Figure 3.3 Waveforms of consonant closure and portions of adjoining vowels in the Fula utterances o dari 'he stood' (top) and o da:nike 'he slept' (bottom), as spoken by a male speaker from Guinee.

At one end of the range of timing options are the laryngealized stops of Serer, in which the laryngealization typically consists of a very rapid change from normal voicing to a glottal stop, followed by a rapid change back to normal voicing again (Ladefoged 1968). The glottal stop usually occurs a few milliseconds before the consonant closure is made. This form of creaky voice is reminiscent of the glottal catch that occurs in Danish. In this language many words have a brief superimposed glottal constriction known as a *stod*. This is clearly not a property of particular stops. It is a suprasegmental or prosodic feature which applies to words as a whole. A full account of the Danish *stod* is therefore outside the scope of this book, in which we are limiting the discussion to the segments of the world's languages, but a comprehensive description has been given by Fischer-Jorgensen (1987).

A creaky voice type of vocal fold vibration persisting through the closure of a stop is often observed in Fula, a language quite closely related to Serer. The distinction between modally voiced and creaky voiced stops is illustrated by the waveforms in figure 3.3. Both these closures are of short duration, about 50 ms, and contain approximately five full voicing periods (i.e. they are similar in fundamental frequency). There are two main differences to note. In the modally voiced stop the amplitude of the vibrations decreases over time, whereas the creaky voiced stop shows a generally increasing amplitude pattern. The modal voice pulses are simpler in shape than the creaky voiced pulses, which show a minor pulse between the major ones. The difference in the amplitude different continua. One concerns the degree of glottal constriction involved; this varies along a continuum from modified voicing to a simultaneously produced glottal stop. The second concerns the timing of oral and laryngeal movements; this is a continuum from a single segment such as d to a sequence such as d? or ?d. The third concerns oropharyngeal expansion; this is a continuum that links modally voiced stops to implosives. We will return to these perspectives as we discuss co-produced glottal stops and airstream mechanisms below. On the first continuum an intermediate state between modal voice and creaky voice can be labeled stiff voice.

Stiff voice

We are using the term stiff voice to denote a slight degree of laryngealization which may be associated with a contraction of the vocalis muscles. Stevens (1988) has suggested that stiff voice is a distinct state of the glottis. We have found that it is often difficult to say when the degree of muscular activity is sufficiently great for a sound to be considered to have stiff voice as opposed to modal voice. It is also often difficult to distinguish between stiff voice and creaky voice, both of them being simply states of increasing glottal constriction, within a continuum of this kind. There may be quantal states of the glottis as suggested by Stevens, but they are not easy to determine in practice. It is also true that there are no linguistic grounds for postulating a greater number of types of stiff or creaky voice. Languages contrast modal voice with no more than one degree of laryngealized voice. Nevertheless there are occasions when there are clear phonetic differences between stiff voice and the kinds of creaky voice that we have been considering in the previous section. There are a number of languages with stops that have a slight degree of laryngealization. A good example is Thai, which has a three way contrast among stops as shown in table 3.3, in which the pair of segments usually symbolized b, d are often pronounced with stiff, or even creaky, voice at least during the onset of the closure.

A language using a different variety of stiff voice in consonants is Korean. In word-initial position this language has three different sets of voiceless stops,

VOICELESS ASPIRATED	p^ha: 'cloth'	t^ha: 'landing place'	tc^ha:m 'bowl'	k^ha: 'leg'

Table 3.4 Contrasts between the three sets of stops in Korean. The stiff voiced stops are transcribed p*, t», k*

	BILABIAL	DENTAL	AFFRICATED POSTALVEOLAR	VELAR
ASPIRATED	p^hul 'grass'	t^hal 'mask'	tpa 'tea'	k^hin 'large'
UNASPIRATED	pul 'fire'	tai 'moon'	tja 'ruler'	kin 'measure of weight'
STIFF VOICE	p*ul 'horn'	t*al 'daughter'	tf*a 'salty'	k*in 'rope'

as shown in table 3.4. These three series are sometimes described as being aspirated, unaspirated lenis, and unaspirated fortis. The fortis series of stops differs from the other two series in a number of ways, but, as has been shown by Dart (1987) many of the observed differences can be attributed to the laryngeal activity associated with the stiff voice position of the vocal folds. Thus there is a higher F_o at voice onset after fortis stops than after lenis stops. In addition, voice onset after fortis stops is very sharp with relatively undamped harmonics in comparison with the lenis stops (cf. also Han and Weitzman 1970, Hardcastle 1973), which is due in part to the increased tension of the vocal folds.

Kagaya (1974) has also noted that the three Korean stop types have very different laryngeal adjustments. He showed that, for utterance-initial stops, during closure the maximum glottal opening is largest for the aspirated stop, intermediate for the lenis stop, and smallest for the fortis stop, and the timing of the laryngeal gesture relative to articulatory release varies between these stops. For the aspirated stops, release generally occurred near the moment of maximal opening of the glottis. For lenis stops, although the glottis was still quite open at release, there was a more or less continuous decline in glottal area throughout the occlusion. On the other hand, during the fortis occlusion,

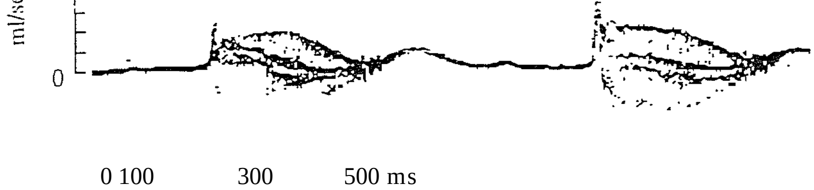


Figure 3.4 Data redrawn from Dart (1987) and Kagaya (1974) illustrating contrasting unaspirated stops in Korean. It should be emphasized that the data combined here were taken from different utterances, and may not truly represent any single speaker.

the vocal folds came together well before release. Fortis closures were also considerably longer than the lenis closures. We should also note that Dart's evidence from modeling indicates tenser vocal tract walls for the fortis stops, and a more rapid increase in respiratory muscle force. Some speakers may exhibit larynx lowering or other supraglottal cavity expansion just before releasing the fortis stop. It is apparent, therefore, that the Korean fortis stops have many distinct phonetic characteristics, a particular laryngeal setting being only one of them. Data from Dart (1987) and Kagaya (1974) illustrating the unaspirated contrasts are given in figure 3.4.

Breathy voice (murmur)

Just as it is convenient to distinguish between stiff voice and creaky voice, so it is also convenient to distinguish between slack voice and breathy voice, using the term breathy voice to describe sounds that have a higher flow rate and a looser form of vibration of the vocal folds than occurs in the sounds with slack voice, which will be described in the next section.

Breathy voice is most readily audible as a distinguishing characteristic of stops only during the release of a closure. The most well-known stops that have breathy voice during their release are those that occur in Indo-Aryan languages such as Hindi and Marathi. However, stops of this kind also occur in

VOICED ASPIRATED	b^{fi}al 'forehead'	d^{fi}ar 'knife'	d^{fi}al 'shield'	d3^{fi}Bl 'glimmer'	g^{r,}an 'bundle'

many other language families in the same general area, including Dravidian languages such as Telugu, Tibeto-Burman languages such as Newari, and Austro-Asiatic languages such as Mundari. Breathy voiced stops also occur in a number of African languages, some of which will be discussed below.

Words illustrating the stop contrasts in Hindi are given in table 3.5. Dixit (1989) has shown that the breathy voiced plosives in Hindi have less activity of the cricothyroid muscle, reflecting a relative slackness of the vocal folds; a moderately open glottis (about 50 percent of that used during aspiration); a high rate of oral airflow; a rapid and brief drop in subglottal air pressure (a feature shared with voiceless aspiration); random distribution of noise in the regions of the upper formants of the following vowel, but with voice also present, and comparatively greater concentration of acoustic energy at the fundamental frequency than at the second harmonic. Very similar results are reported by Kagaya and Hirose (1975) and Benguerel and Bhatia (1980) for Hindi and by Yadav (1984) for Maithili. Their most important findings concern the timing of the glottal opening. As illustrated in figure 3.5, both voiceless and breathy voiced stops are characterized by an abduction of the vocal folds. In the case of the voiceless stops this starts about 80 ms before the release, making it approximately simultaneous with the formation of the closure. For the breathy voiced stop the glottis begins opening at about the mid-point of the duration of the oral closure and reaches its maximum at the time of the release of the stop closure.

A consequence of this timing is that breathy voiced stops in Hindi and many other Indic languages are acoustically distinguished from plain voiced stops by what happens after the release rather than by audible differences during the closure. A breathy voiced stop followed by a vowel shows an acoustically noisy but periodic interval as the glottal gesture overlaps the articulation of the vowel. The spectrograms in figure 3.6 illustrate this contrast in the Hindi words bal 'hair' and b^al 'forehead'. During the voiced stop on the left of the

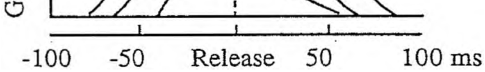


Figure 3.5 Glottal aperture in Hindi stops, based on fiberoptic data in Kagaya and Hirose (1975).

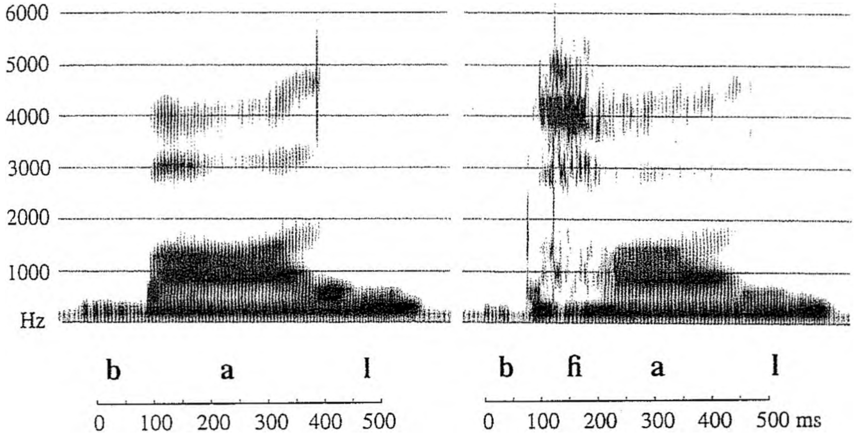


Figure 3.6 Spectrograms illustrating modal and breathy voiced stops in the Hindi words bal 'hair' and b^{B}aJ'forehead'.

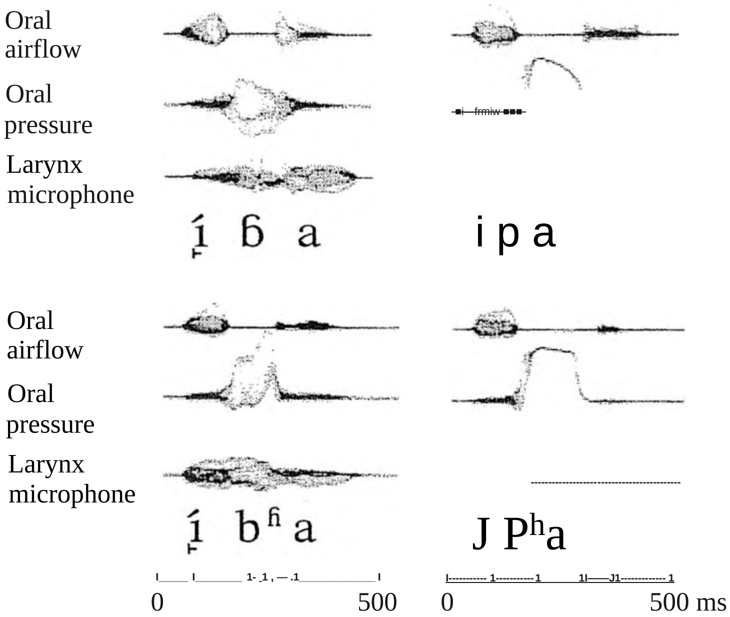
figure there are vocal fold vibrations throughout the stop closure which continue on into the vowel. During the breathy voiced stop on the right of the figure there are also vocal fold vibrations in the first part of the closure, but they become lower in amplitude towards the end as the vocal folds come further apart. For a period of about 100 ms after the closure there are breathy voiced vocal fold vibrations. It has also been shown that vowels before breathy voiced stops tend to be a little longer than before modally voiced stops (Maddieson and Gandour 1977), which may assist in maintaining the perceptual distinction between them.

The breathy voiced stops that occur in languages outside the Indian subcontinent are somewhat different. For example, Owerri Igbo has a four-way stop contrast that is nominally similar to that in Hindi. (Owerri Igbo also has other contrasts involving the glottalic airstream mechanism which we will discuss later.) Table 3.6 (from Ladefoged, Williamson, Elugbe and Uwulaka 1976) shows a set of contrasting stops in this language.

Aerodynamic data illustrating Igbo bilabial stops is given in figure 3.7. Here we will focus on the breathy voice stop, but we will first comment briefly on the other pulmonic stops. As in Hindi and many other languages these sounds contrast in Voice Onset Time (VOT). In the case of the aspirated stop p^h, the airflow record indicates that immediately after the release of the closure there is a burst of air without vibration of the vocal folds; in the unaspirated stop p the voicing vibrations start the instant the closure is released. The pressure record also shows that at the onset of both these voiceless stops the speaker continues the voicing for a short period of time after the closure of the lips. As noted earlier, this sort of delay in the voice offset time in voiceless stops has been observed in other languages, including English (Ladefoged 1967). The pressure and larynx microphone records also show that voicing occurs throughout the closure for the voiced stop b. The implosives in figure 3.7 will be discussed later in this chapter.

In the case of $b^{ɦ}$ the pressure record shows that the vocal folds are vibrating throughout the closure, and the airflow record shows a slightly higher than normal flow rate immediately after the release of the closure. In all our records of this language, the difference in flow rate between the voiced and the breathy voiced stops is not very great, but it is sufficient to indicate that during the release of the breathy voiced stops the vocal folds must be slightly further apart (in terms of the distance between the arytenoid cartilages) than they are during normal voiced sounds.

The change from breathy voice to regular voicing often occurs after only a



Figiire 3.7 Aerodynamic records of six Owerri Igbo bilabial stops.

few vibrations of the vocal folds. It is very difficult to say exactly when the change occurs from data such as the aerodynamic records in figure 3.7. Spectrograms such as those in figure 3.8 are a little more helpful. This figure shows the pronunciation of the voiced velar stop in j ga 'to go' on the left, and the breathy voiced velar stop in j g^a 'to thread' on the right. The voicing throughout the closure is evident for both stops. Spectral components corresponding to periodic vibrations of the vocal folds can be seen in the lower frequencies (near the base line) throughout this interval. As in Hindi, their amplitude decreases during the closure for the breathy voiced stop. The waveform of the breathy voiced stop has greater amplitude in the burst, because of the

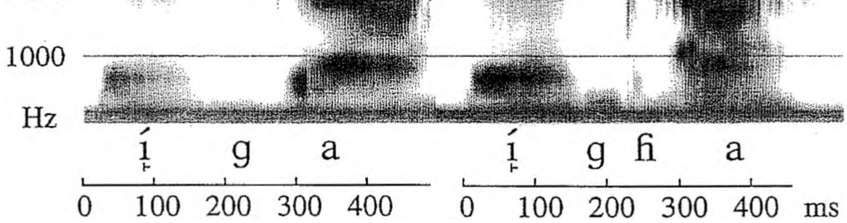


Figure 3.S Spectrograms illustrating voiced and breathy voiced velar stops as produced by a female speaker of the Owerri dialect of Igbo.

greater oral pressure that is being released. After the release, the interval in which there is obvious breathiness is somewhat shorter (about 30 ms) than in the Hindi stop shown in figure 3.6. For this speaker the breathy interval is clearly detectible, but other speakers only a very small difference between the breathy voiced and the regularly voiced stop. Generally speaking, the breathy voiced stops in Owerri Igbo appear to have a shorter breathy voiced period, and to have stronger voicing than the corresponding sounds in Hindi and other Indo-Aryan languages. We have no data on the degree of opening of the glottis, but we would expect the glottal area to be less in Owerri Igbo breathy voiced stops than in Hindi breathy voiced stops.

In these Igbo sounds it seems that even during the stop closure the vocal folds are vibrating more loosely than in the regularly voiced sounds. This fact can be deduced from the oral pressure records which show consistent differences between breathy voiced $b^{\text{ɦ}}$ and regularly voiced b. In most cases (see Ladefoged et al. 1976), the oral pressure reaches a higher value towards the end of the closure in $b^{\text{ɦ}}$ than in b. We must conclude that during the closure (as well as during the release) the vocal folds are vibrating more loosely in the breathy voiced stops, so as to allow more air to flow through the glottis into the mouth in a shorter period of time. The closure duration of the breathy voiced stops is also shorter than that of the voiced stops, which may be an indirect result of the differences in oral pressure.

Yet another kind of sound that might be thought to involve breathy voice occurs in Zhu|'hbasi which has contrasts as shown in table 3.7. The initial stops

VOICED-PLUS-ASPIRATED	bp^he 'to spit out'	dt^ha 'blanket'	gk^haro 'bed'

in the last row are transcribed bh, dh, gh by Snyman (1975) and thus appear to be similar to those in Hindi. In fact they are something more unusual. As Snyman himself has shown, Zhu|'hoasi has a considerable number of consonant clusters that have the first element voiced and the second voiceless. The initial consonant sequences in the last row of this table are examples of such combinations. We will return to the topic of obstruent clusters with mixed voicing in Zhu|'hbasi in our discussion of ejectives.

Slack voice

As with stiff voice, we should note that slack voice designates a region within the continuum of glottal aperture. In this section we will consider stops with slack voice. These stops have a slightly increased glottal aperture beyond that which occurs in modal voice, and a moderate increase in flow. When there is a considerable glottal aperture and a high rate of flow of air while the vocal folds are vibrating, we will say that the sound is pronounced with breathy voice, as discussed above.

One type of slack voice occurs in Javanese, which has contrasting pairs of what we will call slack and stiff voiced stops at the bilabial, dental, retroflex and velar places of articulation, as shown in table 3.8. Fagan (1988) has noted that these stops have been called light versus heavy, tense versus lax, voiceless unaspirated versus voiceless aspirated, and aspirated versus unaspirated. In initial position neither the stiff nor the slack voice stops have vocal fold vibration during the closure. Hayward (personal communication) investigated these sounds using fiberoptic techniques. She found that the arytenoids remained close together during the closure for the stiff voice stops, much as they do in Korean. The stiff and slack voiced stops differ in that the opening between the vocal folds is noticeably greater for slack voice. The