Explosives, Implosives, and Nonexplosives: the Linguistic Function of Air Pressure Differences in Stops

George N. Clements
CNRS, Paris
clements@idf.ext.jussieu.fr

Sylvester Osu
LLACAN-CNRS, Villejuif
sylvester.osu@wanadoo.fr

In Carlos Gussenhoven & Natasha Warner (eds.), *Laboratory Phonology 7*, pp. 299-350.
Berlin: Mouton de Gruyter, 2002.

Abstract

Nonexplosive stops, including implosives and other stops regularly lacking an explosive release burst, occur in roughly 20% of the world's languages, yet their phonological and phonetic properties are still poorly understood. This paper seeks to determine the phonological feature that characterizes this class of sounds. The classical definition of implosives in terms of the ingressive glottalic airstream mechanism raises a number of problems and does not generalize to other types of nonexplosives. It is proposed here instead that the feature underlying the class of nonexplosive stops as a whole is nonobstruence, defined as the absence of positive oral air pressure during occlusion. This definition is shown to extend to a previously undocumented type of nonexplosive stop found in Ikwere, a Niger-Congo language spoken in Nigeria. In this language, the phonemically contrastive nonexplosive bilabial stops [ḅ ’ḅ], though resembling implosives in certain respects, are produced with no lowering of the larynx, nor in the case of [ḅ], any implosion at release. A study of the acoustic, articulatory and aerodynamic properties of these sounds shows that they satisfy the definition of non-obstruent stops. It is finally suggested that apparently contradictory aspects of the phonological patterning of nonexplosive stops across languages can be explained if they are viewed as both nonobstruents and nonsonorants. In this view, phonological feature theory requires both articulatory features such as [±obstruent] and acoustic features such as [±sonorant].

1. Nonexplosive stops

Beside the familiar explosive stops found in all languages, many languages make use of a class of sounds that we shall refer to as *nonexplosive stops*. This class of sounds, defined by their characteristic lack of explosion at release, includes implosives and several related types of stops, as discussed below. Sounds of this class are not uncommon. Implosive, laryngealized or glottalized stops are found in about 20% of the world's languages (Maddieson 1992), and their virtual absence in Indo-European languages must be regarded as an "exotic" feature of this group. But in spite of their frequency, they are still not well understood. Questions for which clear-cut answers are still unavailable include the following:

1. *How many types of nonexplosive stops can be distinguished phonetically?* Linguists have distinguished several types of nonexplosive stops, including voiced and voiceless implosives, laryngealized stops, glottalized and preglottalized stops, and certain varieties of "lenis" and labial-velar stops.[1] However, these stops have been relatively little studied instrumentally, and it can be extremely difficult to determine exactly what is meant by these labels in a given description, or where the dividing line between one category and another is to be drawn.

2. *How many of these sounds contrast with each other phonologically?* Greenberg (1970), extending earlier observations by Haudricourt (1950) and Ladefoged (1967), stated that no language known to him offered two or more phonemic contrasts among implosive, preglottalized and laryngealized stops. Subsequently, several African languages have been found to have phonemic contrasts between voiced implosives and what are often termed voiceless implosives, produced with complete glottal closure (see §3.2). To our knowledge, however, no further phonation type contrasts within this class have been reported.

3. *How do these sounds pattern phonologically?* Relatively little cross-linguistic research has been carried out on this question, and most of what has been done concerns voiced implosives. There is good evidence that implosives constitute a natural class distinct from explosives, but there is little current agreement on how implosives and other non-explosive stops pattern with other sounds.

4. *What is their feature analysis?* Consistently with the disagreement concerning phonological patterning, there are competing views as to how implosives and related sounds should be characterized in terms of phonological features. Some linguists have treated implosives as obstruents, others as sonorants, others as neither obstruents nor sonorants, and still others as obstruents in some languages and sonorants in others.

In sum, nonexplosive stops constitute a poorly-understood area of phonetics and phonology in which there is need for new research.

The main objective of this paper will be to define and motivate the class of nonexplosive stops as a phonological category. It will be proposed, following earlier suggestions by Stewart (1989) and Creissels (1994), that the feature which underlies implosives and other nonexplosive stops is *nonobstruence*, defined as the absence of positive oral air pressure during occlusion. Other criteria for defining this class will be shown to be less satisfactory.

The remaining discussion proceeds as follows. Section 2 reviews the classical characterization of implosives in terms of airstream mechanisms, and discusses several respects in which the proposed diagnostics have proven inadequate in the light of more recent research. Section 3 argues that implosives are better characterized in terms of the feature *nonobstruent*, defined by the absence of air pressure buildup in the oral cavity[2] during occlusion, and shows that other types of nonexplosive stops fall under this definition as well. Section 4 documents a previously unreported type of nonexplosive stop found in Ikwere, a Niger-Congo language spoken in Nigeria. Ikwere has a pair of phonemically contrastive nonexplosive stops which, though similar to implosives in many respects, are produced with no lowering of the larynx. An examination of their phonetic properties shows that these stops, though not implosive in the classical sense of this term, satisfy the definition of nonobstruent stops. Section 5 reviews the phonological properties of nonexplosive stops as a whole, and shows that a characterization as [-obstruent] and [-sonorant] sounds explains the apparently contradictory aspects of their phonological behavior. Section 6 summarizes our main results, and suggests that phonological feature theory requires both the articulatory feature [±obstruent] and the acoustic feature [±sonorant].

2. Characterizing implosives

2.1. The classical account

The modern treatment of implosives is due to the work of J.C. Catford (1939, 1977), inspired by Beach's description of Nama phonetics (1938). In the first of his studies, Catford defined stop consonants in terms of two articulatory parameters: pressure vs. suction, and inner closure point (pulmonic, glottalic, or velaric). These parameters define six airstream mechanisms, of which three are egressive and three are ingressive.[3] Ejectives and implosives are characterized as glottalic stops, that is, stops involving closure at the glottis. Within this class, implosives are described as suction stops in which "the glottis is closed [and] a sudden depression of the larynx, by enlarging the supraglottal cavities, rarefies the imprisoned air, so that an implosion occurs when the outer closure is released" (Catford 1939: 3).

In Catford's account, then, implosive production involves four characteristics: 1) glottal closure, 2) larynx lowering, 3) rarefaction, and 4) implosive release. This way of describing implosives has been widely followed and forms the basis of most textbook treatments up to the present.

2.2. Problems with the classical account

The classical account of implosives, by acknowledging the fundamental role of air pressure and the mechanisms by which it is controlled, represents an important advance over earlier work. However, subsequent research has shown that such an account fails to distinguish implosives clearly from other stop types. It is now known that just like ordinary voiced stops, implosives may be produced with ordinary ("modal") voicing, with no ingressive airstream, and without rarefaction (negative oral air pressure). Moreover, larynx lowering is not unique to implosives, but is commonly observed in the production of ordinary voiced explosives as well. It is consequently no longer clear in what essential respect implosives differ from other types of stops. These problems are briefly reviewed in the following subsections.

2.2.1 Implosives may be produced with modal voicing[4]

The classical taxonomy of stop types, as just summarized, requires the inner closure point to be the glottis for implosives, but the lungs for ordinary explosive stops. While this account provides a good account of voiceless implosives (see §3.2), it proves problematical when applied to voiced implosives. More recent research, beginning with Peter Ladefoged's pioneering study of the phonetics of West African languages (1968), has shown that there are several ways of producing voiced implosives, not all of which involve what can be termed glottal closure. In one common way of producing voiced implosives, the vocal folds are held loosely together in a configuration appropriate for modal voicing, as found in ordinary voiced stops. Ladefoged has summarized his observations in the following terms:

> It is perfectly possible to produce ingressive glottalic sounds by a ... process in which the closed glottis is rapidly lowered ... But this type of sound is rare. The more common airstream process involving the lowering of the glottis does not have the vocal folds held tightly together. Instead, as they descend they are allowed to be set in vibration by the air in the lungs, which is always at a higher than atmospheric pressure during any speech activity. (Ladefoged 1971: 25-6)

The "inner closure point" in such sounds is the lungs, not the glottis.

The idea that implosives involve a glottal closure point might alternatively be understood to imply that they are produced with a stiffer vocal fold configuration than that found in ordinary voiced stops, creating a higher resistance to airflow across the glottis. This configuration could be expected to result in laryngealization or creaky voice. But while it is true that some voiced implosives are laryngealized, not all are. Summarizing their review of the literature on this point, Ladefoged and Maddieson conclude that implosives can be produced with modal voice, with a more tense voice setting, and with complete glottal closure (1996: 82). Only the last type conforms to the classical definition of implosives.

2.2.2 Implosives need not be produced with an ingressive airstream

Another widely-accepted criterion for distinguishing implosive from explosive stops is the presence of an ingressive airstream (implosion), which is often observed at the implosive release. However, this criterion, too, proves inconclusive. Ladefoged (1968, 1971) found few examples of actual ingressive airflow at the release of the implosive stops in his survey of West African languages. He observed:

> The downward movement of the vibrating glottis tended to lower the pressure of the air in the mouth; but this was usually more than offset by the increase in pressure due to the outgoing lung air. These sounds were seldom ingressive in the sense that on the release of the articulatory closure air flowed into the mouth. (Ladefoged 1968: 6)

This result has been confirmed by others. Lex, in a phonetic study of implosives in the Fouladou dialect of Fula, found that airflow can be either ingressive or stationary at the implosive release, and proposed that what marks implosives is the *absence* of egressive airflow (Lex 1994: 137). Assessing the literature, Ladefoged and Maddieson conclude that ingressive airflow provides no categorical distinction between voiced implosives and explosives, and state: “there is a gradient between one form of voiced plosive and what may be called a true implosive, rather than two clearly defined cases” (1996: 82).

2.2.3 Implosives need not involve negative oral air pressure

Several studies, such as Demolin (1995), have confirmed that oral air pressure may indeed be lowered to subatmospheric level during the closure phase of implosives. However, sometimes there is no observable lowering of air pressure. In their phonetic study of Owere Igbo, Ladefoged, Williamson, Elugbe, and Uwulaka remark (1976: 154): “it seems that [ɓ] contrasts with [b] simply by having no increase (rather than by having an actual decrease) in oral pressure during the closure”. Ladefoged (1971: 26) elsewhere states: “in many of the languages I have observed the pressure of the air in the mouth during an ingressive glottalic stop is approximately the same as that outside the mouth."

2.2.4 Larynx lowering is not unique to implosives

If neither glottal closure, ingressive airflow, nor negative air pressure provide robust diagnostics for identifying implosives, what does? Larynx lowering, required to initiate the glottalic airstream mechanism, is the single most commonly cited property in definitions of implosives in the current literature. However, it has been well established since the study of Ewan and Krones (1974) that larynx lowering is not unique to implosives, but is regularly used to maintain voicing in ordinary voiced pulmonic stops.

The explanation for this is quite straightforward. Consider the production of an ordinary pulmonic voiced stop, such as [b]. Assuming that the vocal folds are kept in a position appropriate for modal voicing and that no other special adjustments are made, air pressure starts to build up in the oral cavity just after the labial closure is formed, and the pressure drop across the glottis decreases by a corresponding amount. When this pressure drops below a certain threshold, vocal fold vibration ceases. The decrease in pressure is sufficiently rapid that only one or two glottal pulses would normally occur after the closure is formed. In order for voicing to be sustained for a longer interval, therefore, supplementary adjustments must be made. These may include increasing subglottal pressure, slackening the vocal folds, or decreasing supraglottal pressure. The latter adjustment can be achieved either by venting the airstream outward through the nasal cavity during part of the occlusion, or by expanding the oral cavity. (See e.g. Stevens 1997, 1998 for more detailed discussion.)

The last of these adjustments, oral cavity expansion, is of particular interest to the present discussion. It can be achieved by several different but complementary maneuvers, including larynx lowering, tongue root advancement, relaxation of the soft tissues of the vocal tract walls, raising of the velum, shifting of the oral closure forward to expand cavity size longitudinally, and lowering of the jaw (see e.g. Ewan and Krones 1974, Bell-Berti 1975, Catford 1977; Ohala and Riordan 1979; Westbury 1983, Ladefoged and Maddieson 1996;

Stevens 1998). Most of these mechanisms, including larynx lowering, have been observed in the production of "ordinary" voiced obstruents in better-studied languages such as English and French, often in combination. The combination of larynx lowering and tongue root advancement is illustrated schematically in Figure 1, from Stevens (1998: 467):

(Figure 1 here)

Both of these adjustments, if maintained throughout the stop closure, will tend to sustain voicing.

The effect of relaxing the soft tissues of the walls has been calculated for a labial stop as follows by Westbury (1983, Fig. 3):

(Figure 2 here)

This figure shows that we may expect voicing to continue in a stop for only 7 ms if the vocal tract is bounded by rigid walls (dotted line), for about 30 ms if its tension is analogous to that of the neck wall (lower dashed line), for slightly over 60 ms if its tension is similar to that of the tensed cheeks (solid line), and for 80 ms or more (that is, throughout the normal duration of a stop closure) if its tension is equal to that of the relaxed cheeks (upper dashed line). As Westbury notes, "the cumulative effect of articulatory movements on volume of the cavity above the glottis is more relevant to the problem of voicing maintenance during consonantal closure than are the direction and extent of movements of any single articulator" (Westbury 1983: 1331).

In sum, larynx lowering and other cavity-expanding adjustments are not unique to implosives, and cannot be used as a discrete criterion to distinguish them from ordinary voiced stops. It might be possible to maintain that the difference between the two stop types is gradient, lying primarily in the comparatively larger and more rapid descent of the glottis in implosives (Ladefoged 1971: 27). This view, however, would not explain why languages appear to distinguish at most two phonological categories along this gradient. Under the view that articulatory variation between distinct phonemic categories is marked by rapid shifts in spectral properties, while articulatory variation within any single phonemic category is not (see Stevens' quantal theory of speech, 1989), one would expect to find a categorical property distinguishing implosives and other non-explosive stops from explosive stops. This will be the goal of the next section.

3. Implosives as nonobstruent stops

We have seen that neither glottal closure, ingressive air flow, negative air pressure (rarefaction), nor the presence of larynx lowering provide reliable criteria for distinguishing implosives from explosive stops. It will be proposed here instead that the common property distinguishing implosives from explosives is the *absence of air pressure buildup in the oral cavity*. As will be seen, this property is exactly the correlate of the feature [-obstruent]. This feature provides a categorical basis for distinguishing implosives from explosive sounds. And as the later discussion will show, it generalizes straightforwardly to other kinds of non-explosive stops, and provides an explanatory account of the phonological patterning of the class of nonexplosive stops as a whole.

This section proposes a definition of the feature [obstruent] (§3.1), showing that both voiced and voiceless implosives satisfy this definition (§3.2). It then shows that this definition generalizes to other types of nonexplosive stops as well (§3.3).

3.1. Approaches to the obstruent/nonobstruent distinction

The attempt to define a binary feature assigning all speech sounds to one of two large classes, obstruents and sonorants, has a long history in phonological research. Such a feature is required to define the natural classes of sounds involved in the statement of many common phonological patterns. Thus, for example, Trubetzkoy proposed to characterize the obstruent/sonorant distinction in terms of degree of obstruction to the airflow (Trubetzkoy 1969: 141); however, he allowed this feature to distinguish sonorants and obstruents only in languages lacking a phonemic contrast between stops and fricatives. Chomsky and Halle (1968: 302) give the binary feature [±sonorant] a more central place in their feature system. They defined sonorants as sounds produced with a vocal tract cavity configuration in which spontaneous voicing is possible, and obstruents as sounds whose cavity configuration makes spontaneous voicing impossible.[5] Chomsky and Halle did not define this configuration directly, but maintained that it can be created by narrowing the air passage to the point where airflow velocity at the glottis is reduced below the critical level necessary for spontaneous voicing to take place.

These definitions of the obstruent/sonorant distinction were stated in terms of vocal tract configurations. In contrast, Stevens (1983) proposes an aerodynamic definition, which we quote in full due to its importance for the following discussion:

> Another class of consonants, called *obstruent*, is defined in the articulatory domain by the presence of a pressure increase within the vocal tract during production of the consonant. This pressure increase occurs because a complete closure or a sufficiently narrow constriction is made within the vocal tract to contain the air. The acoustic consequence of this pressure increase is that turbulence noise is generated in the vicinity of the constriction at some point during production of the sound. This noise can occur either throughout the constriction interval (as in a fricative consonant) or at the release of a closure (as in a stop consonant), but in any case it will occur in the time interval in the vicinity of the region where the rapid spectrum change for the consonant occurs. Presumably, a listener is sensitive to the presence or absence of this type of noise in the sound, and this attribute, then, defines the natural class of obstruent consonants. (Stevens 1983: 254)

In contrast, sonorants are produced with no pressure increase, and consequently no audible noise. (Similar accounts have been proposed by Halle and Clements 1983, Halle 1992, and Stevens 1998.) A further attribute of obstruence cited by Stevens (1997: 490) is reduction or cessation of vocal fold vibration during the oral constriction, a mechanical effect of pressure increase as discussed earlier.

One advantage of this definition is that it can be applied to easily obtainable speech data, and readily confirmed, or corrected if need be. To test this definition, one of the authors (GNC) conducted air pressure measurements at the Phonetics Laboratory of the University of Paris 3. Air pressure variation in the anterior oral cavity can be measured by introducing a thin plastic tube into the side of the mouth behind the rear molars so that its open end points toward the center of the oral tract. The other end of the tube is passed through an oral mouth mask and connected to a pressure transducer. The pressure measured is the static pressure behind labial and coronal constrictions. The subject (GNC) read a short passage containing representative English stops, fricatives and sonorants several times into the mouth mask, while simultaneously recording it on the system's audio input. Resulting airflow and air pressure measurements were segmented by examination of spectrograms of the corresponding speech signal and by selective auditory playback of portions of the spectrogram.[6]

Figure 3 presents measurements from a spoken text illustrating obstruents and sonorants in several contexts. Obstruents are labelled to the right of vertical lines aligned with their beginning (onset of closure). The top trace represents the audio signal, the middle trace oral airflow, and the bottom trace oral air pressure.

(Figure 3 here)

It can be observed that every sustained rise in oral pressure corresponds to an obstruent. Similarly, every nonvelar obstruent in this phrase is realized with a sustained increase in oral pressure. (Air pressure buildup behind velar stops is not detected by the transducer due to the placement of the tube in the center of the mouth, and so no pressure rise is recorded for the two velar stops in this text.)

The air pressure pattern in Figure 3, which is similar to other pressure traces obtained in the same way, is thus consistent with Stevens' definition of the class of obstruent sounds.

3.2 Implosives as nonobstruents

Based on this definition of obstruence, we propose that implosives are nonobstruent stops. In contrast, explosive stops, including ejectives and clicks (note 1), will normally qualify as obstruents, because their explosive release implies air pressure buildup.

This analysis of implosives provides an improved basis for understanding their phonetic characteristics. First, although implosives are not always produced with negative air pressure, they are never reported to be produced with positive air pressure; the feature [-obstruent] requires only that they lack positive air pressure. Second, though implosives are not always produced with an ingressive airstream, they are never reported to be produced with an egressive airstream. This, too, follows from their status as nonobstruents, since an egressive airstream requires positive pressure buildup behind the oral closure. Third, the fact that implosives are typically produced by lowering the larynx can be explained by the fact that this gesture increases the volume of the oral cavity and hence, in the absence of any opening, reduces air pressure within. Larynx lowering can thus be understood as a control mechanism for keeping oral air pressure at or below the level of atmospheric air pressure. Finally, this analysis of implosives accounts directly for two of their most salient acoustic characteristics, the absence of turbulence noise (in the form of burst or aspiration) at their release and the steady or rising amplitude of vocal fold vibration during the production of the constriction (for the latter, see Lindau 1984).

This analysis extends readily to voiceless implosives as well. Voiceless implosives are produced by forming a tight closure at the glottis coinciding with the oral closure and then lowering the larynx to create negative air pressure in the oral cavity. Toward the end of the oral closure, air may leak through the glottis, producing a short voicing interval just prior to release which continues uninterrupted into the vowel. Less commonly, the stop is voiceless throughout, with a voicing lag at its release (see data in Pinkerton 1986). At release of the oral closure, there is typically a brief period of rapid ingressive airflow. Voiceless implosives were first described in theoretical terms by Catford (1939) and Pike (1943), and were subsequently observed in several African and Mayan languages (see Greenberg 1970, Campbell 1973, and references therein). The first published phonetic description of these sounds based on instrumental evidence, to our knowledge, was the study of the stops of Owere Igbo by Ladefoged et al. (1976). This work was followed by phonetic studies of voiced and voiceless implosives in Quichean (Mayan) languages by Pinkerton (1986), in Xhosa by Roux (1991), in Fouladou Fula by Lex (1994), in Ngiti by Kutsch Lojenga (1994), and in the closely related Lendu language by Demolin (1995). Voiceless implosives have also been reported in Seereer-Siin by McLaughlin (1992-4).

3.3 Other types of nonobstruent stops

Other types of nonexplosive stops are expected to qualify as nonobstruents as well, since their lack of explosion normally results from the absence of increased oral cavity air pressure during their closure. These include various types of glottalized stops, whose glottal characteristics tend to impede or eliminate transglottal airflow and thus to maintain a low level of oral air pressure.

The term *glottalized* is generally used to refer to stops which involve some degree of glottal constriction beyond that involved in ordinary modal voicing.[7] This class includes voiceless implosives, laryngealized (or creaky voiced) stops, preglottalized stops, and other types. However, due to the lack of experimental studies as well as to inconsistencies in terminology, the distinction among these categories is not always clear. Ladefoged and Maddieson (1996) propose to distinguish voiceless (i.e. fully glottalized) implosives from laryngealized implosives, laryngealized stops, and various other types of stops with accompanying glottal closure. The distinction among some of these categories is subtle, but is often auditorily detectable. For example, the Xhosa implosives, including their voiceless variants, are typically produced with little or no detectable creak (Roux 1991; Michael Jessen, personal communication), while the glottalized stops of Hausa are typically creaky (Lindau 1984, Lindsey, Hayward, and Haruna 1992). Such distinctions are not contrastive in any language, as far as we know.

The distinction between voiceless implosives and *preglottalized* stops is especially hard to pin down. This term is subject to widely varying interpretations. Some linguists use the terms “preglottalized stop” and “implosive” synonymously, but most use them differently. For example, Haudricourt (1950) uses the term “preglottalized” for any sound produced with full glottal closure, regardless of how the glottal closure is phased with the supraglottal articulation. Goyvaerts (1988) considers a stop to be preglottalized if it is produced with minimal implosion, as opposed to the strong implosion of true implosives. For Dimmendaal (1986) and many others, preglottalized stops necessarily involve a sequencing of the glottal and oral closures, in that order. As far as is currently known, such segment-internal sequencing is never lexically contrastive or phonologically relevant.[8] Due to these different and largely incompatible usages, the term “voiceless implosive” is used in this study, following common practice, to refer to all voiceless glottalized implosives, regardless of the sequencing of the glottal and oral articulations.

It seems, then, that the feature [-obstruent] provides an adequate quantal basis for distinguishing implosive (and other nonexplosive) stops from explosive stops. As we have noted, however, many other types of glottalized stops as discussed in this section are still poorly understood, and we currently know of no phonetic studies bearing on the aerodynamic properties of, for example, nonimplosive laryngealized stops, preglottalized stops, or the “consonnes douces” often reported in the Francophone literature. It seems likely, however, that at least some varieties of these sounds, to the extent they are nonexplosive, will prove to be nonobstruent stops as we have defined them here.

4. Nonexplosive stops in Ikwere

We now turn to a phonetic study of two further types of nonexplosive stops, neither of which can be easily identified with any of the stop types reviewed up to this point. These sounds do not satisfy the classical definition of implosives, as they do not involve the glottalic airstream mechanism. Though similar to implosives acoustically, neither is produced with any detectable movement of the larynx, neither is auditorily laryngealized, and only one of them involves glottal closure. In some respects they resemble the “lenis” stops sometimes reported by Africanist scholars (Stewart 1989). The evidence summarized in this section shows that they represent further members of the class of nonobstruent stops.

4.1. Ikwere consonants

Ikwere, a Niger-Congo language spoken in Nigeria,[9] has a pair of bilabial stops written *gb* and *kp* in the standard orthography. These sounds are reflexes of older labial-velar stops, and may still have labial-velar realizations in some varieties of Ikwere. However, in the variety described here, they are realized as bilabial sounds with no velar contact at any point in their production. We transcribe them as [ḅ] and [’ḅ], respectively. Both are relatively common sounds in Ikwere, each having a lexical frequency of over 4% with respect to all consonants. They are phonemically distinctive, contrasting with *p* and *b* as shown in Tables 1 and 2.[10]

Obstruents:							
explosive voiceless stops	p	t	tʃ	k	k^w		
explosive voiced stops	b	d	dʒ	g	g^w		
voiceless fricatives	f	s					
voiced fricatives	v	z					
Nonobstruents:							
nonexplosive voiced stop	ḅ						
nonexplosive glottalized stop	’ḅ						
lateral approximant		l					
central approximants		r	y	ɣ	w		
laryngeals						h	h^w

Table 1. Consonant phonemes in Ikwere

The classification of *ḅ* and *’ḅ* as nonobstruents will be justified below. The nonobstruent consonants of the last five rows have oral realizations before oral vowels and nasal realizations before nasal vowels, giving the pairings [ḅ]/[m], [’ḅ]/[’m], [l]/[n], [r]/[r̃], etc. Each of these pairs constitutes a single phoneme in which nasality is nondistinctive (Clements and Osu, in preparation).

Table 2 gives examples of lexical contrasts between the nonexplosive stops *ḅ, ’ḅ* and the explosive stops *p, b* (´ = high tone, ` = low tone, ˆ = falling tone).

Nonexplosive *ḅ, ’ḅ*:		Explosive *b, p*:	
àḅá (ɛ́fɔ́)	‘to run’	àbá (ézè)	‘to become rich’
ὲḅê	'to prepare food'	ὲbê	'to touch’
à’ḅá	‘to sow’	àpá (ɔ́lú)	‘to climb’
áḅà̰ [ámà̰]	‘machete’	àbà̰	‘jaw’

Table 2. Minimal contrasts involving /ḅ, ’ḅ, p, b/

Due to the uncertainty regarding their classification, a phonetic study was conducted to determine how the Ikwere sounds *ḅ* and *’ḅ* are distinguished phonetically from the “ordinary” bilabials *b* and *p*. All phonetic data were obtained from one of the authors (SO). The main results of this study are presented below. The following questions will be considered in turn: Are *ḅ* and *’ḅ* obstruents? If not, are these sounds implosives? If not, are they glottalized stops? What evidence do their f_0 characteristics provide? Can they be regarded as “lenis” stops? And finally, how is air pressure regulated in the production of *ḅ* and *’ḅ*?

4.2 Are *ḅ* and *’ḅ* obstruents?

It will be recalled that the main auditory correlate of obstruence, in Stevens’ account, is turbulence noise in the vicinity of the constriction. Neither *ḅ* nor *’ḅ* display any such noise, whether in the form of a release burst or of post-release frication noise. Spectrograms comparing the words *àbá* and *àḅá* are shown in Figure 4.[11]

(Figure 4 here)

In these examples, which are typical of our data, a weak voiceless transient of about one glottal pulse in length can be observed at the release of *b* (top spectrogram) but none at the release of *ḅ* (bottom spectrogram). Neither stop is followed by a noise burst or frication.

Spectrograms comparing *àpá* 'to climb' and *à'ḅá* 'to sow' appear in Figure 5.

(Figure 5 here)

In these examples, *p* (top spectrogram) shows a voiceless post-release transient of about 20 ms, followed by voicing. The duration of this transient varies a good deal in our data, a few tokens being heavily aspirated, and others unaspirated. (Explosive stops at other places of articulation typically show a more pronounced burst and a longer post-burst transition filled with noise and aspiration.) *'ḅ* (bottom spectrogram) shows no burst, but a prevoicing segment of about 40 ms in length.

These spectrograms also confirm that we are dealing with bilabial sounds, not labial-velars. Labial-velar stops typically show velar-like transitions on their left (Ladefoged and Maddieson 1996: 334-6). In Figures 4 and 5, however, F2 transitions on the left of *ḅ* and *'ḅ* fall, just as they do before *b* and *p*. This pattern contrasts with that in words like àká 'to fast' and àgâ 'to walk' (not shown here), in which F2 rises at the left edge of the velar stops.

A further acoustic property of voiced obstruents is the tendency for voicing to decay or cease altogether during occlusion (Lindau 1984). Both *b* and *ḅ* are fully voiced in all our data. However, *b* often shows some decay in voicing amplitude toward the end of the occlusion, while *ḅ* often shows an increase in voicing amplitude. The voice bar patterns in Figure 4 are typical in this respect. This distinction does not constitute a reliable criterion for distinguishing *b* from *ḅ*, however, as both stops sometimes show level voicing amplitude throughout their duration.

Airflow and air pressure measurements were also conducted for selected utterances spoken by SO using the methodology described in section 3.1. Figures 6 and 7 show results for representative productions of *b*, *ḅ*, *p*, and *'ḅ*. Egressive airflow is shown by a rise of the airflow trace above the median line, and ingressive airflow (present only in Figure 7b) by a fall. An increase in oral air pressure is shown by a rise in the air pressure trace above the median line, and a decrease (again present only in Figure 7b) by a fall. The top line shows the synchronized audio signal. We now examine Figures 6 and 7 in turn.

Figure 6 presents data for *b* and *ḅ* in the words *àbá* and *àḅá*, spoken in isolation.

(Figure 6 here)

The explosive stop *b* (Figure 6a) shows a brief burst of egressive airflow at its release, lasting for two or three glottal pulses. Air pressure builds up during the occlusion, peaks at release and then drops quickly at the onset of the vowel. In contrast, *ḅ* (Figure 6b) shows no release burst, nor does it show any increase in oral air pressure during occlusion.[12]

Figure 7 presents traces for *p* and *'ḅ* in the words *àpá* and *è'ḅé*, spoken in isolation.

(Figure 7 here)

As with *b*, the voiceless stop *p* (Figure 7a) shows a burst of egressive air at its release and a buildup of oral air pressure during occlusion, peaking just before release. In contrast, *'ḅ* (Figure 7b) presents a pattern similar to that typically found in implosive sounds: an ingressive airstream at release, and a sharp drop in oral air pressure culminating just before release.[13]

Following the definition of obstruence proposed by Stevens (1983), then, Ikwere *ḅ* and *'ḅ* are nonobstruents: neither shows the acoustic properties of obstruence (turbulence noise), and both lack oral air pressure increase during occlusion.

4.3. Are *ḅ* and *'ḅ* implosives?

We have just seen that some instances of *'ḅ* display two typical properties of implosives, negative air pressure and ingressive airflow. An obvious question, then, is whether either *ḅ* or *'ḅ* are produced with a glottalic airstream mechanism, which requires a lowering of the larynx.

External observation of many of SO's productions of *ḅ* and *'ḅ* failed to show visible larynx lowering on any occasion. To study this question more systematically, videotapes were made of Ikwere words containing *ḅ*, *'ḅ* and other stops in intervocalic position. Film speed was 25 frames/sec, yielding one image every 40 ms. These images were viewed in frame-by-frame mode on a large-screen television monitor, and selected sequences were traced onto transparencies. Representative productions of *àḅá* and *à'ḅá* are shown in Figure 8.

(Figure 8 here)

These figures show overlays of three consecutive points at the release of the labial stop into the vowel: (a) shortly after mid-point in the labial closure, (b) just prior to release, and (c) just after release. The protrusion of the larynx (thyroid cartilage) is clearly visible along the profile of the neck, as shown by the arrows. There is no visible descent or rise of the larynx at any point in the production of either sound, either in the frames shown here or in adjacent frames; all movement is located in the region extending from the lips to the chin.

In summary, neither *ḅ* nor *'ḅ* are implosive stops, in the usual definition of this category. Neither sound is produced with detectable larynx lowering, and thus neither can be said to make use of a glottalic airstream mechanism.[14]

4.4. Are *ḅ* and *'ḅ* glottalized stops?

Let us next consider the nature of the glottal closure in these two sounds, beginning with *'ḅ*. Glottalization is auditorily detectable at the left edge of *'ḅ*, where it sounds rather like the *p* in *cap* as pronounced by English speakers who preglottalize their word-final voiceless stops.

Traces of glottalization can be observed toward the end of the vowel preceding *’ḅ* in the spectrogram in Figure 5. In contrast, no glottalization is heard when voicing resumes at the end of the stop, or in the following vowel.

To check for visual evidence of a special glottal configuration in *ḅ* or *’ḅ*, a fiberoptic study of SO’s production of several words containing the four bilabial stops and other sounds was conducted at the Hôpital Laennec, Paris, under the supervision of Dr Lise Crevier-Buchman. The fiberscope was connected to a camera with a time resolution of 25 frames per second. The images were recorded on a Umatic videocassette recorder and transferred to VHS format. After preliminary viewing in frame-by-frame mode, selected sequences were digitized for closer study. Laryngeal views mid-way through the occlusive phases of *’ḅ*, *p*, *ḅ*, and *b* are reproduced in Figure 9.[15]

(Figure 9 here)

The base of the epiglottis is visible at the bottom of each image, and the posterior wall of the pharynx at the top. Prominent structures include the arytenoid cartilages, the aryepiglottic folds which join them to the sides of the epiglottis, the vocal folds, and the ventricular bands (or false vocal folds) lying just above them, sometimes partly concealing them.

The first image shows the occlusion of *’ḅ* toward its beginning. We observe an anterior-posterior compression of the aryepiglottic sphincter in which the arytenoids are drawn forward to approach (but not touch) the base of the epiglottis, while the ventricular bands are drawn laterally together to nearly cover the closed vocal folds. This configuration, found in all tokens of *’ḅ*, also characterizes the glottal stops which are regularly inserted before utterance-initial vowels by this speaker, and is similar to fiberscopic images of glottal stops in other languages published elsewhere in the literature (e.g. Harris 1999). It confirms that *’ḅ* is formed with a tight glottal closure.

The second image shows *p* for comparison. During the occlusion of this sound, the vocal folds are momentarily spread apart, as shown in the image. This configuration is typical of voiceless stops in other languages (e.g. Sawashima and Hirose 1983). Thus though both *’ḅ* and *p* are acoustically voiceless, their voicelessness results from two different articulatory mechanisms, glottal closure in the first case and glottal opening in the second.

The last two images show the closures of *ḅ* and *b*. The glottal configurations in these sounds are virtually indistinguishable. Both involve a loose approximation of the vocal folds as is observed in modal voicing. These images are similar to those of *m* (not shown), as well as to those of other sonorant sounds we have examined. They support the auditory impression that both *ḅ* and *b* are produced with modal voice, similar to that used in sonorants.

Of further interest is what the fiberoptic images did *not* show: there was no evidence of larynx lowering at any point during the closure phases of *’ḅ* or *ḅ*. Larynx lowering appears in fiberoptic films as a “zoom out” effect as the larynx moves downward, with a concomitant decrease in brightness of the arytenoids (Kagaya 1974: 177, n. 11). While evidence of such lowering could conceivably have been missed in any individual sequence due perhaps to the 40-ms interval between successive images or the counteracting effect of sporadic camera movements, it is unlikely that it could have been missed in all images.[16]

We were unable to find any evidence that *ḅ* (or *’ḅ* during the prevoiced portion preceding release) are laryngealized. Auditorily, we were unable to hear any phonatory quality distinguishing the voicing in these sounds from that of the modally voiced *b*. Neither one sounds “creaky”, either during its voiced portion or in the transition to the following vowel.

This auditory impression is supported by the acoustic data. Waveforms of the occlusive phase of intervocalic *b* (top), *ḅ* (middle), and *’ḅ* (bottom) are shown in Figure 10.

(Figure 10 here)

The waveforms of both *ḅ* and *’ḅ* (in its prevoiced portion) resemble that of *b*. These voicing patterns are quasiperiodic throughout, with no aperiodic intervals, increase in period, dips in amplitude, or other irregularities such as are found in typical examples of laryngealized voicing published in the literature. While the *ḅ* trace shows a greater tendency toward biphasic structure than does that of *b*, this difference seems more a matter of degree than kind, since the *b* trace also shows a double peak. An examination of fiberoptic images of *ḅ* and *b*, of which

Figure 9 provides representative examples, also failed to reveal any evidence of a vocal fold configuration characteristic of laryngealization.

In sum, neither of these sounds appears to be produced with laryngealized voice. While *’ḅ* is produced with full glottal closure during its first portion, which may induce some creakiness in the preceding vowel, voicing is modal in its prevoiced portion, and *ḅ* is modally voiced throughout. Nor is there any observable evidence of tighter glottal closure in *ḅ* than in *b*.

4.5. How do *ḅ* and *’ḅ* influence f_0?

Although our data failed to reveal any direct evidence of a special laryngeal state in the Ikwere nonexplosive stops, indirect evidence for such a state might theoretically come to light from a study of f_0 effects at the consonant release. Greater vocal fold tension or stiffness in these sounds, by increasing resistance to airflow at the glottis (Rg), would tend to increase f_0 at the beginning of the following vowel. Conclusive evidence for such increased tension would suggest that the mechanism underlying the nonexplosive stops of Ikwere might be situated in the larynx, and would undermine the evidence for a feature [-obstruent]. This subsection first reviews phonetic studies of the tonal effects of implosive sounds in other languages, and then examines f_0 effects at the release of Ikwere stops.

Implosives are usually observed not to have the tone-depressing effects widely found after other voiced stops (an exception is Xhosa, as discussed by Jessen and Roux 2000). This trend is not yet well understood. Theoretically, the reduction in vocal fold stiffness resulting from larynx lowering[17] should have a tone-lowering effect in implosives, just as it does in ordinary voiced obstruents. To understand why implosives do *not* normally depress tone, it must be assumed that this factor is overridden by others. Addressing this question, Hombert et al. (1979: 48) suggest that the rapid lowering of the larynx during implosive production might generate such a high rate of glottal airflow that f_0 is raised above its normal level; however, as they point out, this explanation could account only for f_0 raising during the implosive closure itself. More recent studies have shown that f_0 raising can continue into the vowel as well. Thus, Wright and Shryock (1993) have shown that the pitch-raising effect of the Siswati voiced implosive *ɓ* on high-tone vowels perseveres well into the vowel. Similar effects are reported for voiceless implosives. Kutsch Lojenga's (1994) f_0 tracings of Ngiti show that the raised f_0 characterizing the final prevoiced portion of voiceless implosives continues well into the vowel,[18] and Demolin (1995) reports analogous effects in the closely-related Lendu language.

To see what f_0 effects are present in the Ikwere nonexplosive stops, a study was conducted of f_0 patterns at the consonant-vowel transition. The consonants examined were [p ’ḅ b ḅ m]. Ten recordings were made of words containing these consonants embedded in a sentence frame.[19] In all test words, the consonants of interest are released into a high-tone vowel, either *a* or *e*. The lengths of the three glottal periods just preceding consonant release and of the seven following release were measured directly from the signal and converted into f_0 values. Averaged values for the ten tokens were plotted on graphs.

The results are shown in Figure 11. This figure overlays f_0 traces for *p* and *’ḅ* (Figure 11a) and *b*, *m*, and *ḅ* (Figure 11b). In these graphs, glottal pulses -2 to 0 represent the final f_0 values of the consonant (absent in the case of voiceless *p*), and glottal pulses 1 to 7 represent the f_0 values of the following vowel.

(Figure 11 here)

Figure 11a shows high f_0 values at the release of *p* (dashed line), as expected after a voiceless consonant. By the third glottal pulse, 20 ms into the vowel, however, f_0 has reached a value appropriate for the following high tone vowel. The f_0 trace of *’ḅ* (solid line) includes the three final values of its prevoiced portion (points -2 to 0), which was present in six of the ten tokens. This trace shows a sharp rise-fall-rise pattern which can be explained by the expected variations in air pressure and airflow. F_0 values first rise sharply during the prevoiced portion of the stop (points -2 to 0), reflecting the high rate of airflow across the glottis just after the glottal closure is released. F_0 drops sharply at the release of the labial closure as air rushes into the oral cavity, reducing transglottal air pressure (point 1), and then quickly rises to a value appropriate for the following high tone vowel as the pulmonic airstream increases subglottal air pressure again and the vocal folds adjust to the configuration required for high tone production (points 2-7). These traces are different from those reported by Kutsch Lojenga and Demolin, who, as noted above, found higher f_0 values to persevere into the vowel. This perseverance may be an effect of the rise of the larynx from its lowered position in Ngiti and Lendu, which takes place during the initial part of the vowel. No similar perseverance would be expected in Ikwere, which, as discussed above, has no detectable larynx lowering.

Figure 11b presents comparable data for *b*, *ḅ*, and *m*. The f_0 traces of these sounds show variants of the rise-fall-rise pattern observed with *’ḅ*, though to a lesser extent. Thus, f_0 values peak just prior to consonant release (point 0), drop at release (point 1), and then climb along a gradually rising high tone ramp (point 2 onward). However, the explosive *b* starts at a much lower f_0 value than do *ḅ* and *m* (point -2), in agreement with the inherently lower pitch usually observed in voiced obstruents.

What do these data show us, then, about the nature of the contrast between nonexplosive *’ḅ*, *ḅ* and the explosives *p*, *b*? The f_0 peak at point 0, immediately preceding release, is especially revealing in this regard: it is highest in *’ḅ*, next highest in *ḅ*, and lowest in *b*. These differences correlate directly with observed differences in pressure drop across the glottis, which, assuming constant subglottal pressure, should be highest in *’ḅ* due to its negative air pressure, next highest in *ḅ* in which oral air pressure is equal to atmospheric pressure, and lowest in *b*, due to its positive oral air pressure. Theoretically, greater pressure drop is expected to increase transglottal airflow and thus to raise f_0.[20]

In sum, the f_0 data can be fully explained on the view that *ḅ* and *’ḅ* are nonobstruent stops characterized by negative or zero air pressure during occlusion. This explanation requires no special assumptions regarding vocal fold stiffness. Given the absence of any independently observable evidence of such stiffness, it can be concluded that such a state, if present at all, is minimal and unlikely to be responsible for the aerodynamic properties of these sounds.

4.6. Are *ḅ* and *'ḅ* lenis stops?

Could *ḅ* and *'ḅ* be alternatively viewed as lenis stops, as have occasionally been reported in African languages? If this proved to be the correct analysis, their reduced oral air pressure could be considered a secondary effect of a more basic feature [+lenis]. In that case the feature [-obstruent] would be redundant, and possibly unnecessary.

The terms "fortis" and "lenis" (or "tense" and "lax") have been used in a variety of senses in the literature. Most commonly, they are employed as broad terms to cover a variety of realizations. In the case of fortis sounds these include voicelessness, aspiration, longer duration, greater air pressure, and greater muscular tension; in the case of lenis sounds, they include voicing, lack of aspiration, shorter duration, lower pressure, and weaker tension. In a recent, comprehensive review of this feature, Jessen (1998) suggests that the most widely-accepted common denominator of the fortis/lenis distinction is duration: in most accounts, fortis sounds differ from lenis sounds in having relatively greater duration. Other properties associated with this feature can, Jessen argues, be best understood as contributing to, or resulting from, these durational differences.

The distinction between *p* and *'ḅ* on the one hand and *b* and *ḅ* on the other shows some of the secondary characteristics of the fortis/lenis distinction. The first member of each pair is produced with positive oral air pressure and greater muscular tension around the lips, and the second with zero or negative air pressure and a general laxing of lip tension. The differences in muscular tension are easily confirmed by external examination of the lips and surrounding tissues (see further discussion below). In addition, while *p* may sometimes be realized with aspiration, *'ḅ* never is.

To determine whether *'ḅ* and *ḅ* might be distinguished from *p* and *b* by the feature fortis/lenis, 10 repetitions of words containing each were recorded in a carrier sentence, and the durations of the stops (including burst and voicing lag, when present) were measured. Values for *m* (the nasal allophone of *ḅ*) are given for comparison. Results are shown in Table 3.[21]

	p	b	'ḅ	ḅ	m
duration (ms)	110.8	90.5	102.4	103.9	96.1
s. d.	9.9	7.4	6.3	7.0	5.5

Table 3. Average durations and standard deviations of *p b 'ḅ ḅ m* in words spoken in the frame *kǎ* __ *ḿḅá lâ* 'say X twice' (N=10).

These results show that *p* and *b* are not both longer than *'ḅ* and *ḅ*, as the fortis/lenis feature would require. Though *p* averages about 8 ms longer than *'ḅ*, there is considerable overlap in their values. Moreover, the voiced explosive *b* is about 13 ms *shorter* than its nonexplosive counterpart *ḅ*. Indeed, *b* is shorter than *m*, which would normally be considered a lenis sound.

It seems, then, that the two sets of stops *'ḅ/ḅ* and *p/b* are not reliably distinguished by the feature fortis/lenis. It is possible, instead, that some of the fortis/lenis stop contrasts reported in the literature may actually reflect a more basic obstruent/nonobstruent distinction, as Stewart (1989) has already suggested. The fact that *ḅ* and *'ḅ* share a lax articulation can be understood as a strategy for allowing passive expansion of the vocal tract walls during occlusion, facilitating realization of the feature [-obstruent].[22]

4.7. How is air pressure regulated in the production of *ḅ* and *'ḅ*?

We have so far seen that *'ḅ* and *ḅ* are not produced with larynx lowering, and that while *'ḅ* is glottalized, *ḅ* shows no clear evidence of any special glottal state. The obvious question is, then: how is air pressure regulated in these sounds? Several possibilities can be considered. We have already pointed out (section 2) that air pressure is regulated in ordinary voiced stops by a variety of cavity-expanding mechanisms, including, but not limited to, larynx lowering. As far as implosives are concerned, Maddieson has suggested: "No measurements have been done to confirm the occurrence of oral cavity expansion by tongue movement, jaw lowering or use of the cheeks in production of implosives... Nonetheless, the theory that such expansion occurs is plausible and appealing” (1984: 119).

Let us consider, then, some of the other mechanisms that might be employed in the Ikwere nonexplosives. As noted earlier, oral cavity expansion can be achieved by either passive or active means. *Passive* oral cavity expansion involves the relaxation of the soft tissues of the vocal tract walls, including those of the lips, cheeks, and/or throat. If these tissues are relaxed, any air pressure increases in the oral cavity will tend to distend them, increasing vocal tract volume and thus tending to keep oral air pressure constant. The importance of this effect in the production of a labial stop was demonstrated in the model shown in Figure 2, and there is evidence of this mechanism in Ikwere. In the production of *’ḅ* and *ḅ*, as shown clearly in the videos, the lips are rounded and held loosely together in a pout-like configuration, with no visible evidence of muscular tension; in the production of *p* and *b*, in contrast, the lips are spread and pressed firmly together in a “smirk”, with evident tensing of the surrounding musculature, as revealed in the characteristic vertical creases visible along the sides of the spread lips. These differences in muscular tension, easily visible in normal speech, are consistent from utterance to utterance, and correspond to differences in lip protrusion, and hence in vocal tract length. They can be best appreciated by examining overlaid profile views of comparable points in the production of these sounds. Figure 12 show representative examples of the stops *’ḅ* (solid line) and *p* (dashed line) as produced in the words *à’ḅá* and *àpá*.

(Figure 12 here)

Each trace shows the maximally protruded lip position for each sound, occurring about halfway through the closure. The lips are visibly more protruded in *’ḅ* than in *p*.

Active vocal tract expansion is achieved by increasing the volume of the oral cavity along one or more dimensions. Apart from lip protrusion as just noted, we have found some evidence that jaw lowering may contribute to regulating air pressure in Ikwere. Figure 8 showed that the mandible is lowered toward the end of the closure portions of *’ḅ* and *ḅ* (compare points a and b). Since the oral cavity is closed during this period of time (apart from leakage at the vibrating glottis), such lowering will tend to lower oral air pressure.[23]

What other factors might be involved in regulating air pressure in Ikwere? We have found no direct evidence of tongue root advancement, velum raising, or any other mechanism of pharyngeal expansion that might distinguish the nonexplosives from the explosives.[24] One suggestion is that strong velarization (i.e., tongue body retraction) may somehow increase oral cavity volume sufficiently to create an ingressive airstream at release (Catford 1977: 36). In fact, a number of languages have been reported in which implosives are produced, at least in part, by tongue retraction with or without larynx lowering:

- In Mbatto (Ngula), implosives are said to be produced by larynx lowering and/or the retraction of the base of the tongue (Grassias 1983: 479)
- In Ebrié, the implosives [ɓ] and [ɗ] are said to be produced by retracting the tongue (Bole-Richard 1983b: 331)
- In one Igbo dialect, it has been reported that the labial implosive is produced by jaw lowering or tongue retraction rather than by lowering the glottis (De Boeck 1948, cited by Anyawu 1998: 27)

These are admittedly impressionistic reports. However, MRI tracings of the bilabial implosive in Mangbetu reproduced by Demolin (1995: 378) show this sound to be strongly velarized, even though it does not, according to Demolin, arise from a labial-velar sound historically. Velarization is not a necessary accompaniment of implosives; for example, Ladefoged (1968: 7) states that implosives are not velarized in Degema and Ijo. It appears, however, that velarization accompanies the production of implosives in some languages, though it still remains to be explained whether and how it can be used to expand oral cavity volume. We have not obtained MRI tracings or other direct evidence of velarization in Ikwere, but auditory and acoustic evidence suggests that *'ḅ* and *ḅ* are at least somewhat velarized.

4.8. Summary: Ikwere nonexplosive stops as nonobstruents

We conclude that the Ikwere stops *'ḅ, ḅ* are members of a natural class of [-obstruent] stops, characterized (among other properties noted in this section) by the absence of air pressure buildup behind the oral closure and the consequent absence of noise turbulence at their release. As observed in §4.1, these stops pattern as a natural class with sonorants in that they take nasal allophones before nasal vowels. It is perhaps remarkable that *'ḅ* and *ḅ* form any kind of natural class at all, given the dramatic difference in their glottal articulations. That they do suggests that the feature [-obstruent] may play a central role in phonological patterning.

5. Nonexplosive stops as [-obstruent], [-sonorant] sounds

Let us now consider the phonological behavior of nonexplosive stops. If all such sounds are [-obstruent], as we have proposed, we expect them to behave like other nonobstruent sounds. We first review several respects in which nonexplosive stops pattern with sonorants. We then consider other respects in which they pattern instead with obstruents, and suggest how this apparent contradiction can be resolved in a feature analysis.

Nonexplosive stops pattern with sonorant consonants, notably nasals and laterals, in many respects. First of all, nonexplosive stops, like sonorants, show a wide tendency to be nasalized in nasal vowel contexts. In Ebrié (Bole-Richard 1983b), for example, /ɓ/ and the sonorants /l y w/ are nasalized to [m n ɲ ŋ], respectively, before and after nasal vowels. In Gbaya (Moñino 1995), /ɓ/ and /ɗ/ are realized as glottalized implosives before oral vowels but as glottalized nasals before nasal vowels: compare [ɓàà] 'dismember' with ['màà] 'rainy season'. In many Ijo languages, sonorants and implosives are nasalized before nasal vowels, while obstruents are not (Williamson 1987). In Ikwere, as will be recalled, the nonobstruent consonants, including /ḅ 'ḅ/ and all sonorants, are realized as oral before oral vowels and nasal before nasal vowels. Such examples can be easily multiplied. In these and many other languages, nonobstruents are nasalized in the context of nasal vowels while obstruents are not. The resistance of obstruents to nasalization is explained by the incompatibility of the increase in air pressure required for obstruent production with the velum lowering required for nasalization (Ohala and Ohala 1993: 227-231).

Secondly, and for similar reasons, nonexplosive stops, as well as sonorants, are widely disfavored in nasal-stop clusters, where in many languages only explosive stops may appear. This constraint is especially strong in tautosyllabic clusters (i.e., pre- and post-nasalized stops). A few examples will suffice. Implosives and liquids are excluded in prenasalized stops in Ngiti (Kutsch-Lojenga 1994) and Seereer-Siin (McLaughlin 1992-4). In Gwari, the implosive stop /ɓ/ and liquids are excluded in postnasalized stops (Hyman and Magaji (1970). Maddieson's crosslinguistic database of 451 phoneme systems (1992) includes 57 languages with pre- or post-nasalized explosive stops, 53 languages with implosive stops, but no languages with pre- or post-nasalized implosives. In Fula (Pulaar), implosives do not occur in prenasalized stops, though they do occur after nasals in a preceding syllable (Paradis 1992). There is much evidence, then, that implosives are strongly disfavored in nasal clusters, especially when they are tautosyllabic. The same is true of sonorant consonants: nasal + consonant clusters such as *nr*, *nl*, *ny*, *nw* tend to be absent in languages that admit prenasalized stops.[25]

Thirdly, as discussed in section 4.6, nonexplosive stops, as well as sonorants, are widely excluded from the class of "depressor consonants" which in many languages have a tone-lowering effect on adjacent vowels (see Bradshaw 1999 for a review). In many West African languages, consonants fall into two classes depending on their tonal influence, voiced obstruents having a tone-lowering effect, while other consonants do not. Implosives, when present, usually fall into the non-lowering class, and occasionally raise tone. For example, in Ega, a language with implosives at five places of articulation, voiced obstruents lower high tones and prevent the rise of low tones to mid, while implosives do not (Bole-Richard 1983a). In Chadic languages, low tones often occur predictably after initial voiced obstruents except for glottalized sounds, including implosives (Wolff 1987). Some, such as Masa, have a third class of "tone raisers" including implosives and voiceless consonants which exclude low tones on a following vowel. The exclusion of implosives and other nonexplosive stops from the class of tone-depressors can be explained by their aerodynamic properties, as discussed in §4.5.

Fourthly, as noted by Kaye (1981) and others, nonexplosive stops are often in complementary distribution with liquids, and may alternate with them. In Ebrié, for example, the phoneme otherwise realized as [l] in oral contexts is realized as [ɗ] before high vocoids (Bole-Richard 1983b). Nonexplosive stops and liquids are commonly cognate in closely-related languages, where e.g. [ɗ] in one language may correspond to [l] in another.

Fifthly, as pointed out by Creissels (1994), the usual value of voicing in nonexplosives, as in sonorants, is [+voice]. As noted in the earlier discussion, this fact is related to the absence of pressure buildup during the occlusion. Although a few languages have voiceless nonexplosives, these sounds, like Ikwere *'ḅ*, typically have a brief period of prevoicing before release.

All these examples of the patterning of nonexplosive stops with sonorants can be related to the fact that both types of sounds lack a buildup of oral air pressure, consistent with their characterization as [-obstruent] sounds.

Given this patterning, one might also be tempted to conclude that nonexplosive stops are members of the class of *sonorants*. This would follow from the commonly-held view that [-obstruent] is strictly equivalent to [+sonorant]. However, there are significant respects in which nonexplosive stops fail to pattern with sonorants, suggesting that this conclusion may be incorrect.

For example, unlike true sonorants (vowels, liquids, nasals), nonexplosive stops such as the implosives *ɓ* and *ɗ* do not appear to function as syllabic sounds in any language. In contrast, not only vowels but liquids and nasals commonly assume the function of syllable peak. Moreover, we know of no languages in which nonexplosive stops bear tone or pitch-accent, even in the syllable coda. These properties may be related to the fact that nonexplosive stops, like most obstruents, are low-amplitude sounds, bearing very little "sonority" in whatever sense we might wish to give this term.

Indeed, nonexplosive stops tend to pattern with obstruents in terms of most of their sonority-related distributional properties. Thus, like other obstruents, they favor syllable onsets and disfavor syllable codas. In some languages, they may precede liquids in syllable-initial clusters, a position in which sonorants are disallowed; in Lendu, for example, implosives, like explosives, cluster with liquids in the syllable onset in words like *blŭ* 'put on heaps', *ɓlŭ* 'have an empty stomach', and *'ɓlŭ* 'mellow' (Dimmendaal 1986). In other languages, obstruents and implosives are excluded as the first member of word-internal consonant clusters, where only sonorants are allowed. In Hausa, for example, underlying C_aC_b sequences whose first member is an obstruent or implosive commonly simplify to a geminate C_bC_b: *zàaf-záafá* → *zàzzáafáa* 'hot', *káɗ-kàɗáa* → *kákkàɗáa* 'keep beating', while sonorants stay in place: *fàrkáaa* 'paramour' (Newman 1987). In Fula, the first member of a coronal cluster must be more sonorous than the second. Liquids and nasals may therefore precede stops (*ld, nd*), but stops, including implosives, may not (**ɗd*, **ɗt*). Phoneme sequences violating this generalization are subject to repair operations such as gemination, as in the example *mɔɗ-t-a* → *mɔtta* 'to swallow again' (Paradis 1992).

In view of such facts, taking up a suggestion by Stewart (1989),[26] it seems appropriate to view nonexplosive stops as neither obstruents nor sonorants, but an intermediate class of [-obstruent, -sonorant] sounds. In this view, [±obstruent] and [±sonorant] are two separate features, which combine to yield a three-way classification of explosive stops (A), nonexplosive stops (B), and true sonorants (C, including nasal stops and laterals) as shown in Table 4:

	A	B	C
obstruent	+	-	-
sonorant	-	-	+

Table 4. Feature classification of stops

For such a proposal to be tenable, the two features must have separate definitions, consistent with the phonetic and phonological properties of the sounds they designate. It has already been suggested that [±obstruent] should be defined in terms of air pressure buildup in the oral cavity. But what about [±sonorant]? Here an acoustic definition appears more appropriate, in keeping with the fact that implosives are observed to pattern with obstruents in terms of sonority-related generalizations. Ladefoged has argued that the class of sonorants can be given a unified definition only at the auditory level: sonorant sounds, in his proposal, are those having a periodic, well-defined formant structure (1997: 615). This definition applies to voiced nasals and approximants, while excluding both oral stops (which lack a formant structure) and voiceless sounds (which lack periodicity, i.e. voicing). While nonexplosive stops are usually voiced, they lack the formant structure required by the definition of [±sonorant]. If sonority rank is defined by the sum of sonority-related features borne by a segment, as proposed by Clements (1990), the low rank of nonexplosive stops on the sonority scale, as discussed above, receives a direct explanation: nonexplosives are identical to obstruents in terms of all sonority-related feature specifications.[27]

Should the feature combination [+obstruent, +sonorant] be universally excluded, as Stewart (1989) suggests? Unlike other mutually exclusive feature values such as [spread glottis] and [constricted glottis], such sounds are physically possible: laxly-articulated voiced fricatives such as *z* and *v* often combine the clearly-marked formant structure characteristic of sonorants with the turbulence noise component characteristic of obstruents, and thus qualify as "sonorant obstruents" under the proposed definitions of these features. However, we have so far been unable to find examples of minimal three-way phonemic contrasts among obstruents, sonorants, and a third term which is both of these, such as one between a fully fricative [β_1], a fully sonorant (i.e. approximant) [β_2], and a "sonorant fricative" [β_3]; indeed, even two-way contrasts within this set seem to be unattested. Nor have we found crucial cases in which voiced fricatives pattern with sonorants to the exclusion of obstruents, as such a feature characterization would also predict to be possible. Unless evidence to this effect is forthcoming, it would seem appropriate to retain Stewart's constraint.

A further question is whether the three-way distinction proposed for stops in Table 4 is required for continuant sounds as well. Do we ever find a three-way distinction within the class of continuants among obstruents, sonorants and a third type of sound which is *neither* of these? Such sounds would theoretically be produced with no buildup in oral air pressure and without voicing, or without a clearly-marked formant structure. The obvious candidates to fill this slot are the so-called voiceless sonorants, including the laryngeals *h* and *ʔ*. These sounds have been notoriously difficult to classify in feature terms in the past, due to their behavior in some respects as obstruents, in others as sonorants. An analysis of these sounds as [-obstruent, -sonorant] sounds might go some way toward explaining this ambiguity.

6. Summary and discussion

This paper has proposed that the class of nonexplosive stops, that is, implosives and several related sounds including the nonexplosive pulmonic stops of Ikwere, is characterized by the features [-obstruent] and [-sonorant]. What characterizes the class as a whole phonetically is the absence of air pressure buildup during the occlusion phase combined with a lack of well-defined formant structure. This feature characterization explains a wide range of phonetic and phonological properties of these sounds. We are now in a position to return to the questions raised at the outset of this paper:

How many types of nonexplosive stops can be distinguished phonetically? The number of *phonetic* distinctions that can be drawn within the class of nonexplosive stops is large and perhaps open-ended, as Ladefoged and Maddieson (1996) suggest. It includes not only implosives in the classical sense -- sounds produced with a glottalic ingressive airstream -- but many other sounds, including the nonexplosive stops *ḅ, ’ḅ* of Ikwere described above.

How many of these sounds ever contrast with each other phonologically? Within this large and diverse class, at most a two-way phonological distinction has been documented within any single language, one of whose terms is voiced and the other of which is fully glottalized, that is, produced with complete glottal closure. Other imaginable phonation type contrasts within this class, such as voiced implosive vs. laryngealized, or laryngealized vs. preglottalized, appear to be unattested.

How do these sounds pattern phonologically? Nonobstruent stops exhibit two types of behavior: in some respects, they pattern like sonorants, and in others, like obstruents. Their sonorant-like behavior appears related to their aerodynamic properties (lack of air pressure buildup), while their obstruent-like behavior may be related to their auditory properties (lack of sonority).

What is their feature analysis? The dual phonological behavior of nonexplosive stops supports an analysis characterizing the class as a whole as both [-obstruent] and [-sonorant]. Within this class, voiced and voiceless nonexplosives may be distinguished by the features [constricted glottis], and perhaps [-voice], depending on their status in the system. We conclude that no special features such as [suction], [glottalic airstream mechanism], [lowered larynx], and the like are required to distinguish nonexplosive stops from other stops, or to account for other aspects of their phonological patterning.

We conclude by pointing out a more general consequence of our study for phonological feature theory. The results presented here cannot be easily reconciled with versions of feature theory which hold that phonological primes are defined only in articulatory terms, or only in acoustic-auditory terms, as some current views maintain. The feature [±obstruent] is most easily interpreted as an aerodynamically-based articulatory feature based on the presence vs. absence of increased oral air pressure, as its major acoustic correlate, turbulence noise, is often found to be weak or lacking in voiced obstruents.[28] In contrast, [±sonorant] is most easily defined in the acoustic-auditory domain, since it is difficult to find any unique articulatory definition of the class of sonorants as a whole. This result is consistent with the view that phonological features are best understood as couplings of articulatory and acoustic properties (Lieberman 1970, Halle 1983, Stevens 1983, 1989). In some cases it is simpler to define a given feature in terms of its articulatory correlates, and in other cases an acoustic definition may be more straightforward, but we should be careful to avoid the mistake of extrapolating from a few instances of one case or the other to feature theory as a whole. Phonological features link the abstract representations of phonology to physical continua in both the articulatory and acoustic-auditory domains, and both seem to be essential to a complete understanding of phonology/phonetics relations.

Acknowledgements

We would like to thank Dr Lise Crevier-Buchman of the ORL Service 2, Hôpital Européen Georges Pompidou, Paris, for her valuable assistance in helping us to film and interpret the fiberoptic images discussed in section 4. We have also benefited from many valuable questions and suggestions received from participants at LabPhon 7 and other meetings, including Mary Beckman, Bruce Connell, Didier Demolin, Ian Maddieson, Shinji Maeda, and Janet Pierrehumbert, as well as the useful comments of an anonymous reviewer. Naturally, all responsibility for the content of this paper remains our own.

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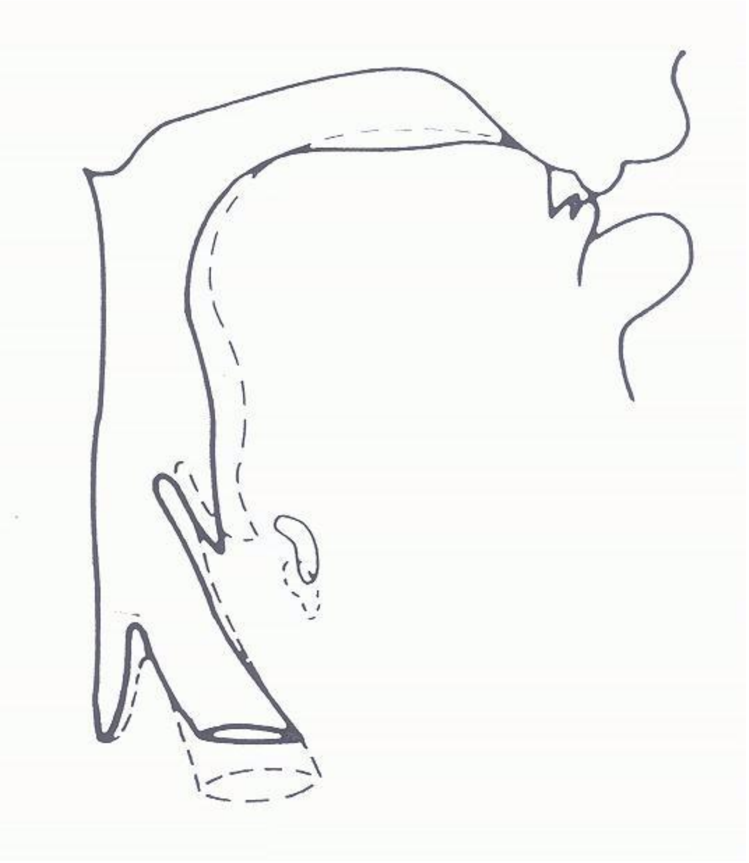


Figure 1. Schematic representation of the midsaggital section of the vocal tract at two points in time during the production of intervocalic [d]: during the consonant closure (solid line); immediately before the consonant is released (dashed line). (After Stevens 1998, Figure 8.69)

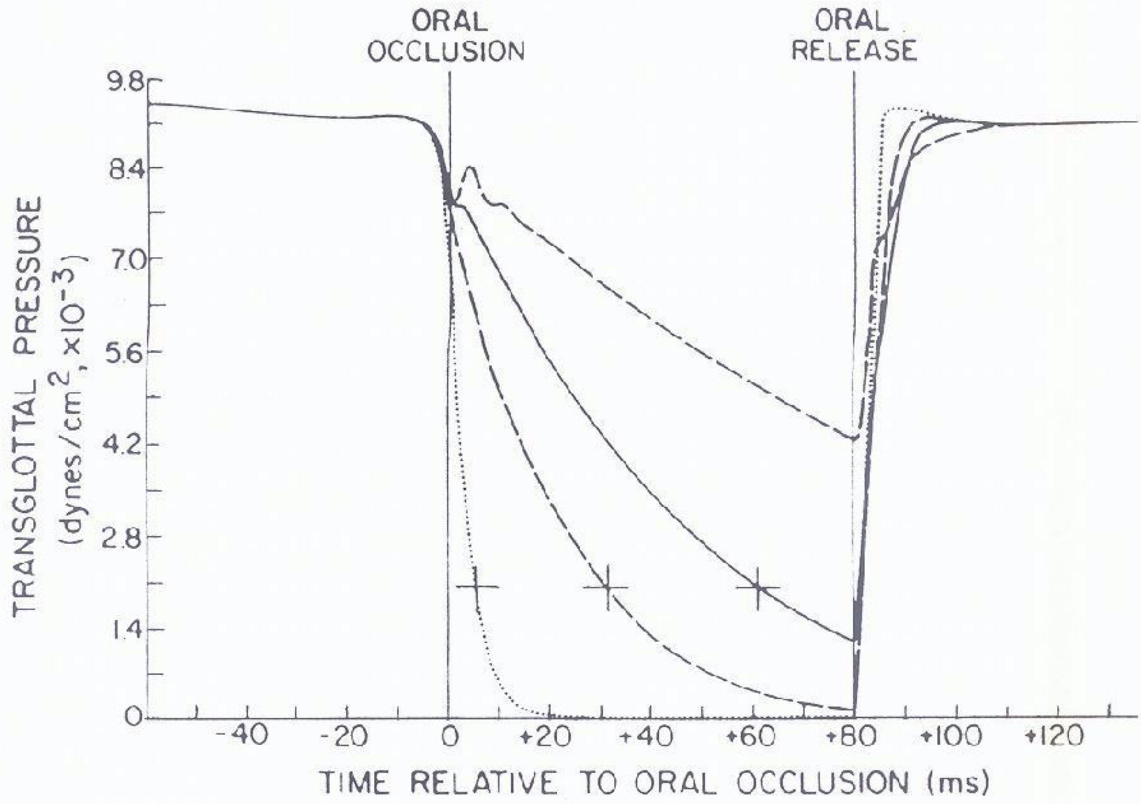


Figure 2. Synthesized time functions of the transglottal pressure gradient during an intervocalic labial stop bounded by rigid walls (dotted line), walls mechanically analogous to the neck wall (lower dashed line), tensed cheeks (solid line), or relaxed cheeks (upper dashed line). Crosses indicate points where the pressure gradient falls below voicing threshold. (After Westbury 1983, Figure 3)

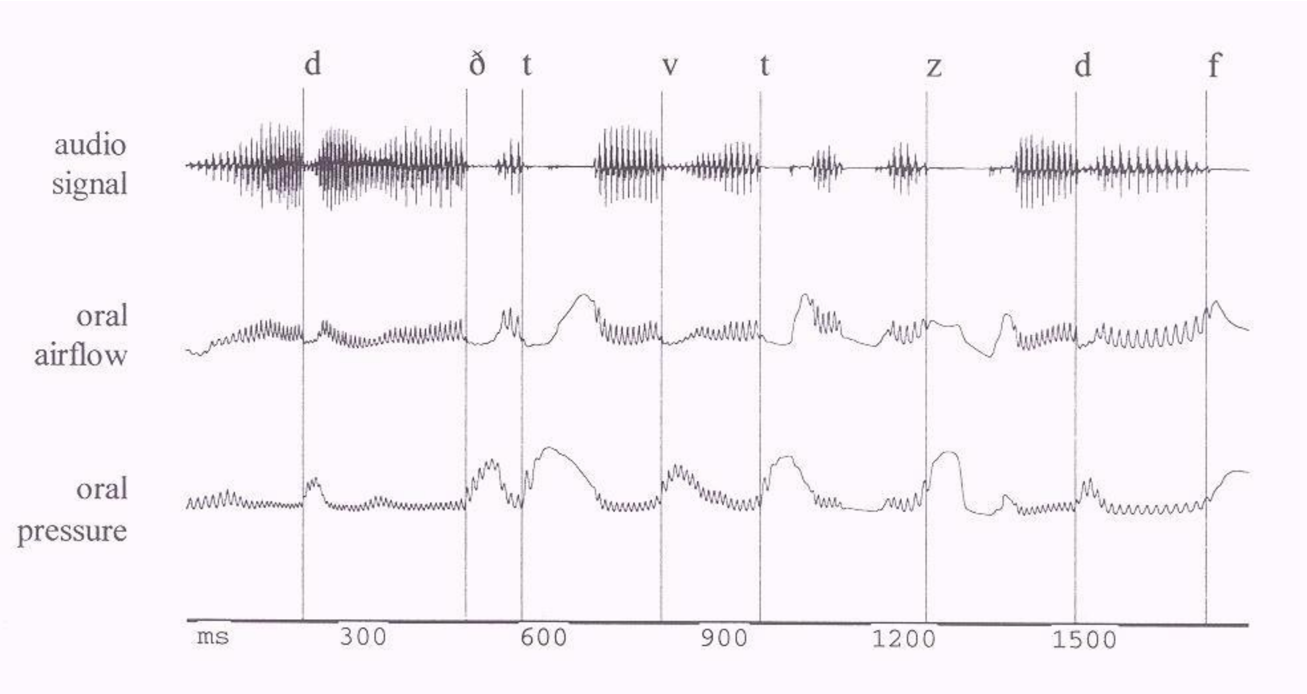


Figure 3. Oral airflow (middle line) and oral air pressure variation (bottom line) during a reading of the passage *right away the traveller took his coat off*. Obstruents are labelled to the right of vertical lines aligned with their beginning (onset of closure). The top line represents the audio signal.

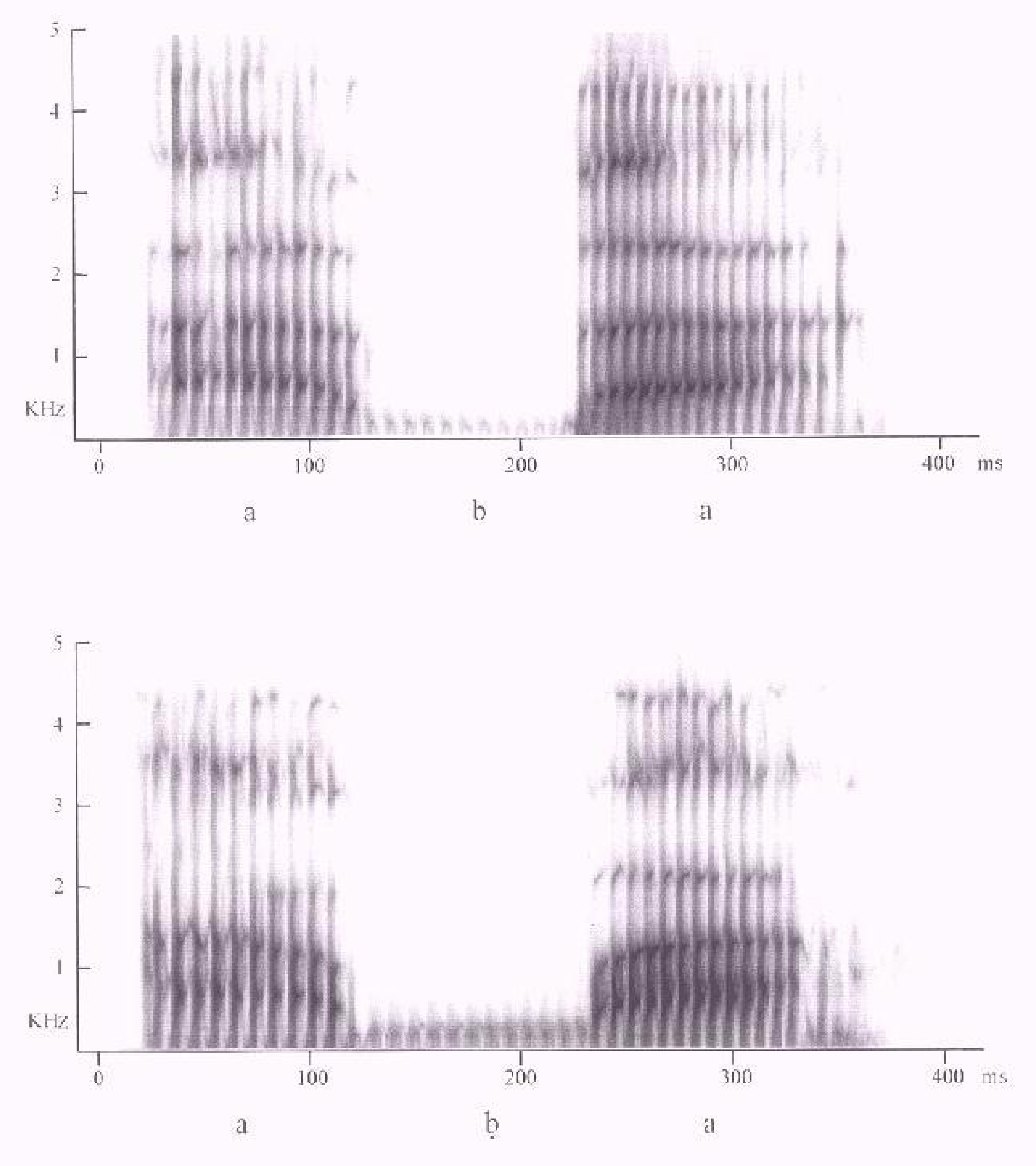


Figure 4. Spectrograms of the words *àbá* (top) and *àḅá* (bottom).

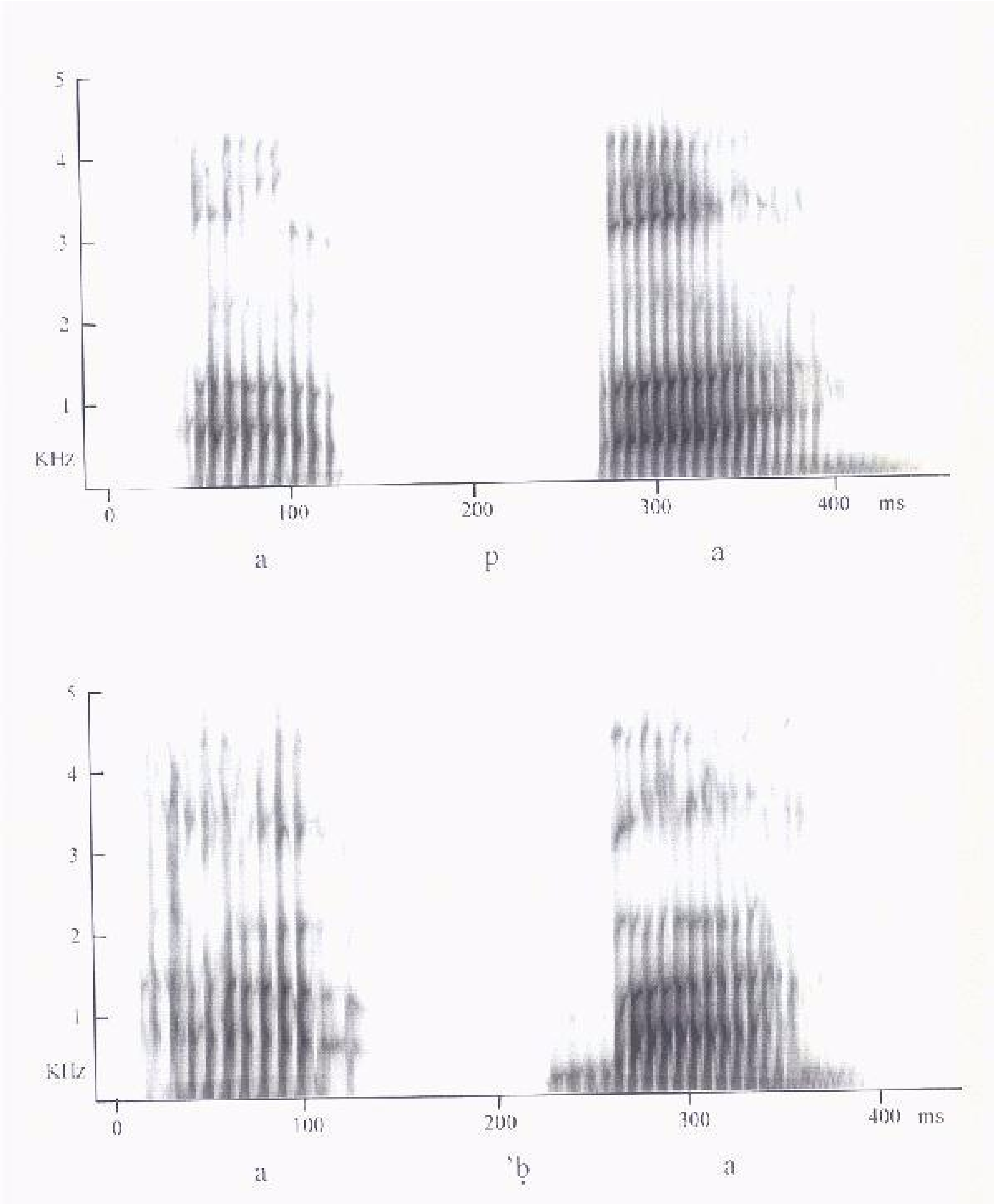


Figure 5. Spectrograms of *àpá* (top) and *à'ḅá* (bottom).

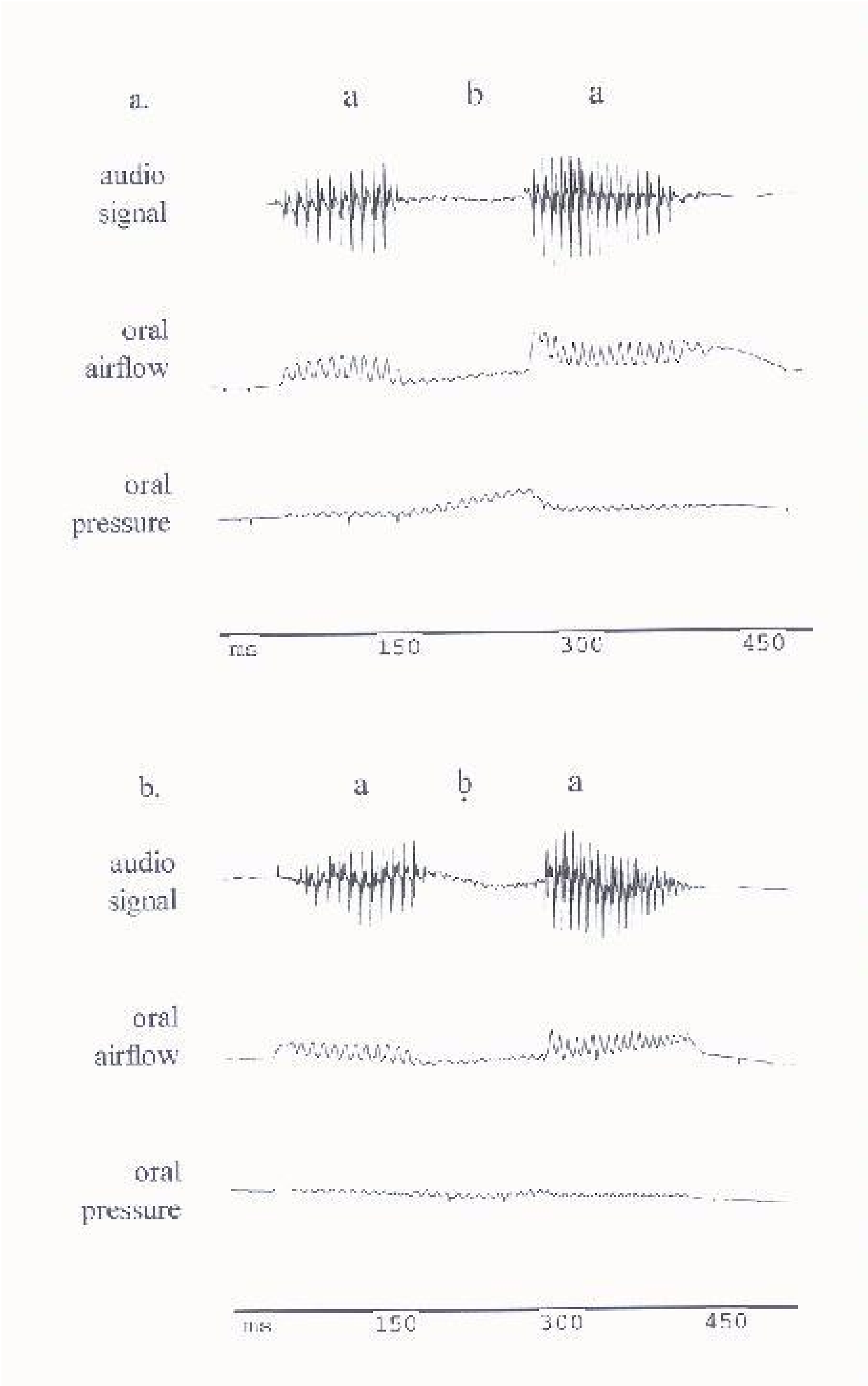


Figure 6. Airflow traces (middle line) and air pressure traces (bottom line) for *b* and *ḅ* in the words *àbá* and *àḅá*. Egressive airflow is shown by a rise of the airflow trace (middle line) above the baseline. Increase in air pressure is shown by a rise in the air pressure trace above the baseline. The top line shows the synchronized audio signal.

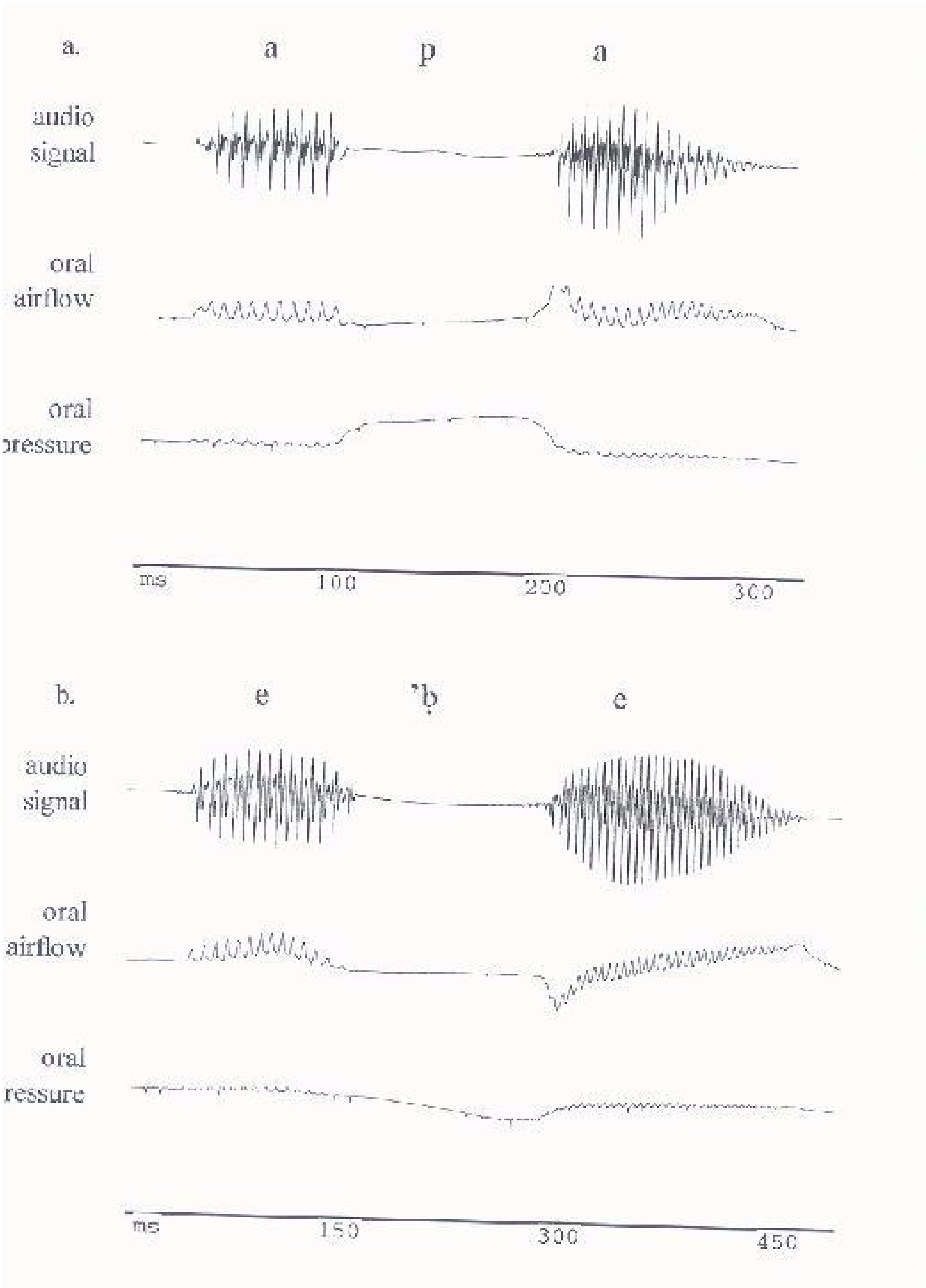


Figure 7. Airflow traces (middle line) and air pressure traces (bottom line) for *p* in *àpá* (a) and *'ḅ* in *è'ḅé* (b). Egressive airflow is shown by a rise of the airflow trace above the baseline, and ingressive airflow by a fall. An increase in oral air pressure is shown by a rise in the air pressure trace, and a decrease by a fall.

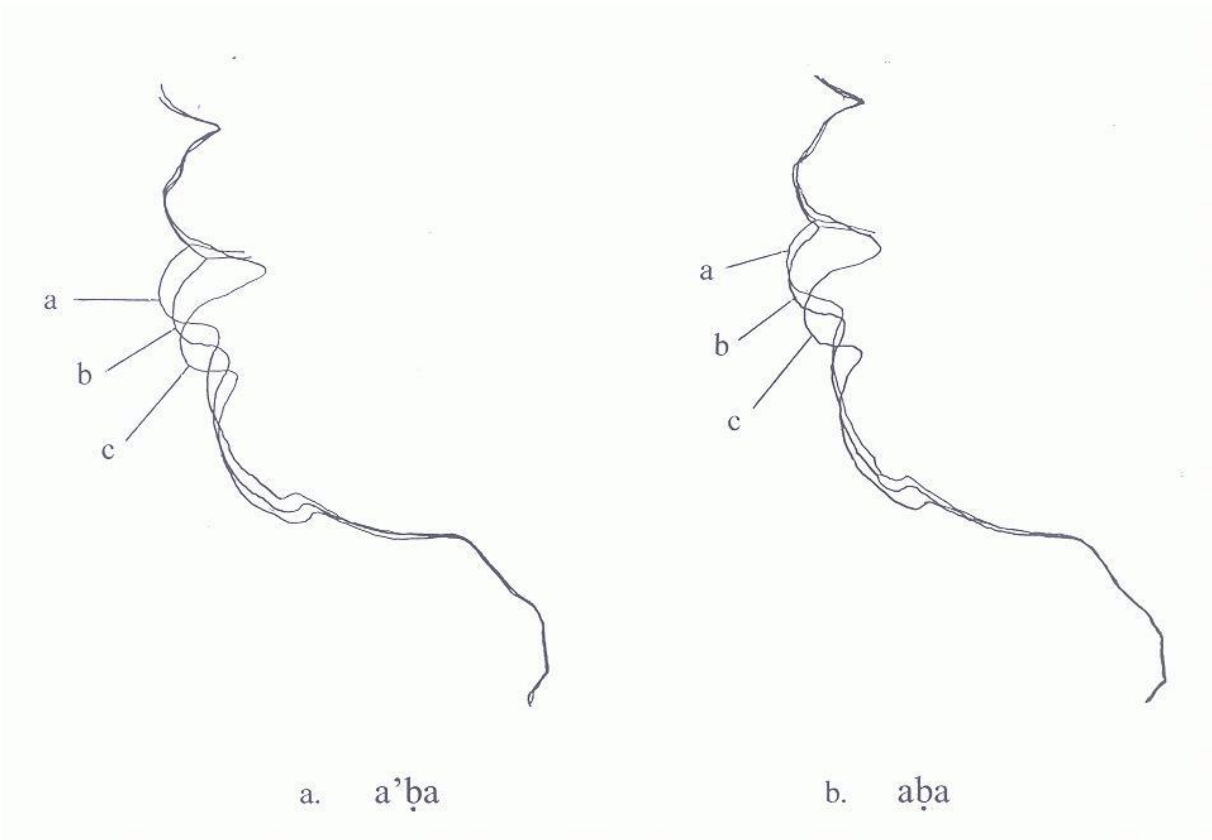
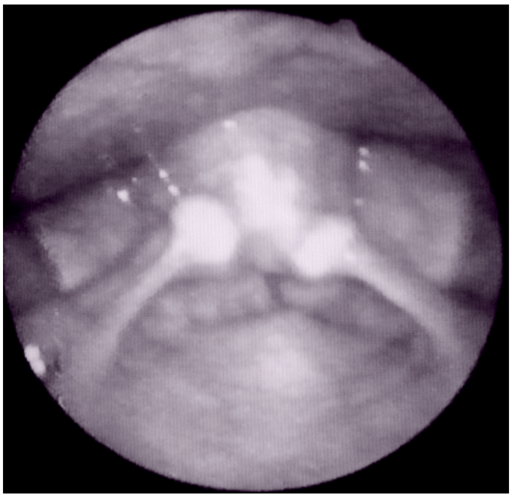
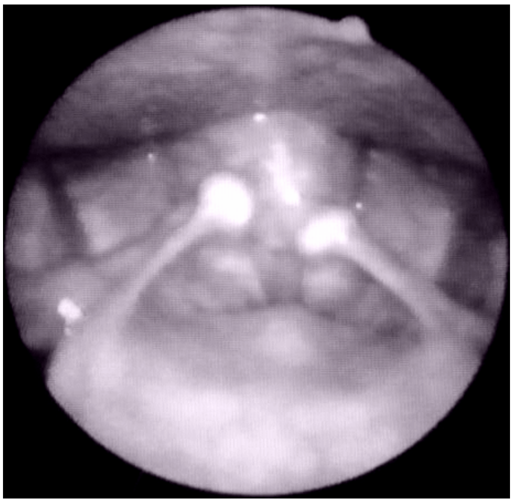


Figure 8. Overlaid profile tracings of three consecutive points at 40 ms intervals during the release of the labial stop into the following vowel in the words *à’ḅá* and *àḅá*: (a) shortly after mid-point in the labial closure, (b) just prior to release, and (c) just after release. The protrusion of the larynx is clearly visible along the profile of the neck, as shown by the arrows.

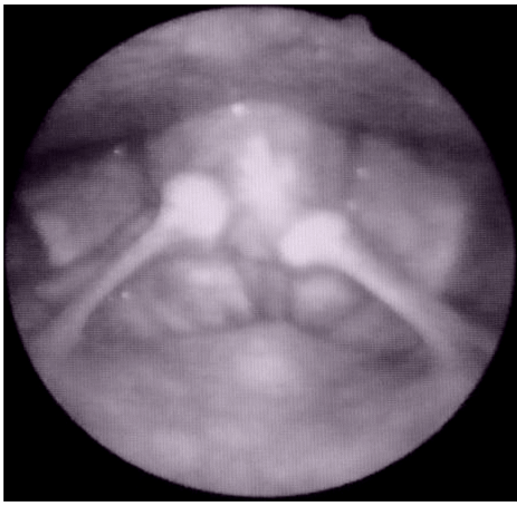


’ḅ

p



ḅ



b

Figure 9. Fiberoptic video frames showing laryngeal views mid-way through the occlusive phases of *’ḅ* (upper left), *p* (upper right), *ḅ* (lower left), and *b* (lower right). The base of the epiglottis is visible at the bottom and the posterior wall of the pharynx at the top.

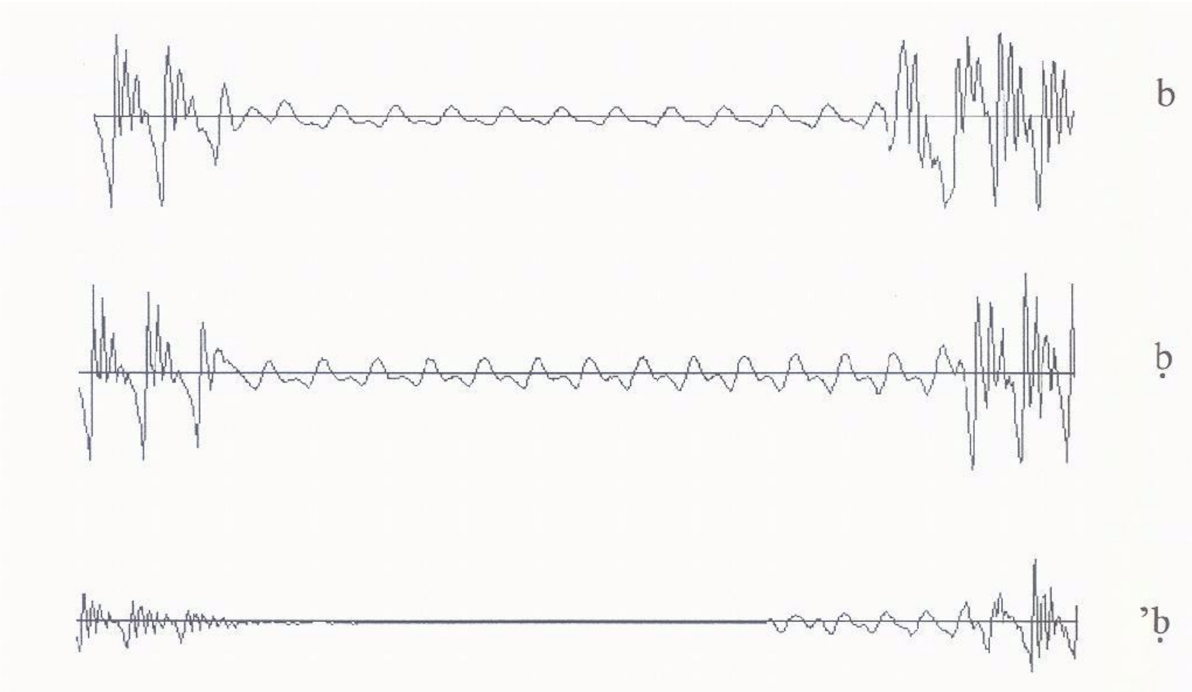


Figure 10. Acoustic waveforms of the occlusive phase of intervocalic *b* (top), *ḅ* (middle), and *'ḅ* (bottom).

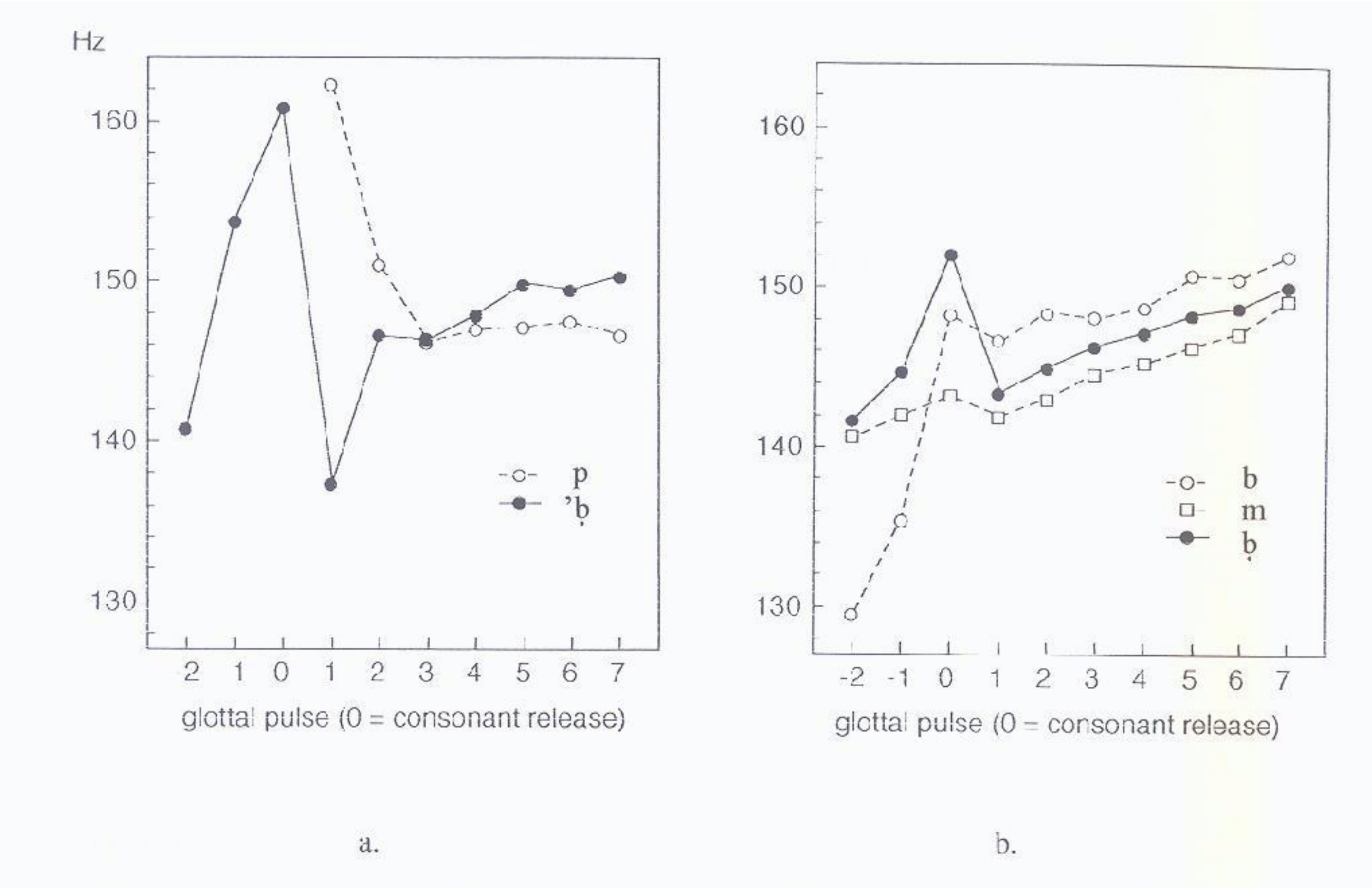


Figure 11. Overlaid f_0 traces for *p* and *’ḅ* (a) and *b*, *m*, and *ḅ* (b), showing averaged f_0 values of ten glottal pulses preceding and following the consonant release. In these graphs, glottal pulses -2 to 0 represent the final f_0 values of the consonant (absent in the case of voiceless *p*), and glottal pulses 1 to 7 represent the f_0 values of the following vowel. N=10.

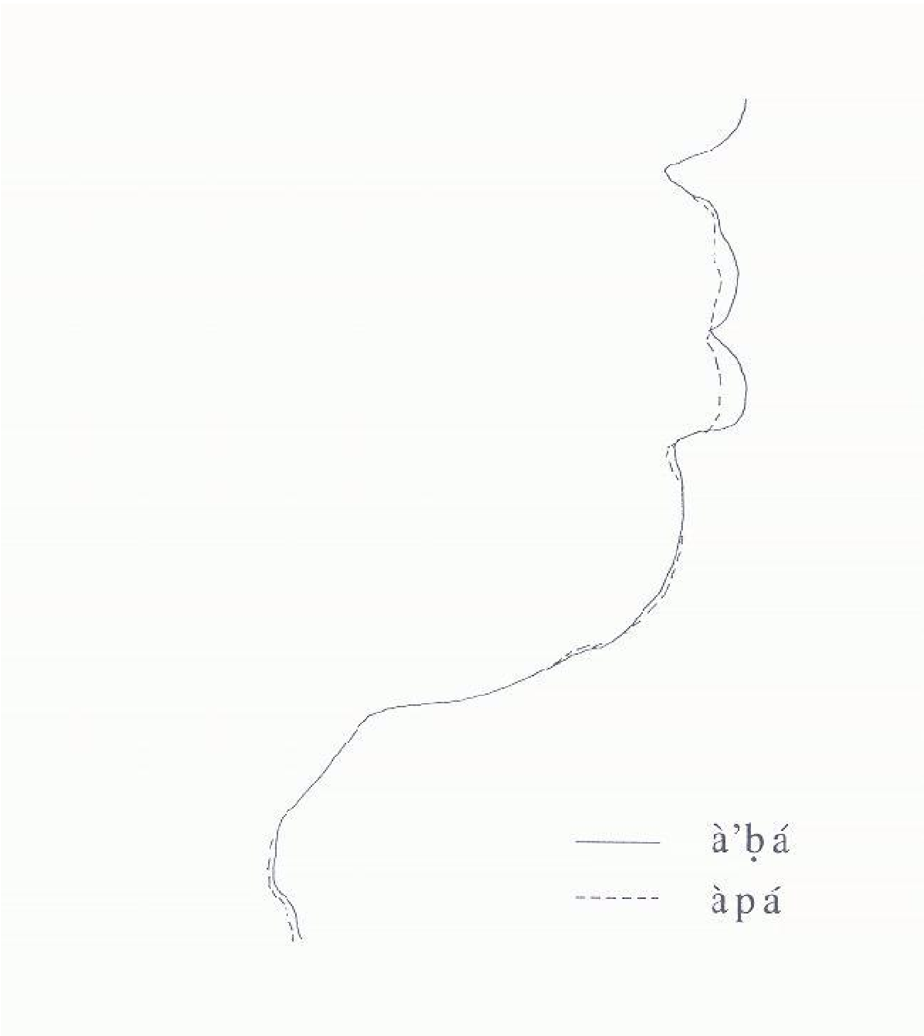


Figure 12. Overlaid profile views of comparable points in the production of the stops *ʼḅ* (solid line) and *p* (dashed line) as produced in the words *àʼḅá* and *àpá*.

Notes

[1] Two further types of "nonstandard" stops are not discussed in this paper, since they are fully or partly explosive: ejectives, produced with complete glottal closure and an egressive airstream following the glottal and oral releases, and clicks, produced with a double closure in the oral cavity and an egressive airstream following the release of the posterior closure.

[2] The term "oral cavity" is used in this paper to refer to the portion of the vocal tract extending from the larynx to the lips, excluding the nasal cavity.

[3] The term "airstream mechanism" is due to Pike (1943). Catford, though using the term "mechanism" in his 1939 paper, later preferred to speak of "initiator types" (1977: 247-8).

[4] In modal voicing, the glottis closes completely during part of the cycle, but the vocal folds are not pushed tightly together during the closed phase (Stevens 1998: 59).

[5] Chomsky and Halle held that voicing is "spontaneous" when the vocal cords are placed so as to vibrate spontaneously in response to an unimpeded airflow. When the airflow is impeded, as in obstruents, air pressure builds up behind the constriction in the oral cavity, reducing airflow velocity across the glottis. Under this condition, supplementary adjustments must be made if vocal cord vibration is to be maintained. Chomsky and Halle speculated that vibration may be facilitated by increasing the size or duration of the glottal opening on each glottal cycle; however, this speculation has not been confirmed in subsequent work (see e.g. Ladefoged 1971: 109-110).

[6] The device used for obtaining air pressure measurements was PCQuirer, a pressure and airflow measurement apparatus manufactured by SciCon, Los Angeles, CA. Speech produced with an oral face mask tightly fitted over the mouth is not entirely natural. However, pressure variation over different types of speech sounds proves to be relatively constant from one reading to another, and is assumed here to be representative of more natural speech in relevant respects.

[7] Maddieson (1984) draws a distinction between *glottalized* sounds, in which a glottal constriction is superimposed on a pulmonic airstream mechanism, and *glottalic* sounds, produced with the glottalic airstream mechanism. As Catford notes (1977: 248, note 2), it is often useful to extend the term "glottalized" to both types of sounds in phonological descriptions, since they frequently pattern together and are rarely if ever contrastive. This practice is followed here, except when the difference between "glottalic" and "glottalized" sounds is relevant to the discussion.

8 However, Dimmendaal (1986) argues that preglottalized stops represent a genuine phonetic and phonological category distinct from voiceless implosives, citing arguments such as their auditory distinctiveness, the presence of an independent glottalized sonorant series in some languages (such as Lendu), and, assuming them to be basically voiced sounds, their general conformity with the generalization that voiced consonants favor front places of articulation.

9 Ikwere [ìkʷéré] is spoken by a people of the same name inhabiting the Rivers State in Southeast Nigeria (Osu 1998). It is classified among the Delta Igboid languages of the Benue-Congo subgroup of Niger-Congo (Williamson, in press). The present study is based on the speech of one of the authors (SO), from Ogbakiri [ɔ̀ḅàkìrì]. The discussion in this section draws in part on material presented in Clements and Osu (2000).

10 We use a non-IPA symbol (the subscript dot) to transcribe the nonexplosive pulmonic stops *'ḅ* and *ḅ*, as no existing IPA symbol seems completely appropriate for these sounds.

11 Spectrograms and waveforms were made with the CSRE42 speech analysis package (Avaaz Innovations, Inc., Ontario).

12 Some of our traces for *ḅ* show a small amount of oral air pressure increase, always well below values for *b*.

13 While these tokens of *'ḅ* are typical of most that we have seen of deliberate citation-form utterances, other tokens, especially in utterance-medial position, show a flat air pressure trace and no ingressive (or egressive) airflow.

14 It is possible, as Ian Maddieson suggests to us, that further laboratory tests using specialized equipment might reveal small larynx movements that we were unable to detect in the videos. We do not know whether such minute movements could account for the air pressure and airflow differences we have observed in Ikwere, though they might well contribute to them. It is unlikely, in any case, that field reports of larynx lowering in implosives in other languages are based upon movements undetectable by eye, and it seems reasonable to conclude that the Ikwere stops are produced by a different mechanism than the canonic implosives reported in the descriptive literature.

15 These sounds occurred in the words *è'ḅé* 'to pray', *èpérú* 'to take a liquid', *èḅê* 'to fry', and *èbé* 'weevil'.

[16] Fiberscopic evidence for larynx movement is indirect and must be interpreted with caution. Since the fiberscope rides on the velum, lowering of the velum moves the objective lens closer to the larynx, giving a “zoom in” effect similar to that resulting from larynx raising, and conversely for velum raising. We have noted such effects at transitions between oral and nasal sounds and have excluded them in interpreting our data.

[17] The tone-depressing effect of ordinary voiced obstruents is usually attributed to the reduced vocal fold tension associated with larynx lowering (Hombert et al. 1979). According to Stevens (1998: 466-7), larynx lowering tends to shorten of the vocal folds by about 2-3 percent, which theoretically decreases vocal fold stiffness in the range of 9-15 percent. This reduction in stiffness facilitates voicing during the closure phase of a stop, and when carried over into an adjacent vowel should lower its fundamental frequency by an estimated 5-7 percent. (See Ewan and Krones 1974, Ohala 1978, Traill et al. 1987, and Maddieson 1997 for further discussion.)

[18] Kutsch Lojenga found no clear raising or lowering effects after voiced implosives. She suggests that the greater f_0 rise in voiceless implosives might be due to their full glottal closure, which creates a greater transglottal pressure buildup.

[19] The words were *àpá* 'to climb', *à'ḅá* 'to sow', *èbê* 'to touch', *èḅê* 'to prepare food', and *àmá̰* 'to show wisdom', and the frame sentence was *kǎ* __ *míḅá lâ* 'say X twice'. The lexical falling tones of *èbê* and *èḅê* were realized as high tones in this context.

[20] In the case of *m*, the small spike at point 0 probably has another cause, since sonorants produced with a continuous airstream passing through the mouth or nose are expected to perturb f_0 minimally or not at all (Hombert et al. 1979: 40).

[21] Test words were *àpá* ‘to climb’, *à'ḅá* ‘to fast’, *èbê* ‘to touch’, *èḅê* ‘to prepare food’, and *àmá̰* ‘to show wisdom’.

[22] We also exclude an analysis in which *'ḅ* and *ḅ* are treated as distinctively rounded stops, as opposed to spread *p* and *b*, for two main reasons. First, our videotapes show that the lips are maximally protruded at the mid-point of *'ḅ* and *ḅ*, rather than at their release. In distinctively rounded sounds, such as Ikwere k^w, g^w, h^w, maximum protrusion coincides with release and is typically prolonged into the vowel, creating a *w*-like transitional sound which provides a cue to the rounding of the consonant. These effects are not present in Ikwere *'ḅ*, *ḅ* Second, while the feature [obstruent]

accounts for a full range of phonetic and phonological properties of *’ḅ* and *ḅ*, including but not limited to the fact that they are produced with lip protrusion (which, by lengthening the vocal tract, tends to reduce oral air pressure), a feature [round] would not account for the other properties of these sounds.

[23] Our videotapes show that *p* and *b* are also produced with some jaw lowering before release of the lip constriction. However, a frame-by-frame examination of the data suggests that *’ḅ* and *ḅ* are produced with a faster descent of the lower lip than are *p* and *b*, perhaps due to the fact that the lower lip drops to a lower position after the release of *’ḅ*, *ḅ* than it does after *p* and *b* over the same period of time, creating a larger lip aperture at the beginning of the following vowel. These differences, together with differences in lip protrusion at release, may be responsible for the rapidly rising formant transitions observed at the release of *’ḅ* and *ḅ* (see Figures 4 and 5), which provide one of the main auditory cues distinguishing *’ḅ* and *ḅ* from their explosive counterparts.

[24] Our fiberoptic images show that the epiglottis moves forward during the stop phase of *’ḅ* and *ḅ*, but it is also advanced during the stop phase of *p* and *b*.

[25] Some West African languages, such as Igbo and Ikwere, appear to contradict this generalization. However, in these languages the sounds written *n*, *m*, etc. before liquids, glides and other consonants are tone-bearing and probably represent nasal vowels, rather than true consonants. In some other languages allowing *n*, *m* before liquids and glides, such as Ganda (Luganda), the nasal constitutes a tone-bearing mora. As these cases do not involve true consonant clusters, they do not constitute exceptions to the above statement.

[26] Stewart's discussion pertains primarily to what he calls “lenis” stops, but he takes these sounds to be comparable to implosives in relevant respects (1989: 232-3).

[27] The sonority-defining features, in Clements’ proposal, are [+sonorant], [+approximant], and [+vocoid], the latter corresponding to the more familiar [-consonantal].

[28] Recall, for example, the spectrogram of Ikwere [b] in Figure 4, showing a weak transient at the stop release but no noise burst as such.