth considering why phoneticians have no difficulty in recognizing that there are six different sounds although they do not all contrast in a single language. The first four are all contrastive in two of our exemplifying languages, !Xóõ and Zhu|hõasi. The fifth and sixth, the clicks with murmured plosive and murmured nasal accompaniments, occur only in Nguni languages, here exemplified by Xhosa. As we noted earlier, the description of these sounds as being murmured is largely a phonological designation of them as being tone depressors (Traill *et al.*, 1987). Accordingly, the murmured velar plosive accompaniment might be considered as simply the Nguni variant of the voiced velar plosive accompaniment, as these

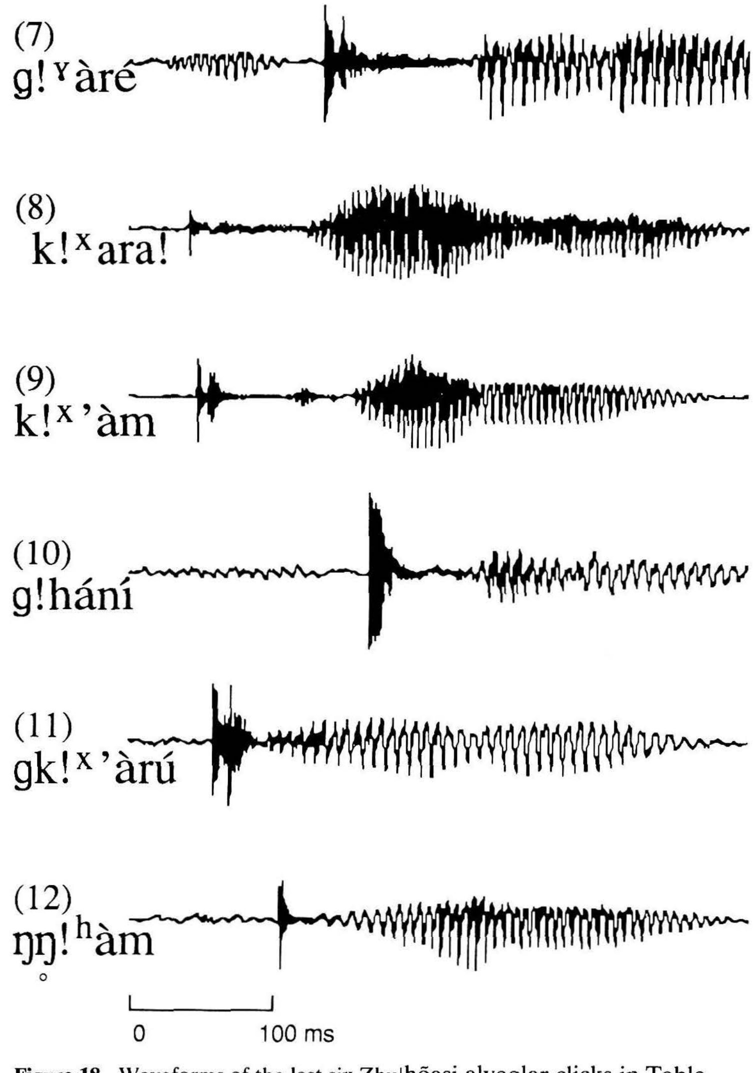


Figure 18. Waveforms of the last six Zhu|hõasi alveolar clicks in Table VII.

languages do not have this possibility. But there are two points against this interpretation. Firstly, this solution is not available in the case of the murmured velar nasal accompaniment, as there is a contrasting voiced velar nasal accompaniment in these languages. This makes it evident that a murmured accompaniment has to be recognized as distinctive for some clicks. Secondly, these languages also contrast voiced velar plosives and murmured velar plosives in the non-click consonant series. This also makes it plausible to consider the voiced velar plosive accompaniment and the murmured velar plosive accompaniment as potentially contrastive. It seems as if the first six accompaniments are all potentially contrastive and therefore they must be considered as phonetically distinct sounds.

A different problem arises in the case of the seventh item, the delayed aspiration accompaniment. There is instrumental evidence showing that these sounds differ in

TABLE VIII. A systematic representation of clicks and their accompaniments, here shown with the alveolar click [!]. In other clicks the symbol [!] would be replaced by one of the symbols [ʘ, |, ||, ǂ]. The example languages are chosen from Xhosa, Nama, !Xóõ, and Zhu|hõasi (a dialect of !Xũ)

Symbol	Description	Example languages
	Alveolar click plus:	
(1) g!	Voiced velar plosive	!Xóõ, Zhu|hõasi
(2) k!	Voiceless unaspirated velar plosive	all four
(3) k!^{h}	Aspirated velar plosive	all four
(4) ŋ!	Voiced velar nasal	all four
(5) g̤!	Murmured velar plosive	Xhosa
(6) ŋ̤!	Murmured velar nasal	Xhosa
(7) ŋ̊!^{h}	Voiceless aspirated velar nasal (delayed aspirated)	Nama,!Xóõ, Zhu|hõasi
(8) k̊!ˀ	Voiceless velar plosive and glottal stop	Nama,!Xóõ, Zhu|hõasi
(9) k!^{x}	Voiceless affricated velar plosive	!Xóõ, Zhu|hõasi
(10) g!h	Voiced velar plosive followed by aspiration	!Xóõ, Zhu|hõasi
(11) gk!^{x}	Voiced velar plosive followed by voiceless velar fricative	!Xóõ, Zhu|hõasi
(12) k!^{x}'	Affricated velar ejective	Zhu|hõasi
(13) g!k^{x}'	Voiced velar plosive followed by voiceless affricated ejective	Zhu|hõasi
(14) ŋŋ̊!^{h}	Voiced velar nasal followed by voiceless aspirated velar nasal	Zhu|hõasi
(15) ŋ̊!	Voiceless velar nasal	!Xóõ
(16) ˀŋ!	Preglottalized velar nasal	!Xóõ
(17) ɢ!	Voiced (optionally pre-nasalized) uvular plosive	!Xóõ
(18) q!	Voiceless unaspirated uvular plosive	!Xóõ
(19) k!'q'	Voiceless velar ejective, followed by uvular ejective	!Xóõ
(20) g!q'	Voiced velar plosive, followed by uvular ejective	!Xóõ
(21) ɢ!h	Voiced uvular plosive, followed by aspiration	!Xóõ

Nama and !Xóõ. Ladefoged & Traill (1984) showed that in Nama there is a voiceless velar nasal with a plumonic egressive airstream. Traill (1991*b*) showed that in !Xóõ there is also a voiceless velar nasal, but an ingressive plumonic airstream. Moreover, these differences have phonological implications, in that the Nama delayed aspirated clicks give rise to an inserted voiced velar nasal when they occur intervocalically, but the !Xóõ sounds do not. Nevertheless, we have decided to regard these two click accompaniments as being phonetically the same at some classificatory phonetic level, on the grounds that no language could use the difference between them to form phonological contrasts. Considering the amazing (to our ears) small contrasts that languages do use, this is an act of faith on our part. And we would be happy to be proved wrong.

Items (7) through (14) all occur in Zhu|hõasi as contrasting sounds, and are plainly phonetically distinct (at least to speakers of Zhu|hõasi). Similarly items (15) through (21) all occur in !Xóõ. The only question is whether any of those listed as occurring in !Xóõ but not in Zhu|hõasi could in fact be identified with any of the Zhu|hõasi items. We have already discussed some cases in which this can be done. Items (12) and (13) in Zhu|hõasi, [k!^{x}'] and [gk!^{x}'], are comparable with items (19) and (20) in !Xóõ, [k!'q'] and [g!q'], in the sense that the Zhu|hõasi forms occur in !Xóõ as dialectal variants of the forms listed for !Xóõ. Another pair of items that are fairly similar are (14), [ŋŋ̊!ʰ], the voiced velar nasal followed by a voiceless aspirated velar nasal in Zhu|hõasi, and (15) [ŋ̊!], the voiceless velar nasal, in !Xóõ. There are no strong arguments for regarding these non-contrasting sounds as distinct at a phonetic classificatory level. But, just as we held in the case of the different delayed aspirate accompaniments that they were not likely to be used contrastively, so we simply offer it as our opinion that the opposite is true in these cases: these pairs of sounds are sufficiently distinct to justify classifying them as different phonetic items that are potentially contrastive.

The other items, (16) through (21), that occur in !Xóõ, have no counterparts in Zhu|hõasi. The pre-glottalized velar nasal accompaniment does not occur outside !Xóõ; and Zhu|hõasi also lacks all the contrastive uvular accompaniments.

Table VIII shows that if we include possible sequences involving more than one segment, then there might be $5 \times 21 = 105$ ways of beginning a word with a click. As we have seen in Table VI, 83 of these actually occur as phonologically contrastive items in !Xóõ. If we consider items (10, 11, 13, 14, 19, 20, 21) to be sequences, then there are still $14 \times 5 = 70$ phonetically distinct click segments, 55 of which occur in !Xóõ. Some of these are complex articulations; but many are simple sounds, that are fairly easy to produce. Almost any child can, and probably does, make bilabial, dental and lateral clicks as extralinguistic noises. Nor have we found any real difficulty in teaching students to integrate these sounds into syllables. In our experience, most clicks are much easier to teach people to make than ejectives or implosives. Considering also their perceptual salience, it might seem as if they should be highly favored consonants in the world's languages. Their desirability is evidenced by the fact that they were readily borrowed from Khoisan into the neighboring Nguni languages. They were incorporated into these languages through a process of pidginization and language shift, but their ready acceptance and retention was no doubt facilitated by their phonetic qualities. Indeed, we cannot explain why these easy to make and perceptually optimal consonants are found in so few languages. It is only the addition of diverse complex accompaniments that provides real phonetic challenge. !Xóõ words such as [ŋ̊!ʰài], "fall", with a voiceless pulmonic ingressive nasal, and complex sequences of clicks and ejectives such as that in [k||'q'âã], "grass" are among the most difficult articulations that we know of in common words in the world's languages. But most people can easily learn to say simple words such as [k|àa], "move off".

Finally, it is worth considering the limits of the list that we have given in Table VIII. When we consider the wide variety of click accompaniments that do occur, then a number of other possibilities must be considered as just accidental gaps that might have occurred but are not attested. Combinations using additional phonation types would be possible. We should also consider other airstream mechanisms that might be used. It is comparatively easy to produce a voiced velar implosive while producing a click. In fact, it is probably easier for most non-Khoisan phoneticians to say [ɠ!a] than it is to say [g!q'a]. But implosives never occur as click accompaniments. We must constantly remember that although the world's languages contain, from our ethnocentric point of view, many unusual sounds, there are many other possible sounds that have not been found—yet. And who knows what happened 10 000 years ago, or will happen will happen 10 000 years or hence?

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References

Beach, D. M. (1938) *The phonetics of the Hottentot language*. Cambridge: W. Heffer & Sons Ltd.

Bleek, W. H. I. & Lloyd, L. C. [1911 (republished 1968)] *Specimens of Bushmen folklore*. Capetown: C. Struik.

Dart, S. (1991) Articulatory and Acoustic Properties of Apical and Laminal Articulations, *UCLA Working Papers in Phonetics*, **79**, 1–155.

Doke, C. M. (1925) The phonetics of ꞔũ Bushman, *Bantu Studies*, **2**, 129–165.

Doke, C. M. (1937) An outline of ǂKhomani Bushman phonetics. In *Bushmen of the Southern Kalahari* (J. D. Rheinallt Jones & C. M. Doke, editors.), pp. 61–68. Johannesburg: University of the Witwatersrand Press.

Fuller, J. M. (1990) Pulmonic ingressive fricatives in Tsou, *Journal of the International Phonetic Association*, **20**, 9–14.

Hale, K. & Nash, D. (1987) Lardil and Damin phonotactics, *Australian Linguistics Society*.

International Phonetic Association (1989) Report on the 1989 Kiel Convention, *Journal of the International Phonetic Association*, **19**, 67–80.

Jakobson, R. (1968) Extra-pulmonic consonants (ejectives, implosives, clicks), *RLE Quarterly Progress Report, MIT*, **90**, 221–227.

Jakobson, R., Fant, C. G. M. & Halle, M. [1951 (reprinted 1969)] *Preliminaries to speech analysis: the distinctive features and their correlates*. Cambridge, MA: MIT Press.

Johnson, K. (1990) Contrast and normalization in vowel perception, *Journal of Phonetics*, **18**, 229–254.

Kagaya, R. (1978) Sound spectrographic analysis of Naron clicks: A preliminary report, *Annual Bulletin of the Research Institute of Logopedics and Phoniatrics, Faculty of Medicine, University of Tokyo*, **12**, 113–125.

Köhler, O. (1981) La langue !Xũ. In *Les Langues Khoisan* (G. Manessy, editor). Paris: Centre de la Recherche Scientifique.

Köhler, O., Ladefoged, P., Synman, J., Traill, A. & Vossen, R. (1988) The symbols for clicks, *Journal of the International Phonetic Association*, **18**, 140–142.

Ladefoged, P. (1990) Some reflections on the IPA, *Journal of Phonetics* **18**, 335–346.

Ladefoged, P. (forthcoming) Pulmonic ingressive fricatives do NOT occur in Tsou, *Journal of the International Phonetic Association*, **23**.

Ladefoged, P. (1993) *A course in phonetics*. Orlando: Harcourt Brace Jovanovich.

Ladefoged, P. & Traill, A. (1984) Linguistic phonetic description of clicks, *Language*, **60**, 1–20.

Lanham, L. W. (1964) Bantu phonemic systems. In *Proceedings of the Ninth International Congress of Linguists*. The Hague: Mouton.

Louw, J. A. (1977) Clicks as loans in Xhosa. In *Bushman and Hottentot Linguistic Studies* 1975 (*papers of a seminar held on 25 October 1975*) (J. W. Synman, editor). Pretoria: University of South Africa, Department of Bantu Languages.

Maddieson, I. (1984) *Patterns of sounds*. Cambridge: Cambridge University Press.

Maddieson, I., Ladefoged, P. & Sands, B. (1992) East African click languages. Paper presented at the 23rd African Languages Conference (in press).

Sagey, E. (1986) The representation of features and relations in nonlinear phonology. Ph.D dissertation, MIT.

Sands, B. (1991) Evidence for click features: acoustic characteristics of Xhosa clicks, *UCLA Working Papers in Phonetics*, **80**, 6–37.

Snyman, J. W. (1970) *An introduction to the !Xũ language*. Cape Town: Balkema.

Synman, J. W. (1975) *Zu|'hoasi fonologie en woordeboek*. Cape Town: Balkema.

Snyman, J. (1978) The clicks of Zhu|hõasi. *Second Africa Languages Congress of UNISA*. Pretoria: University of South Africa.

Snyman, J. W. (1980) The relationship between Angolan !Xũ and Zu|'õasi. *Bushman and Hottentot Linguistic Studies* 1979. Pretoria: UNISA.

Taljaard, P. O. & Snyman, J. W. (1990) *An introduction to Zulu phonetics*. Hout Bay: M. Lubbe.

Traill, A. (1985) *Phonetic and phonological Studies of !Xóõ Bushman*. Quellen zur Khoisan-Forschung, 1. Hamburg: Helmut Buske.

Traill, A. (1991*a*) A confusion of sound: the phonetic description of !Xu clicks. In *Festschrift for E.O.J. Westphal.* (D. Gowlett, editor), Pretoria: Via Afrika.
Traill, A. (1991*b*) 'Pulmonic control, nasal venting and aspiration in Khoisan languages', *Journal of the International Phonetic Association,* **21**, 13–18.
Traill, A. (1992*a*) The feature geometry of clicks. In *Festschrift for E.B. van Wyk.* (P. von Staden, editor). Pretoria: Via Afrika.
Traill, A. (1992*b*) Place of articulation features for clicks: anomalies for universals. In *In Honour of J. D. O'Connor* (J. Windsor Lewis, editor). London: Pergamon Press.
Traill, A. (1992*c*). The perception of clicks in !Xóõ. Paper presented at the 23rd African Languages Conference.
Traill, A. (in press) *A Dictionary of !Xóõ.* Köln: Rüdiger Köppe Verlag.
Traill, A. (forthcoming) Perceptual features of clicks.
Traill, A., Khumalo, J. S. M. & Fridjhon, P. (1987) Depressing facts about Zulu, *African Studies,* **46**, 255–274.
Vossen, R. (1986). Zur phonologie der ||Ani-Sprache. In *Contemporary Studies on Khoisan.* (*Quellen zur Khoisan-Forschung,* 5) (R. Vossen & K. Keuthmann, editors), pp. 321–345. Hamburg: Helmut Buske.