Phonetic characteristics of an unexploded palatal implosive in Hendo

Didier Demolin
Hubert Ngonga-Ke-Mbembe
Alain Soquet
Phonology Laboratory, Université Libre de Bruxelles
ddemoli@ulb.ac.be

This paper describes the phonetic characteristics of an unexploded palatal implosive in Hendo, a Bantu language spoken in the Democratic Republic of Congo. This sound is an allophone of a palatal affricate implosive. Consideration of acoustic, aerodynamic and articulatory data obtained from various methods give a precise description of this sound.

1 Introduction

Lohendo is spoken in Western Kasaï within the Kole area of the Democratic Republic of Congo. Several studies have quoted this language under the name of Songomeno (Guthrie 1948) or Nkutshu (Hulstaert 1950; Van Bulck 1948, 1952; Bongo 1968). The first is a nickname and the second is a generic term. Bongo (1968) points out that what he calls 'Ohendo' is an Nkutshu dialect. The survey of Zairian (now Congolese) languages (Atlas Linguistique de l'Afrique Centrale 1983) opts for Lohe:hendo. We will adopt the convention for Bantu languages that languages should be quoted by the root of their name, in this case Hendo. According to standard classification of Bantu languages (Guthrie 1948), this language is classified as falling within area C 82, but in the revised classification proposed by Bastin et al. (1983), Hendo belongs to the same area but in a different group, C 73.

One of the striking phonetic features of this language is the existence of an unexploded palatal implosive consonant at the beginning of words belonging to morphological classes 5 and 8. This sound is transcribed here with the IPA symbol [ʄ̚]; it is syllabic and occurs before both voiced and voiceless consonants. This sound lengthens the voicing of a voiced initial consonant and shows weak amplitude voicing before voiceless consonants. Examples of words containing [ʄ̚] are presented for all possible contexts in table 1 below.

The aim of this paper is to describe the articulatory, aerodynamic and acoustic characteristics of this sound, the realization of which is difficult to explain. Several attempts have been made to describe its particular properties. For Léon Stappers (personal communication), it is a voiced glottal stop; for Bongo (1968), it is an indication of consonant lengthening for both voiced and voiceless consonants. None of these explanations seems satisfying, first, because voicing is not compatible with the

Journal of the International Phonetic Association (2002) 32/1

DOI:10.1017/S0025100302000117
Printed in the United Kingdom

articulation of a glottal stop, unless there is some laryngealization, which is not the case in Hendo. Second, although it is true that there is a lengthening effect produced by this sound for voiced consonants, it is clearly distinguished from the neighboring consonant. Indeed, this sound is syllabic and different from the next consonant when the latter is voiceless.

2 Phonological remarks

Before describing the phonetic realization of the unexploded palatal implosive stop of Hendo, a few phonological remarks are necessary to understand the status of this sound. This syllabic consonant is found only in the initial syllable of words and is the allophone of a palatal affricate implosive sound /ɗʒ/ before consonants. Before vowels, the palatal affricate implosive is realized in a CV morpheme (ɗʒi) (class 5 and 8 prefixes having both allomorphs [ʄ̚] and [ɗʒi]). (Note that when the class 5 and 8 prefixes have the form /ɗʒi/, the vowel /i/ is deleted because in Hendo there is a rule that the first of two consecutive non-identical vowels is deleted.) The palatal affricate implosive has a non-implosive free variant [dʒ]. This can be summed up as follows:

/ɗʒ/ → [ʄ̚] / #__ C
→ [ɗʒ] ~ [dʒ] / #__ V

That the sound can be implosive in a CV environment is established on aerodynamic grounds (see section 4 for more details). Indeed, in all the data collected from the two subjects of our study (H1 and H2) who participated in the aerodynamic measurements, there was a negative (or zero in a few cases) pharyngeal pressure during the stop part of the affricate. For the speakers in our study, most phonetic realizations of the class 5 and 8 prefixes – in noun classes before vowels and in pronominal classes – were made with the stop part of the affricate as an implosive (see figures 1, 5 and 6 for examples of this).

In addition to its distribution, the unexploded palatal implosive [ʄ̚] shows an interesting behavior in Hendo word games. When an initial [ʄ̚] (which is syllabic) is permuted to another syllabic position within a word, it is realized either as [ɗʒi] or as [i]. For example, the word ʄ̚pele 'wall' becomes pelei and the bi-syllabic word ʄ̚pfo 'hair' becomes pfoɗʒi when the syllables of the word are permuted. Of course, this does not prove anything phonetically but it shows at least that there are three morphological variants of the class 5 and 8 prefixes and that two of these variants involve the phonetic realization of an implosive consonant.

3 Material

Data were collected with three Hendo speakers (H1, H2, H3) at the Phonology Laboratory of the Université Libre de Bruxelles. Each experiment was performed by at least two speakers except for the video, MRI and Movetrack experiments, which involved only one speaker (H1). The phonetic material used for these experiments is given in tables 1 and 2, which show data in isolated words and in short sentences. Material from tables 1 and 2 was used in the aerodynamic and acoustic measurements. Video, MRI and Movetrack experiments used only material from table 1.

Table 1 Isolated words studied in experiments (tones omitted).

[ʄ̚paka]	'moth'	[ʄ̚bve]	'stone'
[ʄ̚pele]	'wall'	[ʄ̚toi]	'ear'
[ʄ̚peke]	'raffia'	[ʄ̚daka]	'promise'
[ʄ̚pɛka]	'shoulder'	[ʄ̚deko]	'season'
[ʄ̚pfumbo]	'braid'	[ʄ̚dɔka]	'sourcerer'
[ʄ̚pfumba]	'ant'	[ʄ̚demba]	'body'
[ʄ̚pfo]	'hair'	[ʄ̚katʃi]	'hand'
[ʄ̚bala]	'wedding'	[ʄ̚kfundu]	'stomach'
[ʄ̚beŋga]	'wild pigeon'	[ʄ̚kfuku]	'something in decomposition'

Table 2 Short sentences containing words studied in the experiments (tones omitted).

ɔpa ʄ̚katʃi ɗʒɛnde	'Cut his hand.'
am bɔwɛmba la ʄ̚pɛka ɗʒɛ wome	'He carries on the right shoulder.'
wola ʄ̚pele dʒe mbvulu	'Break the wall of the house.'
tɔpeɲi ʄ̚demba ɗʒɛko	'We do not see your body.'
ambɔpɛtʃɛ ʄ̚bala ɲimpɔlɛ	'She got married to a thief.'
ɔsa ʄ̚beŋga ɗʒɛɲɛ	'Take the visible wild pigeons.'

4 Aerodynamic data

4.1 Material and method

Aerodynamic recordings were made using the Physiologia workstation (Teston & Galindo 1995) linked to a data collection system equipped with different transducers. Oral airflow measurements were taken with a small flexible silicon mask placed against the mouth. Nasal airflow was measured at the end of one nostril via a small tube linked to the data collection system. Pharyngeal pressure was recorded with a small flexible plastic tube (ID 2 mm) inserted through the nasal cavity into the oro-pharynx. Two speakers took part in this experiment (H1 and H2).

4.2 Results and measurements

No nasal airflow was observed in the data for the unexploded palatal implosive. This sound is not nasal, contrary to the auditory impression it sometimes gives. Figure 1 shows oral airflow, nasal airflow plots, audio waveform and pharyngeal pressure plot for the sentence [ɔsa ʄ̚benga ɗʒɛɲɛ] 'Take the visible wild pigeons'. As shown in the nasal airflow plot, there was no nasal airflow detectable at the onset of the word ʄ̚benga. Similar measurements made in isolated words have confirmed that there is no nasal airflow accompanying this sound.

Figures 2, 3 and 4 illustrate the realization of a word containing [ʄ̚] followed by voiceless and voiced consonants. Figures 2 and 3 show the variation observed in the rise in pharyngeal pressure for two speakers in the same word containing [ʄ̚]. The following events can be deduced from the pharyngeal pressure plots. At the beginning, (1), the pharyngeal pressure decreases. The oral airflow record (not shown in the figures) indicated that there was no negative oral airflow. There is also no indication of voicing in the audio signal, and it seems that the glottis must have been closed. Other evidence, to be discussed later, indicates that there was an oral closure. A descending

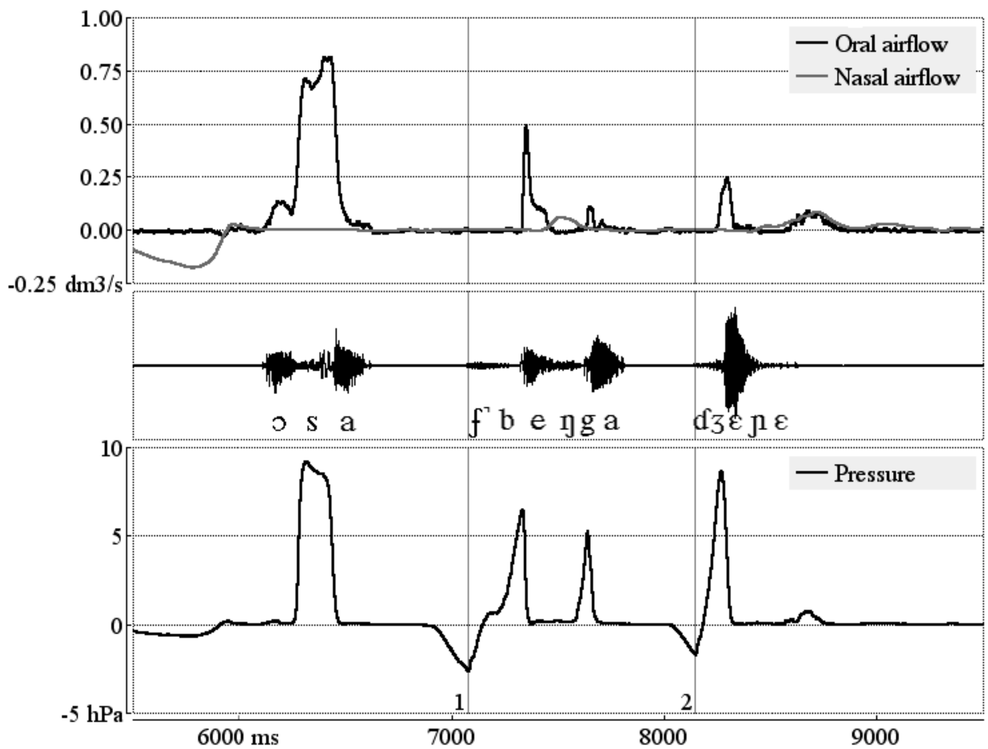

Figure 1 Oral airflow, nasal airflow, waveform and pharyngeal pressure for the sentence ɔsa ʄ̚beŋga ɗʒɛɲɛ 'Take the visible wild pigeons' pronounced by the first speaker (H1). Airflow plots indicate that there is no nasal airflow during the voiced part of [ʄ̚], (1) indicates the negative pharyngeal pressure starting before the voiced part of [ʄ̚], (2) indicates the negative pharyngeal pressure for the stop part of [ɗʒ].

closed glottis, resulting in an expansion of the pharyngeal cavity, is the most likely explanation for the decrease in pharyngeal pressure. As will be shown, the other factors contributing to the expansion of the pharyngeal cavity are tongue body lowering and tongue root fronting. Generally speaking, the reduction of pharyngeal pressure due to larynx lowering, tongue body lowering and tongue root fronting is longer and more important when voiced consonants follow [ʄ̚].

At time (2) in the figures, there is a rise in pharyngeal pressure as the pharyngeal cavity size is reduced by the backward movement of different parts of the tongue and by the upward movement of the larynx. This phenomenon continues until the stop or constriction release. There is a second phase in this pressure build-up, starting around (3) in the figures. This second, sharply-increasing interval of pharyngeal pressure can be accounted for by the glottal setting, which is wide for voiceless consonants and narrow for voiced consonants. The data show that the pharyngeal pressure increase occurs in two phases for both subjects in the experiments. The first phase corresponds to the voicing of [ʄ̚] and the second to the glottal setting of the following consonant.

The mean value of pharyngeal pressure at the release of the stop is 14.5 hPa before voiceless consonants and 9.74 hPa before voiced consonants (averaged over 20 measurements). Mean values for stops not preceded by [ʄ̚] are 7.3 hPa for voiceless consonants and 4.1 hPa for voiced consonants (averaged over 20 measurements).

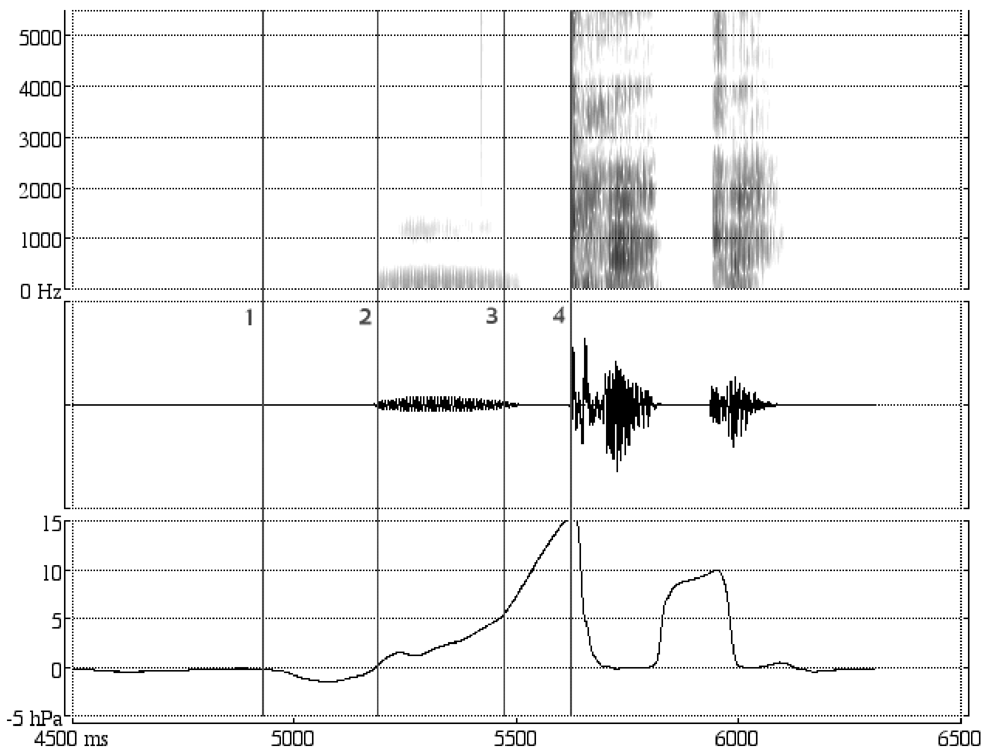

Figure 2 Spectrogram, waveform and pharyngeal pressure for the word ʄ˺paka ‘moth’ pronounced by the first speaker (H1). (1) indicates the starting point of [ʄ˺] and the start of pharyngeal cavity expansion, (2) shows when the voicing starts, (3) indicates the end of the voicing and the end of the first phase of the pharyngeal pressure rise, (4) shows the release of the bilabial stop closure made for [p].

The preceding examples show realizations of the unexploded palatal implosive in isolated words. Figures 5 and 6 present short sentences containing the words ʄ˺beŋga ‘wild pigeon’ and ʄ˺pɛka ‘shoulder’. These examples show that the silent period (visible on the audio waveform), during which pharyngeal pressure starts to decrease and which is made with a closed glottis, is an integral part of the sound. This period is present when [ʄ˺] precedes either a voiced or a voiceless consonant. This fact, therefore, suggests that this sound is only partially voiced, voicing occurring during the rising phase of the pressure.

Figure 6 also presents an example of the palatal affricate implosive [ɗʒ] in the word ɗʒɛɲɛ. The pharyngeal pressure plot clearly shows a negative value, before the voicing of the stop part of the affricate begins. Here as for the unexploded palatal implosive, the silent part preceding voicing is an integral part of the consonant. Since negative pharyngeal pressure is always accounted for when the glottis is closed, it is not possible to describe this sound as preglottalized, but rather as a partially-voiced consonant.

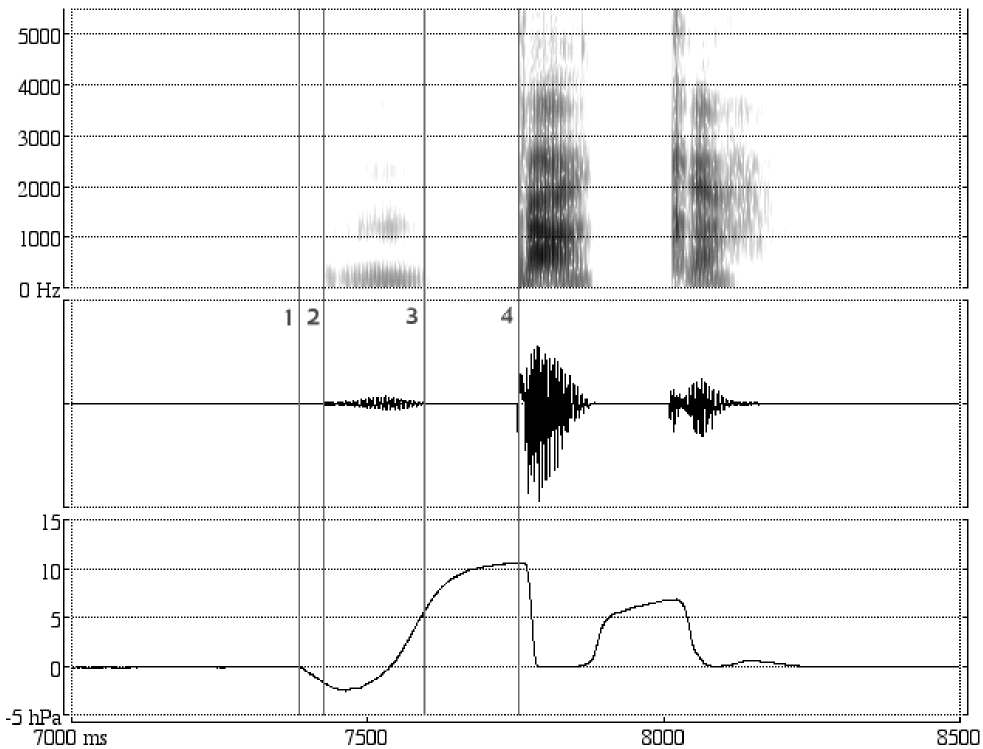

Figure 3 Spectrogram, waveform and pharyngeal pressure for the word ʄ̚paka 'moth' pronounced by the second speaker (H2). (1) indicates the starting point of [ʄ̚] and the start of pharyngeal cavity expansion, (2) shows when the voicing starts, (3) indicates the end of the voicing and the end of the first phase of the pharyngeal pressure rise, (4) shows the release of the bilabial stop closure made for [p].

5 Acoustic data

5.1 Method

Acoustic recordings were made using the Physiologia workstation (Teston & Galindo 1995) linked to a data collection system. These recordings were made simultaneously with the aerodynamic recordings described in section 4. Three speakers took part in the experiments (H1, H2, H3).

5.2 Results and measurements

Examination of the audio signal and spectrogram (figures 2, 3 and 4) shows that [ʄ̚] is always voiced, and that there is an identifiable resonance around 250 Hz when [ʄ̚] precedes a voiceless consonant, as well as when it precedes a voiced consonant. When [ʄ̚] precedes a voiced consonant, it is not possible to measure the duration of this consonant alone because the contact with the following voiced consonant does not show any observable transition. Before a voiceless consonant, [ʄ̚] appears with one or two weak-amplitude resonances before the voiceless consonant. As the vocal tract is still closed, it is suggested that these resonances are due to the intensity of the

https://doi.org/10.1017/S0025100302000117 Published online by Cambridge University Press

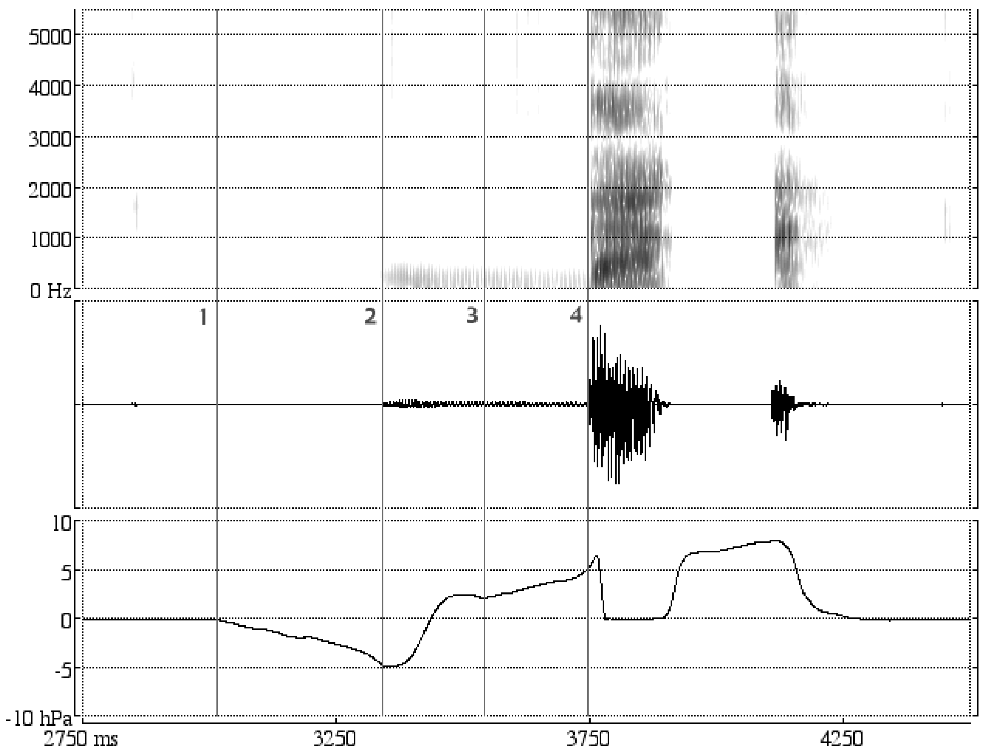

Figure 4 Spectrogram, waveform and pharyngeal pressure for the word ʄ̚daka 'promise' pronounced by the first speaker (H1). (1) indicates the starting point of [ʄ̚] and the start of pharyngeal cavity expansion, (2) shows when the voicing starts, (3) shows the end of the first phase of pharyngeal pressure raising, (4) shows the release of the alveolar stop closure made for [d].

phenomenon. The mean duration of the cluster [ʄ̚] + stop, fricative or affricate ([p, t, k, f, pf, tʃ, kf]) is 504.6 ms (n = 20). When [ʄ̚] alone precedes a voiceless stop, the mean duration is 314.4 ms (n = 20). The clusters [ʄ̚] + voiced stop have a mean duration of 390.6 ms (n = 20). In all cases, the transition into the following consonant is made by a gradual damping of vocal fold vibration and by the absence of a burst.

These acoustic data, while important, do not in themselves explain the nature of this sound. Therefore, it is necessary to turn to more detailed articulatory descriptions in order to understand better the phonetic basis of this phenomenon.

6 Video data

6.1 Material and method

Articulatory data were collected during three different recording sessions. The first involved simultaneous recording of face and profile images using a high-speed video camera. Profile images were obtained by putting a mirror against the cheek of the speaker, at a 45° angle to the sagittal plane. These data were intended to study the relative timing of jaw, tongue and larynx movements during the realization of the

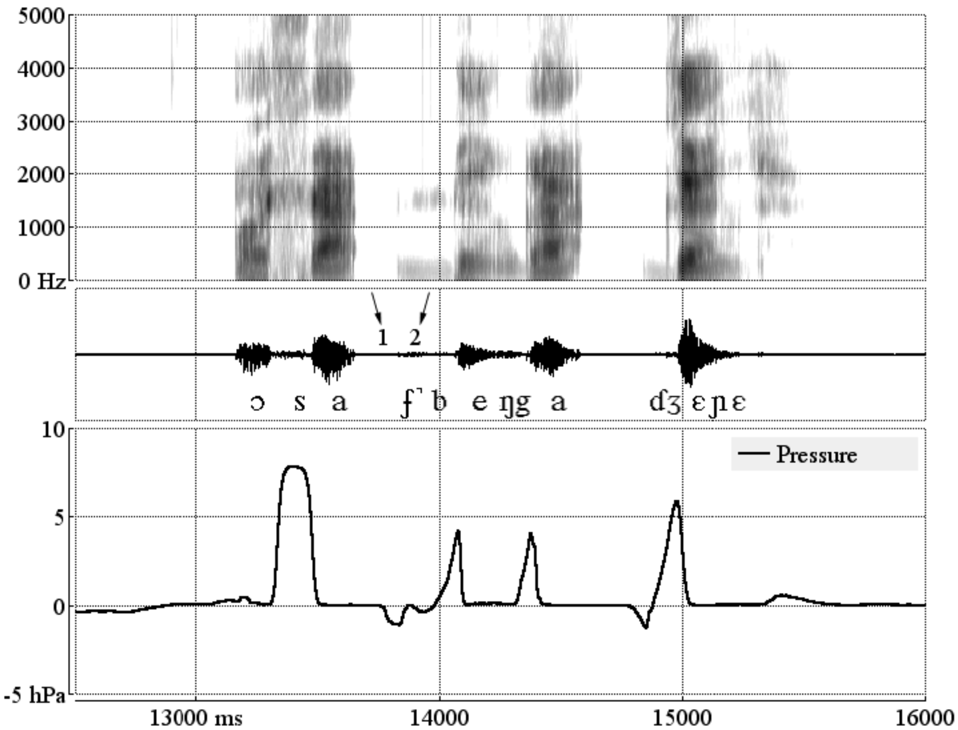

Figure 5 Spectrogram, audio waveform and pharyngeal pressure of the short sentence ɔsa ʄˋbeŋga ɗʒeɲɛ 'Take the visible wild pigeons' pronounced by the first speaker (H1). (1) indicates the silent part preceding the voiced part of [ʄˋ] shown by (2).

sound [ʄˋ]. The camera was used to record the sequence of articulatory events involved in the production of [ʄˋ] in order to allow for comparisons to be made with previously-gathered acoustic and aerodynamic data. The video camera was configured to record gray scale images (240 × 192 pixels) at a rate of 125 images per second. Audio signal and trigger pulses corresponding to each image acquisition were recorded simultaneously on a DAT. The pulses were used to synchronize the analyses of the audio signal and the video data. The evolution in time of a slice superimposed on the recorded image was used to track the movement and synchronization of different articulators. The size of the slice can be measured from fixed anatomical structures. We chose the vertical dimension of the nose as a reference length. This technique permits precise recording of articulatory movements as well as observation of jaw, larynx and tongue body positions. The latter were deduced from the movement of the skin between the jawbone and the neck. The most difficult movement to observe is larynx lowering because it is variable in amplitude and because of the subjects' physiological characteristics.

6.2 Results and measurements

During the production of [ʄˋ], the lower jaw position is not appreciably modified in comparison with the rapid movement of the tongue that is observed in all cases for both subjects. This latter movement of variable amplitude is easily identifiable; its duration is quite short and corresponds to a large expansion of the pharyngeal cavity.

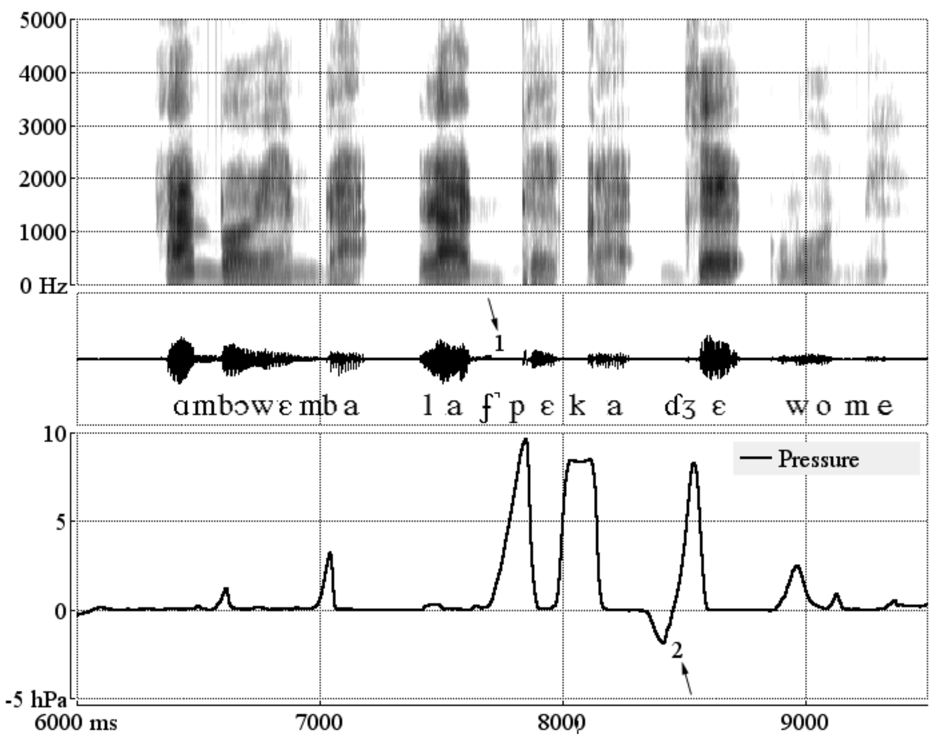

Figure 6 Spectrogram, audio waveform and pharyngeal pressure of the short sentence ɑmbɔwɛmba la ʄ̚pɛka ɗʒɛ wome 'He carries on the right shoulder' pronounced by the first speaker (H1). (1) indicates the silent part of [ʄ̚], (2) indicates negative pharyngeal pressure during the stop part of the affricate [ɗʒ].

The retraction of the tongue to a higher position corresponds to the increase of pressure in the pharyngeal cavity, as previously discussed. The pharyngeal cavity expansion is necessary to maintain voicing during [ʄ̚].

Figure 7 describes the main events observed by using this video technique for the word ʄ̚toi 'ear' and figure 8, the word ʄ̚bve 'stone'. The data presented in figures 7 and 8 reveal the following sequence of events. First, between times (1) and (2), there is a lowering movement of the tongue body corresponding to the observed negative pharyngeal pressure. This movement continues until the end of the [ʄ̚] voicing (time 3). At this point, a passive expansion of the vocal tract can also be noted, made by inflating the cheeks. Next there is a raising movement of the tongue body, simultaneous with a lowering of the jaw. This last movement is made to anticipate the jaw position for the following vowel.

7 MRI data

7.1 Material and method

During the second recording session two sets of data were collected using magnetic resonance imaging (MRI) at the Hôpital Erasme of the Université Libre de Bruxelles. The aim was to observe tongue and larynx positions during the production of [ʄ̚].

https://doi.org/10.1017/S0025100302000117 Published online by Cambridge University Press

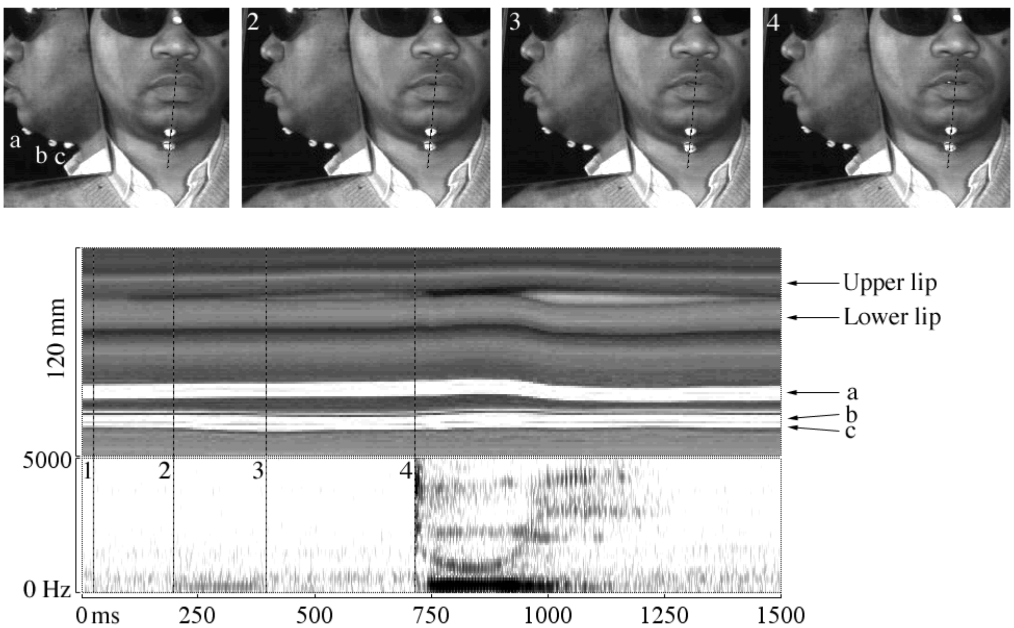

Figure 7 Profile and front images of a speaker pronouncing the word ʄ̚toi 'ear' at instants (1) to (4). The spectrogram of the word is synchronized with the evolution in time of a slice of the image (line on the front images). Displacement of the upper lip, lower lip and the three pellets (a, b and c) identified on the first front image can be observed. (1) is the beginning of the pharyngeal expansion, (2) is the point where voicing starts, (3) is the end of [ʄ̚] voicing and the end of tongue body lowering, (4) is the image just before the alveolar stop release.

The first data set consisted of sagittal images. The imaging was carried out with a 1.5 T MRI system with a quadrature Head-Neck coil (Philips Gyroscan NT ACS, Best, The Netherlands). Each image consisted of one sagittal slice. Each-proton-density-weighted acquisition took 6 seconds to complete with the following parameters: TR = 1716 ms, TE = 9 ms, gradient profile low-high, ETL = 11; Partial Fourier Encoding: 60%; Field of view: 250 × 200 mm, Matrix 161 × 256. The slice thickness was 4 mm. Accurate positioning of the slice was planned on a reference image. Image acquisition was launched immediately after the beginning of phonation.

The second data set of MRI images was performed with the TSE Zoom sequence (Van Vaals et al. 1994, Demolin et al. 1997). One sagittal T1-weighted section 6 mm thick was continuously scanned over a period of at least 20 seconds, using a quadrature neck coil at 1.5 T (Philips Gyroscan ACS NT, Best, The Netherlands). The acquisition parameters were: TR = 250 ms, TE = 30 ms, $q = 60^\circ$, ESP = 7.8 ms, ETL = 19; 60% Partial Fourier Acquisition; Field of View: 300 × 150 mm with a 32 × 128 Matrix. The TSE Zoom sequence is designed such that the initial 60° and the subsequent 180° refocusing pulses excite perpendicular slabs, resulting in an intersecting slice, free of foldover artifacts but without compromising the spatial resolution. Real-time MRI data were recorded to observe the articulatory coordination used to produce this sound.

7.2 Results and measurements

From an articulatory point of view, one last thing must be established: the closure location of [ʄ̚]. Based on mid-sagittal MRI slices, it can be remarked that there is a

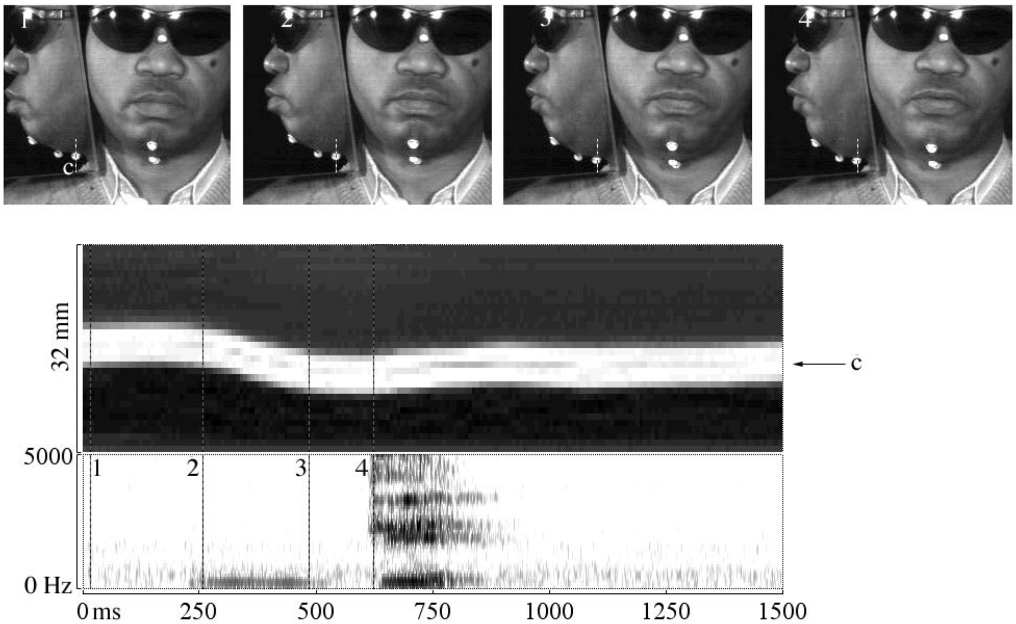

Figure 8 Profile and front images of a speaker pronouncing the word ʄ̚bve 'stone' at instants (1) to (4). The spectrogram of the word is synchronized with the evolution in time of a slice of the image (line on the front images). Vertical displacement of the pellet (c) identified on the front image can be observed. (1) is the beginning of the pharyngeal expansion, (2) is the point were voicing starts, (3) is the end of [ʄ̚] voicing and the end of tongue body lowering, (4) is the image just before the bilabial stop release.

pre-palatal, or sometimes palatal, closure corresponding to a closure of the constriction normally made for [i]. Consequently, this can be interpreted as an articulatory 'overshoot' of the vowel [i] which generated this particular allophone. Figure 9 shows a mid-sagittal slice of [ʄ̚], where it is possible to observe a pre-palatal contact, a large pharyngeal volume, and a low larynx position.

The dynamic MRI sequence of images shows that the order of events deduced from aerodynamic and acoustic measurements is correct. First, there is a lowering of the larynx, accompanied by an expansion of the pharyngeal cavity made by fronting of the tongue root and by lowering of the tongue body (figure 10, images 2–5). Second, after the release of the bilabial stop (images 5–6), there is a reduction of the pharyngeal cavity made by the retraction of the different articulators.

8 Movetrack data

8.1 Material and method

The third recording session involved the collection of electromagnetometric articulatory data using the Movetrack system (Branderud 1985) in order to observe jaw movements and the raising and lowering of the skin between the lower jawbone and the neck. The latter movement is considered to reflect vocal tract expansion produced by lowering and raising of the tongue body. The Movetrack system allows the movement of

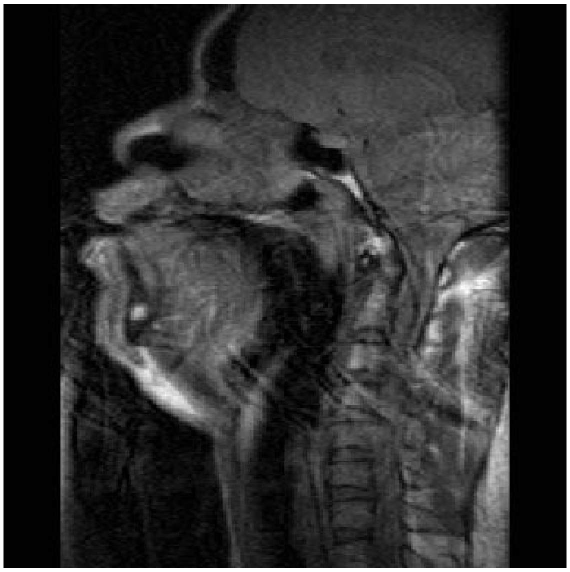

Figure 9 MRI mid-sagittal slice of a sustained [ʄ̀].

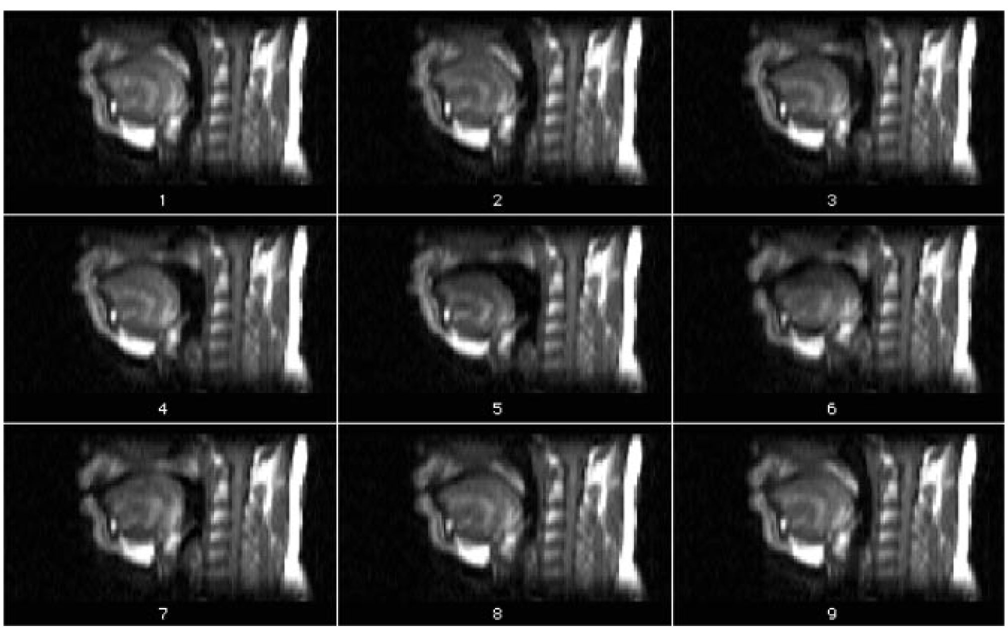

Figure 10 Real-time MRI mid-sagittal slice of the word [ʄ̀]paka 'moth (one image every 20 ms).

different pellets placed in the mid-sagittal plane to be recorded. Three pellets were glued respectively on top of the nose, on the lower incisor, and on the chin. The recorded signals correspond to the distances between the pellets and the two coils mounted on the helmet. Both signals were subsequently transformed into X and Y coordinates. The X and Y coordinates increase when the pellet moves forward and upward.

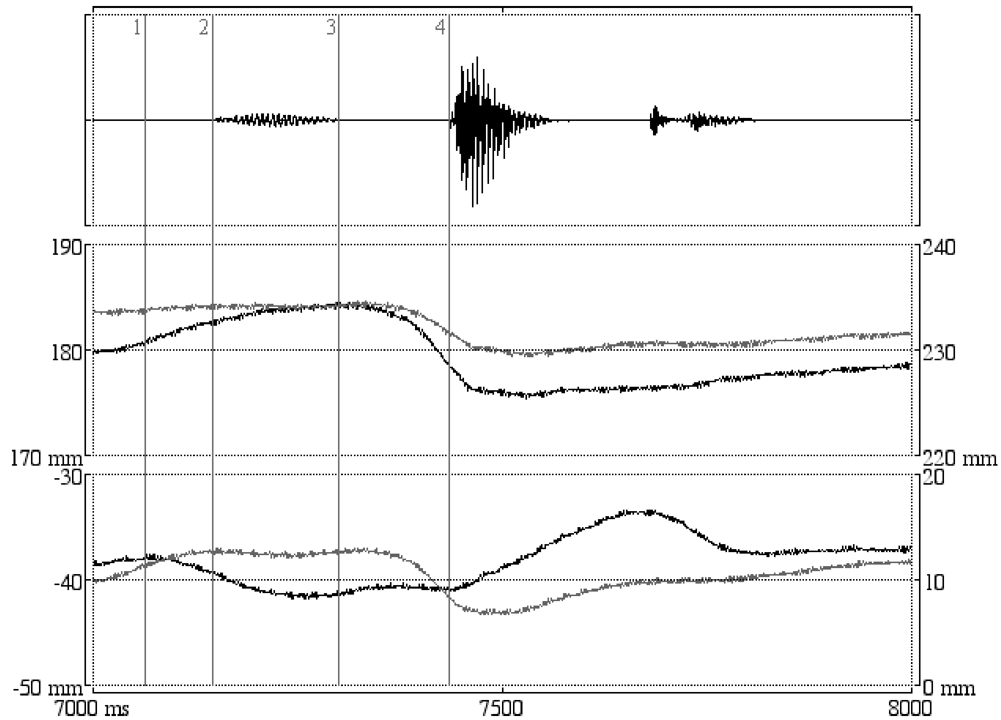

Figure 11 X and Y plots of chin and jaw movements recorded with the Movetrack, for the word ʄ̚paka 'moth' pronounced by the second speaker (H2). The signal was recorded simultaneously with the Movetrack. (1) indicates the starting point of [ʄ̚] and the start of tongue body lowering and fronting, (2) shows when the voicing starts, (3) indicates the end of the voicing and the end of tongue body lowering, (4) shows the release of the bilabial stop closure made for [p] with a lowered jaw.

8.2 Results and measurements

The Movetrack plots shown in Figure 11 can be interpreted as follows. Jaw movement along the X axis indicates that, during the realization of [ʄ̚], the jaw moves slightly forward and starts to retract just before closure release, in order to anticipate the production of [a]; along the Y axis, it can be seen that the jaw is in a high position during [ʄ̚] and starts to lower towards the end of the bilabial stop in order to prepare for [a]. The movement of the underside of the tongue body along the X-axis indicates a progressive fronting whereas along the Y-axis, one can observe lowering of the tongue. This movement reaches a maximum at the end of the [ʄ̚] voicing, as already observed in figure 8. The Movetrack data thus corroborate the sequence of events observed in acoustic, aerodynamic, video and MRI recordings, in addition to providing data on the timing and amplitude of these events.

9 Discussion

One important fact to note when aerodynamic and acoustic data are compared is the decrease in voicing amplitude which can always be observed at the end of [ʄ̚], due to

https://doi.org/10.1017/S0025100302000117 Published online by Cambridge University Press

the balance between pharyngeal and subglottal pressure at this moment. This seems to be the opposite of what was observed e.g. by Lindau (1984), who showed that the amplitude of voicing increases towards the end of an implosive or is made with a higher amplitude when compared to a modal stop. However, in Lindau's data, there is always a vowel following the implosive which is not the case in Hendo. Indeed, increasing pharyngeal pressure and zero oral airflow indicate that there is a closure in the vocal tract associated with a stop-consonant-to-stop-consonant transition and not a consonant-to-vowel transition, as shown in Lindau's data. This last fact accounts for the decrease in voicing amplitude observed at the end of [ʄ̚]. The pressure increase is much greater than that found in stops not preceded by [ʄ̚]. The reason why pharyngeal pressure reaches higher values when [ʄ̚] precedes other consonants is difficult to understand at first sight. However, it is possible to suggest that the reduction in pharyngeal cavity size during the backward movement of tongue body and tongue root contributes to the first phase of the pressure rise. The second phase, with its associated high-pressure value, is made when the glottal aperture is set for the following consonant. The characteristic voicing of [ʄ̚] generally starts after pharyngeal pressure has reached its lowest level. This suggests a decrease in vocal fold tension when the larynx is raised.

As mentioned above, the silent part preceding voicing is an integral part of the consonant both for the unexploded palatal implosive and in the palatal implosive affricate. Since negative pharyngeal pressure is always accounted for when the glottis is closed, it is not possible to describe this sound as preglottalized but rather as a partially voiced consonant.

Articulatory data obtained from video, MRI and Movetrack recordings corroborate the aerodynamic and acoustic observations. First, one can notice that there is a lowering of the larynx, accompanied by an expansion of the pharyngeal cavity made by fronting of the tongue root and by lowering of the tongue body. Second, after the release of the bilabial stop there is a reduction of the pharyngeal cavity made by the retraction of the different articulators.

The existence of implosive consonants in morphemes accounting for class 5 and 8 prefixes of Hendo is not so surprising if one considers that the Bantu proto-form of this prefix has been reconstructed with an implosive (Guthrie 1948). The most surprising fact is rather the partial devoicing of these implosives, which could be interpreted as voiceless implosives but not, as mentioned above, as preglottalized stops. The main difference from the voiceless implosive sounds found in Igbo (Ladefoged et al. 1976), Sereer (Faye 1979) and Lendu (Demolin 1995) is that the prevoicing found in those languages is much shorter than in Hendo. For example, the prevoicing found in Lendu is 40 ms on average while the voiced part of [ʄ̚] lasts for 314 ms in our measurements in Hendo. Therefore we suggest describing the Hendo implosives as partially-voiced implosives, one being unexploded ([ʄ̚]) and the second being the stop part of an affricate ([ɗʒ]).

10 Conclusion

Acoustic, aerodynamic and articulatory techniques have permitted a precise description of a particular allophone of /i/ in Hendo. This sound is rather surprising as an allophone of /i/, since it suggests that a vowel may have a consonantal allophone. This can, however, be easily understood if one considers that [ʄ̚] is produced by an overshoot of the gesture necessary to produce the vowel [i]. The articulation of [ʄ̚] can, therefore, be described as a closing gesture made by contact of the upper part of the tongue body with the hard palate. This closure inhibits voicing, which is, however, maintained for a while by an enlargement of the vocal tract produced by lowering the larynx and by fronting the tongue root.

Acknowledgements

This research was supported by the Convention ARC 'Dynamique des systèmes phonologiques' 98–02, n°226 and by a FNRS grant n°1.5.194.97. We wish to thank Ian Maddieson, Peter Ladefoged and Anthony Traill for their comments on an earlier version of this paper, and Gordon Ramsay for his critical remarks and helpful suggestions. These comments and remarks greatly improved the final version of this paper.

References

ATLAS LINGUISTIQUE DE L'AFRIQUE CENTRALE. (1983). *Zaïre*. Paris: ACCT–Cerdortola.

BASTIN, Y., COUPEZ, A. & DE HALLEUX, B. (1983). Classification lexicostatistique des langues bantoues (214 relevés). *Bulletin de l'Académie Royale des Sciences d'Outre-Mer*, 173–199.

BONGO, C. (1968). Esquisse phonologique du nkutshu, dialecte ohendo. *Mémoire de l'Université de Lovanium*.

BRANDERUD, P. (1985). Movetrack – a movement tracking system. In *Proceedings of the French Swedish Symposium on Speech*, 113–122. Grenoble: GALF.

DEMOLIN, D. (1995). The phonetics and phonology of glottalized consonants in Lendu. In Connell, B. & Arvaniti, A. (eds.), *Papers in Laboratory Phonology 4*, 368–385. Cambridge: Cambridge University Press.

DEMOLIN, D., GEORGE, M., LECUIT, V., METENS, T., SOQUET A. & RAEYMAEKERS, H. (1997). Coarticulation and articulatory compensations studied by dynamic MRI. In Kokkinakis, G., Fakotakis, N. & Dermatas, E. (eds.), *Proceedings of Eurospeech 97*, 31–34. WCL, University of Patras, Greece.

FAYE, W. (1979). *Etude morphosyntaxique du Sereer Singandum (Region de Jaxaaw–Naaxar)*. Thèse pour le 3ème cycle, Université de Grenoble.

GUTHRIE, M. (1948). *The Classification of Bantu Languages*. London: International African Institute.

HULSTAERT, G. (1950). *Carte linguistique du Congo belge*. Bruxelles: Institut Royal Colonial Belge.

LADEFOGED, P., WILLIAMSON, K., ELUGBE, B. O. & UWULAKA, A. (1976). The stops of Owerri Igbo. *Studies in African Linguistics Supplement* **6**, 147–163.

LINDAU. M. (1984). Phonetic differences in glottalic consonants. *Journal of Phonetics* **12**, 147–155.

TESTON, B. & GALINDO, B. (1995). A diagnostic and rehabilitation aid workstation for speech and voice pathologies. In Pardo, J. M., Enríquez, E., Ortega, J., Ferreiros, J., Macas, J. & Valverde, F. J. (eds.), *Proceedings of Eurospeech 95*, 1883–1886. GHT, UPM, Spain.

VAN BULCK, V. (1948). *Les recherches linguistiques au Congo belge, résultats acquis, nouvelles enquêtes à entreprendre*. Bruxelles: Institut Royal Colonial Belge.

VAN BULCK, V. (1952). *Les deux cartes linguistiques du Congo belge*. Bruxelles: Institut Royal Colonial Belge.

VAN VAALS J., VAN YPEREN, G., HOOGENBOOM, A. & DUIVESTIJN, M. (1994). Local Look (LOLO): Zoom fluoroscopy of a moving target. *Proceedings of the First SMR Meeting*, abstract No. 38. Dallas, TX.