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PHONETIC CHARACTERISTICS OF IMPLOSIVES AND THEIR ALLOPHONIC PLOSIVES IN BANTU MPIEMO (A86c)

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Abstract
This study investigates and documents the acoustic-phonetic characteristics of implosives and their allophonic-voiced plosives in Mpiemo (A86c), a Bantu language spoken in the Central African Republic. In Mpiemo, allophonic plosives are found before super-high vowels in the stem-initial and post-nasal positions. The present study shows an increasing versus decreasing voicing amplitude and positive versus negative fundamental frequency (F0) as typical acoustic properties for implosives and plosives. However, both implosives and plosives have a voicing amplitude that does not show an apparent change. In utterance medial intervocalic and non-focal positions, the F0 pattern is better associated with implosives and plosives than with voicing amplitude. In the utterance-initial position, some tokens of F0 show the influence of upcoming tone and intonation.

Keywords: Mpiemo, implosive, plosive, voicing amplitude, fundamental frequency (F0)

Afàyọ
Iṣẹ́ ayèwò fínní-fínní yii ṣe iwadii ati akosile awọn abuda acoustic-phonetic ti awọn implosives ati awọn akùnyùn plosives tó jẹ́ ẹ̀da fóònù (allophonic) wọn, ni èdè Mpiemo ti a ń sọ ni Central African Republic. Ni Mpiemo, awọn ẹ̀da fóònù (allophonic) plosives máa ń ṣáájú awọn faweli giga-giga ni ipo ibẹrẹ-òpó ati lẹ́yin iró aránmú. Iṣẹ́ yìí ṣe afihan gbígbéga àti díndínkùn kíkùnyùn ìgbalẹ̀-ohùn (amplitude) ati fíkúẹ́nsì (frequency F0) alésódo àti adínsódo gẹgẹ bi àbùdá fun implosive ati plosive. Síwájú síi, kíkùnyùn ìgbalẹ̀-ohùn implosives ati plosives kìí sábàá yí padà. Ní àárin gbólóhùn, láàrin fáwẹ̀lì méjì àti nínu gbólóhùn aláìṣàkiyèsí, batani fíkúẹ́nsì ló dára láti fi dá awọn implosives ati plosives mọ, dipo kíkùnyùn ìgbalẹ̀-ohùn (amplitude). Ní ìbẹ̀rẹ̀ ọ̀rọ̀, àwọn ìjẹyọ F0 kọ̀ọ̀kan má ń fi ipa ohùn ati ìwọ́hùn tó wà níwájú hàn.

Àwọn ọ̀rọ̀ gbòógì: Mpiemo, implosive, plosive, voicing amplitude, fundamental frequency (F0)

1. Introduction

A stop consonant called implosive is frequent among West African languages (Maddieson, 1984). According to Clements and Rialland (2008), implosives, particularly [ɓ] and [ɗ], are frequent in the languages of the Sudanic belt, and their occurrence is about 12 times more common than elsewhere in the world. Because of their typological and genetic importance, Clements and Rialland pay special attention to implosives and other non-obstruent stops in the area. As for Bantu languages, Maddieson and Sands (2019) report that implosives are commonly found in Africa's northwest, eastern coastal, and Southeast. They draw attention to diversity in the phonetic patterns in Bantu and encourage more acoustic-phonetic studies that enable objective comparisons.

Previous studies on implosives indicate variations regarding the source of historical change, phonological patterning, and phonetic characteristics. Ladefoged (1975:118) considers that languages tend to develop implosives from voiced plosives when plosives become more and more voiced by lowering the larynx to continue voicing. He cites the historical development of voiced plosives in Sindhi, which has well-documented historical evidence, and remarks that implosives are simply allophones of voiced plosives in many languages. For Bantu languages, Maddieson and Sands (2019) state that most Bantu languages have two series of plosives, voiced and voiceless, which follow the Proto-Bantu reconstruction of Meeussen (1967). Furthermore, the reconstructed voiced plosives most commonly correspond to voiced approximant or implosives in modern languages, an exception being in post-nasal environments and sometimes before Meeussen's reconstructed super-high vowels. For Chaozhou, a Min dialect of Chinese, Cun (2009) reports that forced voiceless stops are one of the sources of implosives. The sound change is motivated by the aerodynamic need to initiate vocal fold vibration, and implosives are observed as the phonetic variation of the voiceless stops.

The Bantu language Mpiemo (A86c) is spoken in the southwestern area of the Central African Republic, which is close to the border with Cameroon and across its border in the Northwest Bantu area. Although many languages in the area have implosives, their exact phonetic characteristics and phonological status are still largely understudied. Grimm (2019) points out the lack of phonetic studies and the difficulties in the consequent phonological analysis for the A80 group of Bantu languages to which Mpiemo belongs. Uncertainty in phonological patterning and phonetic characteristics is found even in a well-studied language, such as Swahili (Coburn and Hjotnaes, 2019). A frequently asked question by field linguists is, 'Is this sound an implosive, or just a plosive?'. Indeed, the phonetic characteristics of implosives have been known to vary considerably, presumably because of the complexity of their production mechanisms, which, in turn, allow some variations and freedom in production. Such phonetic variations can be language-, speaker-, and even token-specific (Painter, 1978; Lindau, 1984; Wright and Shryock, 1993; Demolin, 2002; Jessen, 2002; Jessen and Roux, 2002; Cun, 2009). Although little has been discussed in the literature, it is considered that the phonetic characteristics of implosives and plosives may also reflect their phonological status and patterning with other stop consonants in the language.

The present study investigates and documents the acoustic-phonetic characteristics of implosives and their allophonic voiced plosives in Mpiemo (A86c). In Mpiemo, /ɓ/ and /ɗ/ are realized as [b] and [d(z)] in stem-initial position or in the prefix before /i, u/ as well as in after-nasal context. In the stem-medial position, implosive phonemes are realized as corresponding approximants with or without friction.

A preliminary analysis of Mpiemo with four elderly speakers revealed two acoustic-phonetic parameters: voicing amplitude and fundamental frequency (F0) change during the stop closure, which must be examined in detail. Another parameter, such as closure release, is found to be speaker-specific or token-specific. Voicing amplitude refers to the magnitude of vocal cord vibrations as shown in the soundwave, and it is the most cited acoustic correlate of implosives across languages. Painter (1978) states that an increase in voicing amplitude and F0 change during the stop closure of implosive is due to the increased air pressure in the supra-glottal vocal cavity. Both are potential acoustic parameters of implosives but are still inadequately studied. Since air pressure in the vocal cavity is a critical feature of implosives (cf. Clements and Osu, 2002), its acoustic correlates play a significant role in future research and acoustic documentation. In addition to voicing amplitude and F0 change, the closure duration is measured as the third parameter, partly because we use two production forms (word isolation versus embedded in a carrier sentence), which may influence the durations of implosives and plosive. It is also partly because the duration of implosives has not received much attention compared to that of other stop consonants. The present paper is structured as follows:1. Introduction, 2. Phonetics and phonology of Mpiemo, 3. Acoustic analyses (Method, Closure duration, Voicing amplitude, F0 during the stop closure, and Acoustic illustrations), and 4. Conclusion.

2. Phonetics and Phonology of Mpiemo

The data were gathered in the urban area of Nola in the Central African Republic, close to the border with Cameroon. Nola is the only urban area of the Mpiemo people in the Central African Republic, and today, the area has become multilingual. Besides their mother tongue, most of Nola's residents today are proficient in Sango, a recent creole that could be classified as an Ubangi language (Thornell 1997). Many are also good at Gbaya, another Ubangi language. Those who have been to school can also speak French to a certain extent. For details about language use in the area, see Thornell (1991, 2005) and Thornell et al. (2007).

2.1 Vowels

Figure 1 shows the vowel formant chart of the seven vowels in Mpiemo. Each point represents the mean F1 and F2 obtained from 16 tokens produced by four male speakers (A, B, I, and Z). The F1 and F2 for each vowel were measured from the first vowel of the near minimal pairs listed below.

[dìβí] ‘open (v)’
[ɗèlí] ‘bury (v)’
[ɗɛ́ɣì] ‘chair (n)’
[ɗáɣí] ‘lift (v)’
[ɗɔ̀lɔ́] ‘furuncle (n)’
[ɗóɣí] ‘return (v)’
[dúlí] ‘follow (v)’

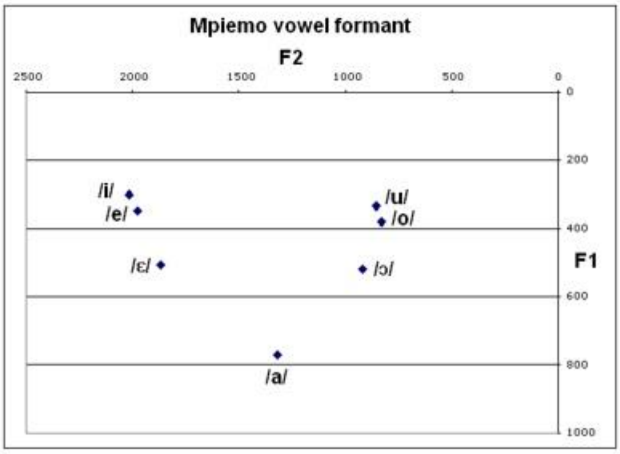

Figure 1. Mpiemo vowel formant means.

The pattern shows that the two high vowel pairs /i, e/ and /u, o/ are remarkably close to each other, and it is sometimes difficult to distinguish between them in perception. The vowel /i/ is regularly accompanied by a strong [ç]-like friction in utterance-final position produced by speakers A and Z indicating that the centre of the tongue is very close to the upper palate when producing /i/. Therefore, /i/ and /u/ in Mpiemo are considered vowels corresponding to Meeussen’s (1967) super-high vowels in Bantu languages. In Figure 9 produced by speaker A, the friction is clearly shown.

As for vowel typology, most Bantu languages, particularly in Northwest Africa, are said to have five or seven vowel systems, where a significant difference is found in the patterning of /e/ and /o/ (Maddieson and Sands, 2019). In some languages, /e/ and /o/ are remarkably close to /i/ and /u/, while they are more evenly spaced in other languages. The Mpiemo vowel space shows the former pattern, similar to Vove (B305) spoken in Gabon, cited in Maddieson and Sands.

2.2 Consonants

Table 1 shows the primary consonant sounds in Mpiemo. Doubly articulated labial–velar plosives are found only in loan words from the Ubangi language, Gbaya**.**

Table 1. Sounds in Mpiemo

	BL	LD	A	PA	P	V	LV	G
Stops	**p b**		**t d**		**c ɟ**	**k g**	**k͡p g͡b**	
Labialised stops						**k^w g^w**		
Implosives	**ɓ**		**ɗ**					
Nasals	**m**		**n**		**ɲ**	**ŋ**		
Tap/Trill			**r**					
Fricatives		**f**	**s**	**ʃ**		**ɣ**		**h**
Affricates			**dz**					
Approximants	**β**		**ɹ**		**j**			
Lateral			**l**					

BL=bilabial, LD=labiodental, A=alveolar, PA=palato-alveolar, P=palatal, V=velar, LV=labial-velar, G=glottal

2.3 Distribution of implosives and their allophones

In the pioneering work of Mpiemo by Beavon (1978), the implosives /ɓ, ɗ/ are analysed as contrasting with /b, d/. However, in the preliminary analysis by Thornell and Nagano-Madsen (2004), [ɓ, ɗ] and [b, d] are analysed as in complementary distribution, and /ɓ, ɗ/ contrast with /p, t/ in voicing. In the present study, the allophonic environments are updated as follows; for more examples, see the wordlist in APPENDIX:

(i) The basic allophones of /ɓ, ɗ/ are [ɓ, ɗ], which appear in the stem-initial position before all vowels except for super high vowel /i/ or /u/. For instance, **[ɓɔ́gí]** ‘bring up (v) ’ and **[ɗelí]** ‘bury (v) ’.
(ii) When a stem-initial /ɓ, ɗ/ appear before a super high vowel /i/ or /u/, or post-nasal, they become [b/d]. Examples are **[dúlí]** ‘follow (v)’, **[biligɔ]** ‘now (adv)’, **[kémbí]** ‘shout (n)’, **[mbɛli]** ‘a sick person (n)’ and **[kándá]** ‘country (n)’.
(iii) In stem-medial position, intervocalic /ɓ/ tends to become an approximant with or without friction as in **[diβí]** ‘open (v)’. By contrast, /ɗ/ or its allophone does not occur in that position as far as our knowledge goes. These sounds are not treated in the present paper.

These allophonic conditions of implosives in Mpiemo align well with those documented by Maddieson and Sands (2019) for Bantu languages. As for the effect of the following vowel on implosives, Cun’s experiment (2009, pp. 69–70) for Chinese dialects indicates that the intra-oral pressure (Po) for implosives before [u] and [i] is significantly lower than before [a], suggesting a smaller supra-glottal vocal cavity for high vowels. Since super-high vowels are produced close to the upper palate, initiating the glottalic ingressive airstream makes it difficult to produce implosives. Similarly, producing an implosive directly after a nasal stop proves difficult. Moreover, stop consonants transforming into approximants in intervocalic positions is widely observed across languages.

2.4 Prosody

Two previous works focused on Mpiemo tones (Wanabenetsia, Beavon, and Nkali, 1986; Festen, 2008). Both marked three surface tones, but Festen, who analysed tones for verbs, postulated only two underlying tones,
respectively. There is a good agreement of approximately 85–90% in tonal pattern among the four speakers for the 110 words in the original wordlist, a mix of nouns and verbs. The H and L tonal relationship tends to be suppressed when embedded in a career sentence, sometimes making the H-L or L-H pattern almost like L-L unless the word starts a new intonation unit with a pitch reset. The influence of tone and intonation becomes relevant in interpreting the F0 analysis during the stop closure; this is discussed further in sections 3.4 and 3.5.

3. Acoustic analyses

3.1 Method

The original wordlist used for recordings consists of 110 words that contain implosives and their allophonic plosives in various contexts and word lengths. For the present study, 65 words (780 tokens) listed in the Appendix, similar in vowel environment, word length, and tone, were selected for acoustic analyses. The speakers were four native male speakers of Mpiemo who had grown up in the Mpiemo-speaking area. Speaker B was in his eighties, while the rest of the speakers were between 45–55 years old at the time of the recording. The recordings were made using a cassette tape recorder (Sony TC-D5 PROII) with an electret condenser microphone (Sony ECM-66B) in the town of Nola in 2005. Each test word was first spoken in French or Mpiemo to confirm its meaning, and then the speaker produced each test word twice in word isolation and once in a career sentence **[ɓɛ laɛ dino ______ kunaa]** ‘say the word _____ quickly’. The acoustic measurements were done manually using PRAAT's phonetic analyzing software while SUGI Speechanalyzer made all the figures. Detailed analysis methods for each parameter are described in the respective section.

3.2 Closure duration

The closure duration is measured to examine the effect of the production form (word isolation vs. sentence embedded) on the stop closure duration of implosives and plosives. Furthermore, the closure duration of implosives has not been studied to the same extent as that of plosives. Many studies, particularly for English, have reported that the closure duration of stop consonants varies as a function of several parameters, with the place of articulation being one of them; bilabials tend to be longer than alveolars. See Stathopoulos's and Weismer's study (1983) for more details. As for implosives, Lindau’s study (1984) of implosives in five Nigerian languages (Kalabari, Orika, Bumo, Degema, and Hausa) shows that the closure duration of [ɓ] is longer than that of [ɗ].

The measurement of closure duration was based on the spectrograms shown in Figures 6–11 under Section 3.5. It is defined as the distance between the onset and offset (before the release) of closure. For a sequence of a nasal followed by a plosive, segmentation is based on spectral change and monitoring, but certain ambiguity is allowed.

3.2.1 Results and discussion

The results of the stop closure measurements, averaged for all four speakers, are presented in Table 2. The closure duration for each allophone is shown as a function of position (word-initial or word-medial) and production form (word in isolation or sentence embedded). All the stop closures became shorter when embedded in a carrier sentence: 17% shorter for implosives, 20% for word-initial plosives, and 21% for after-nasal plosives. Closure durations are markedly shorter for post-nasal plosives than all other allophones in both word-isolation and sentence-embedded forms. Unlike Lindau’s study (1984), which showed a longer duration for [ɓ] than [ɗ], the duration of these two sounds is very similar in our data, except in the post-nasal position. The difference in results between ours and Lindau’s presumably arose because our test materials vary more in structure and complexity.

Table 2. Closure duration of implosives and plosives in milliseconds (ms) averaged for the four speakers. N=number of tokens, SD=standard deviation

		Word-initial position		Word-medial position	
		Word in isolation	Sentence frame	Word in isolation	Sentence frame
ɓ	Mean in ms	**121**	**100**	**132**	**101**
	N (SD)	78 (35)	37 (37)	56 (29)	28 (23)
ɗ	Mean	**119**	**104**	**124***	**114***
	N (SD)	80 (37)	40 (32)	32 (27)	16 (28)
b	Mean in ms	**129**	**98**	-	-
	N (SD)	57 (41)	31 (36)	-	-
d(z)	Mean	**140**	**117**	-	-
	N (SD)	56 (37)	28 (34)	-	-
(m)b	Mean in ms	-	-	**33**	**26**
	N (SD)	-	-	78 (8)	39 (8)
(n)d	Mean in ms	-	-	**24**	**19**
	N (SD)	-	-	72 (6)	32 (6)

*A smaller number of tokens and tokens are similar in segmental composition.

3.3. Voicing amplitude

3.3.1 Voicing

Before examining the voicing amplitudes of implosives and plosives, it is necessary to investigate the voicing itself. It has been known that voiced implosives are far more common than voiceless implosives. Ladefoged (1975:116) describes that the downward-moving larynx is not usually completely closed in producing implosives. However, a recent study states that implosives can be produced with a modal voice, a more tense voice setting, and complete glottal closure (Ladefoged and Maddieson, 1996:82).

It is well known that phonologically 'voiced' plosives are not necessarily phonetically voiced for plosives. In some languages, the voice onset time (VOT) provides a perceptual cue for phonologically contrastive voiced versus voiceless plosives (Lisker and Abramson, 1964). Even for implosives, VOT plays a significant role. Cun's study (2009) shows that the timing and amount of voicing differ for the implosives among the four Chinese dialects examined.

For Bantu languages, Naidoo (2010) reported that half of the closure duration of /b/ was voiceless, while /ɓ/ was fully voiced in Zulu (S42). In Bantu Xhosa (S41), for which /p/, /b/, and /ɓ/ are in contrast, Jessen (2002) reports phonologically 'voiced' /b/ is much closer to a voiceless plosive than a voiced plosive, the percentage of voicing being below 20%, which is lower than that reported for English and German. Furthermore, even implosives are not necessarily fully voiced in Xhosa. In Jessen and Roux (2002), the exact amount of voicing for /ɓ/ in Xhosa is speaker-specific, and full voicing during the stop closure was found in only half of their eight speakers. Jessen and Roux conclude that Xhosa implosive is produced with long voicing and low-burst amplitude compared to other plosives. Xhosa implosive is also accompanied by specific voice quality, breathy or slank. However, Clements and Osu (2002) question if these stop consonants with breathy voice quality should be included in implosives. In Painter's (1978) experiments, we note that a stop consonant with breathy phonation goes in the opposite direction of implosive concerning the air pressure during the vocal cavity. During the discussion of depressor consonants, Maddieson and Sands (2019) also expressed their view on separating voice quality from pure laryngeal activities.

3.3.2 Voicing amplitude as acoustic correlates of implosive

The voicing amplitude is the magnitude of the vocal cord vibrations shown in the soundwave. Presumably, the increasing voicing amplitude is the most frequently cited acoustic characteristic of implosives in the phonetic literature. According to Painter (1978), the increasing voicing amplitude for implosive results from the air pressure drop in the vocal cavity caused by the glottalic ingressive airstream mechanism. It is predicted that the lower the air pressure in the vocal cavity drops, the wider the voicing amplitude becomes. Conversely, the higher the air pressure rises, the narrower the voicing amplitude becomes for voiced plosives. Such a prediction is well attested in Lindau's analysis (1984) of a voiced plosive [b] and an implosive [ɓ] in Degema, an Edoid language spoken in Nigeria, as well as in Mc Laughlin's (2005) acoustic illustrations for Serer-Sin spoken in Senegal. Ladefoged (1996) remarks that such an opposite direction of voicing amplitude is particularly salient when an implosive and a voiced plosive are phonologically contrastive.

More recently, Cun (2009:67) also reported an excellent correlation between intraoral pressure and the configuration of voicing amplitude for the data from Chinese dialects. Of Cun's four acoustic parameters, the increasing voicing amplitude was the only parameter shared by all four dialects for implosives. Other acoustic parameters in Cun's study were VOT, stop closure release, and resonance in terms of the formant structure in the spectrogram.

In addition to the increasing voicing amplitude, some studies have also noted that implosives can have a level or unchanging voicing amplitude as an acoustic correlate, though no details were mentioned regarding where they occur (Lindau, 1984; Clements and Osu, 2002; Naido, 2009).

3.3.3 Distribution of voicing amplitude types

This section examines how voicing amplitude correlates with implosives and plosives in Mpiemo. The voicing amplitude type was analysed qualitatively from the sound wave during the stop closure of implosives and plosives. A preliminary examination revealed three main types of voicing amplitudes, as shown in Figure 2: they are (a) increasing, (b) decreasing, and (c) level/constant. In addition to these three types, we also set a category (d) exception, which does not fit any of the three types.

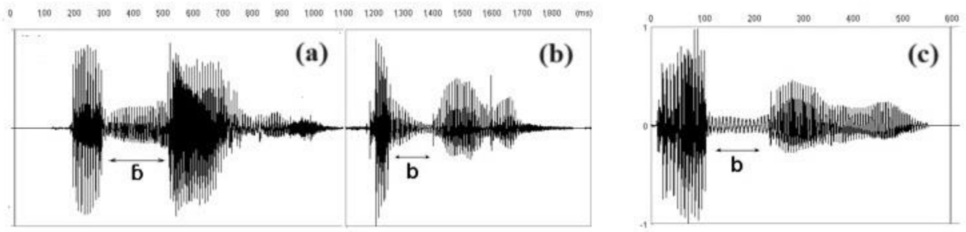

Figure 2. Three types of voicing amplitude: (a) increasing, (b) decreasing, and (c) constant/level.

3.3.4 Results and discussion

3.3.4.1 Voicing

In Mpiemo, implosives [ɓ] and [ɗ] and the plosive [d] are fully voiced in all the contexts. An exception in voicing is found for [b], for which some utterance-initial tokens produced by speaker I exhibit weak voicing. Furthermore, some utterance-medial [b] tokens produced by speaker Z are realized as short approximants rather than stop consonants. These speaker- and token-specific variations differ from such systematic changes in voicing in terms of VOT, which is used to differentiate phonologically voiceless and voiced stop consonants, such as those found in English (cf. Lisker and Abramson, 1964).

The results of voicing in Mpiemo implosives and plosives also differ from Xhosa and Zulu, in which implosives and plosives are contrastive. We consider that the difference between Mpiemo and the cited languages is due to the phonological patterning of stop consonants in a language. In Mpiemo, voiced plosives [b, d] are allophones of implosive phonemes as outlined in section 2.3, contrasting in voicing to /p, t/. Does a level voicing amplitude mean there is no building of negative air pressure in the vocal cavity, which is typical for implosives? Alternatively, does the voicing amplitude accurately reflect air pressure in the vocal cavity? This discussion continues after examining the F0 during the stop closure presented in the next section.

3.3.4.2 Voicing amplitude

The distribution of voicing amplitude types is shown graphically in Figure 3 (word isolation form) and Figure 4 (embedded in a sentence). Since all post-nasal plosives in word isolation and sentence-embedded form have decreasing voicing amplitude, their results are not included in the graph. As for implosives, the distributions for i) [ɓ] vs. [ɗ] and ii) word-initial vs. word-medial were examined.

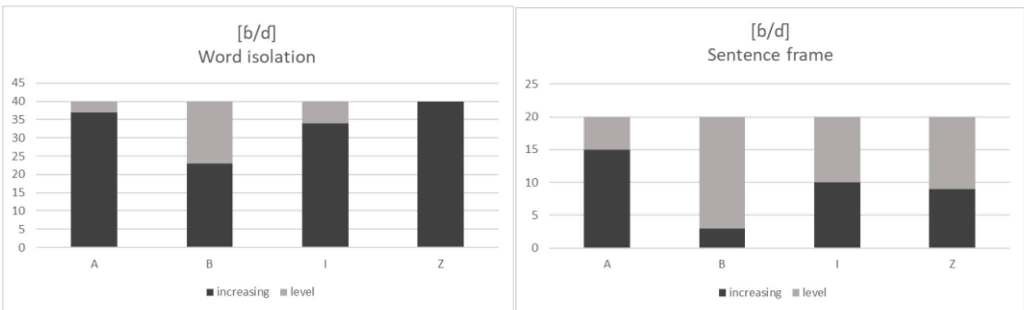

Figure 3. Distribution of voicing amplitude types for implosives ([ɓ] and [ɗ] pooled) produced as word isolation form vs. sentence-embedded form by the four speakers.

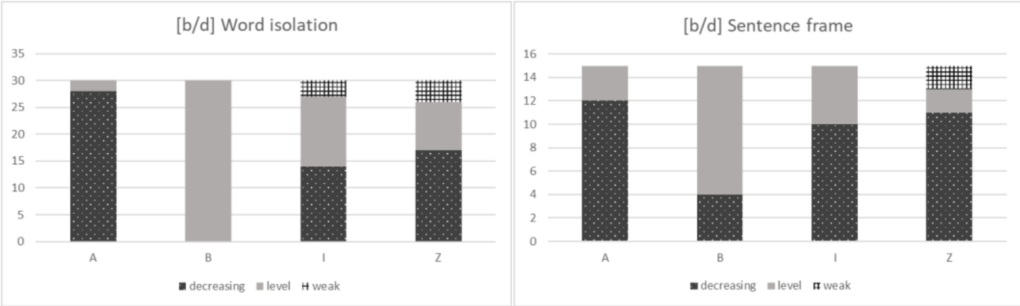

Figure 4. Distribution of voicing amplitude types for plosives ([b] and [d] pooled) produced as word isolation form vs. sentence-embedded form by the four speakers.

The results in Figures 3 and 4 show that increasing voicing amplitude is associated only with implosives, and decreasing voicing amplitude is associated only with plosives, while the level type is associated with both implosives and plosives. The occurrence of the level type is partly speaker-specific and partly production form-specific. It appears more frequently for Speaker B and implosives in the sentence-embedded form.

When produced in a word-isolation form, the increasing voicing amplitude dominates at an average of 86% for all speakers. When embedded in a career sentence, its occurrence is reduced to 49%, while the rest have a level voicing amplitude. An increase in the level voicing amplitude in a sentence context is found for all four speakers. On the other hand, the occurrence of the expected decreasing voicing amplitude for plosives increases from 50% in the word-isolation form to 62% in the sentence context (cf. Figure 4).

The asymmetry in the voicing amplitude between implosives and plosives is interpreted in the following way. In the sentence-embedded form, the original word-initial implosive/plosive is preceded by a vowel, which makes the position of the sound intervocalic. As for plosives, the voicing of the preceding vowel gradually weakens and eventually stops. It means terminating the voicing of the preceding vowel for implosives since the glottis is needed to initiate a glottalic airstream for an implosive. Therefore, it would be more time-consuming, particularly when the stop closure duration is shortened for the sentence-embedded form. Even when implosives have constant voicing amplitudes, they are still perceived as implosives, and there is always a stop closure. In Mpiemo, implosive phonemes are realized as approximants in the stem-medial intervocalic position. Still, there is no sign of weakening of implosives in intervocalic position when embedded in a sentence, even when spoken fast.

3.4 F0 during the stop closure

According to Painter (1978), both voicing amplitude and F0 during the stop closure reflect the air pressure in the vocal cavity. It is predicted that low air pressure in the vocal cavity raises F0, as is the case for implosives, while high air pressure in the vocal cavity lowers F0, as is the case for voiced plosives. However, some acoustic illustrations indicate that the voicing amplitude and F0 do not always behave identically during the stop closure. While increasing voicing amplitude has been cited as a typical acoustic correlate of implosives for diverse languages in the phonetic literature, F0 has not received much attention as an acoustic correlate of implosives or plosives, the exception being the case of 'depressor' consonants, see Maddieson and Sands (2019) for an overview.

In his pioneering work, Painter (1978) cites Greenberg (1970:132–133), who had drawn attention to Hobley's (1964) work on a Kru language spoken in Liberia, which discussed the effect of voiceless and voiced consonants on the pitch of the following vowel. In Kru, voiceless consonants usually raised the pitch of the following vowel, while voiced consonants lowered it, but surprisingly, [ɓ] behaved more like voiceless consonants. Painter examined what happened to F0 during the stop closure and after the release of the implosive and ten other types of consonants by using nonsense words produced by himself to enable the condition to be as equal as possible. His data show that F0 is highest during the stop closure up to the C-V boundary for [k͡p] and [ɓ], while F0 is lower in [b] and lowest in [bɦ] (breathy voice). The pitch-raising effect by [k͡p] or the lowering effect by [bɦ] continued to the steady state of the following vowel, while the F0 rising effect of [ɓ] and the lowering effect of [b] were much shorter.

Different results have been reported regarding the consonantal effect of implosives, indicating that such an effect is language-specific. Still, it may also depend on the phonological patterning of the language's implosive and other stop consonants. Wright and Shryock (1993) compared the F0 effect of implosives on the following vowel with that of the voiceless stop in Swati (S43), another Bantu language spoken in Eswatini. Contrary to predictions made in the literature (Hombert, 1978; Ohala, 1976), implosives did not pattern like voiceless unaspirated stops concerning their effect on F0 in Swati. Wright and Shryock consider this may be because implosives are contrastive to voiceless stops in Swati; the two must be separated.

According to Painter's (1978) model, a proper F0 control for linguistic tone starts only after the stop closures release. However, Cun (2009: 97–98), who conducted an aerodynamic and acoustic analysis of Chinese dialects, questions Painter's model of implosive. In Cun's study, F0 during implosive closure correlates well with vocal cord tension, trans-glottal pressure drop, and weakly with sub-glottal pressure. As for voiced plosives, the only correlate of F0 was the trans-glottal pressure drop. Cun's data show that the F0 contour varies during the stop closure depending on the tone of the vowel. Cun also concludes that an implosive has neither a raising nor a lowering effect on the following vowel for Chinese dialects, while a voiced plosive has a depressor effect.

Our preliminary examination of the Mpiemo with limited number of tokens and speakers found that some cases of F0 raised the effect by implosive at the onset of the following vowel. However, a thorough examination of the entire Mpiemo data obtained from the four speakers indicates that the consonantal effect of implosives is more speaker- and token-specific. Instead, the positive versus negative F0 during the implosive and plosive stop closures is far more consistent across speakers, despite some exceptions.

3.4.1 Measurement of F0 change

The F0 change during the stop closure was measured manually by extracting the F0 minima from the F0 maxima (cf. Figure 5). In the calculation, the unit semitone might have been more accurate in averaging the F0 values obtained from multiple speakers. However, because the number of speakers is limited and all are elderly male speakers, the measurement is done in Hz, which is probably more familiar to readers. Small samples were compared in Hz and semitones, but this did not affect the basic pattern obtained here.

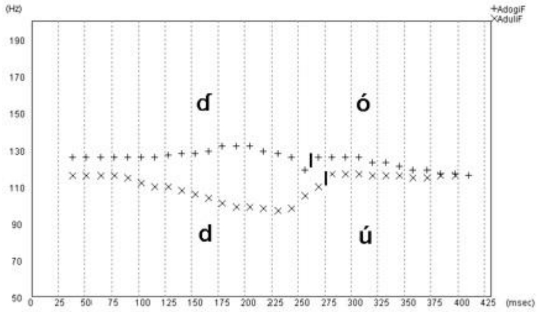

Figure 5. F0 of the first syllable of the words **[ɗóɣí]** 'to return' and **[dúlí]** 'to follow.'

3.4.2 Results and discussion

The mean F0 change during the stop closure of implosives and plosives averaged for the four speakers, is shown in Table 3.

Table 3. Mean F0 changes during the stop closure in Hz averaged for the four speakers. N=number of tokens, SD=standard deviation

		Word-initial position		Word-medial position	
		Word in isolation	Sentence frame	Word in isolation	Sentence frame
ɓ	Mean in Hz	**16.7**	**11.1**	**16.4**	**16.3**
	N (SD)	69 (12.5)	37 (7.2)	56 (9.7)	27 (9.4)
ɗ	Mean in Hz	**15.2**	**9.9**	**7.3***	**6.2***
	N (SD)	72 (14.5)	39 (6.3)	24 (5.0)	16 (4.1)
b	Mean in Hz	**-12.2**	**-9.2**	-	-
	N (SD)	54 (9.4)	27 (7.1)	-	-
d(z)	Mean in Hz	**-10.1**	**-13.1**	-	-
	N (SD)	39 (6.5)	26 (10.3)	-	-
(m)b	Mean in Hz	-	-	**-7.2**	**-5.5**
	N (SD)	-	-	80 (4.5)	40 (4.5)
(n)d	Mean in Hz	-	-	**-6.2**	**-4.1**
	N (SD)	-	-	72 (4.1)	32 (2.7)

*A limited number of tokens and tokens are similar in segmental composition

A hypothesis based on a preliminary examination is that implosives have a positive F0 and plosives have a negative F0 during the stop closure, following Painter (1978). There were some exceptions, which are excluded from the calculation shown in Table 3 and analysed separately. The null (0) F0 value occurred for both implosives and plosives and is included in the calculation. The results in Table 3 indicate a strong tendency for the amount of F0 change to correlate with time (duration) and place of articulation, be that positive or negative. The F0 change is more significant when produced in isolated words, with a longer stop closure duration than in sentence-embedded form (cf. Section 3 about the closure duration). This F0 behaviour is comparable to the degree of increase in voicing amplitude, which is assumed to reflect air pressure in the vocal cavity as a function of time in most West African languages (Lindau, 1984).

For further analysis, the present results of the F0 analysis are compared with McLaughlin’s (2005) study on Serer-Sin. McLaughlin measured intraoral air pressure for six implosives and six voiced and voiceless plosives under the hypothesis that implosive stops are characterized by rarefaction, namely a measurable pressure drop, as the glottis lowers after closure. The results show that all the implosives had negative oral air pressure, including two null (0) tokens, while all plosives had positive oral air pressure. Mc Laughlin’s oral air pressure measurements from Serer-Sin stops uphold Clements and Osu’s (2002) proposal that implosives are characterized by the absence of positive oral air pressure rather than negative oral air pressure during the stop closure.

McLaughlin’s oral air pressure measurements agree with the results of F0 measurements, which show the reverse relation with the oral air pressure. The negative oral air pressure corresponds to the positive F0, while the positive oral air pressure corresponds to the negative F0. Furthermore, the results agree with the air pressure measurements concerning the place of articulation, showing that bilabials have a more significant amount of F0 change than alveolars, with one exception ([d(z)] in sentence context).

Some exceptions of implosives and plosives did not meet expectations regarding the positive versus negative F0 change during the stop closure. The exceptions are eight tokens of implosives produced by Speaker A or Speaker Z and eleven tokens, including both plosives and implosives produced by Speaker B. A closer examination reveals that exceptions are found in an utterance-initial position of a higher-level intonation unit, where the F0 is raised in anticipation of the forthcoming F0 event. It can also be in an embedded sentence if the word in question starts a new intonation unit by pitch reset preceded by a pause. These exceptions regarding the expected positive versus negative F0 during the stop closure align with Cun’s data (2009: 97–98), in which the F0 during the stop closure anticipates the coming tone. On the other hand, in utterance medial non-focal position, where the H and L relation becomes suppressed, the positive versus negative F0 correlated with implosive and plosive, respectively, and was near perfect.

3.5 Acoustic illustrations

This section provides some of their acoustic samples after examining the acoustic correlates of implosives and their allophonic plosives. They show typical samples and variations in voicing amplitude and F0 during the stop closure.

Figures 6, 7, 8, and 9 show the tokens produced by Speaker A. Note that this speaker often has a strong [ç]-like friction after [i] in the utterance-final position. Figures 6(a) and 6(b) show two words with a LHH pattern, where the word-medial [ɓ] and [b] demonstrate different acoustic correlates. In (a), an increasing voicing amplitude and rising/positive F0 for an implosive are shown, while in (b), a decreasing/negative voicing amplitude, showing an F0 dip for a plosive are shown. Speaker A uses increasing versus decreasing voicing amplitude for implosive and plosive more often than other speakers in word isolation and sentence-embedded forms (cf. Figures 6 and 7).

Similarly, in Figures 7(b) and 7(c), HH tonal patterns and increasing voicing amplitude with positive F0 for implosive and decreasing voicing amplitude with negative F0 for plosive are shown in the word-initial position. Figure 7(a) shows an LH pattern. In Figures 7(a) and 7(b), the voicing amplitude starts with a wide amplitude, indicating that the glottis is not tightly closed, while that in Figure 6(a) starts with a closed glottis. These data indicate that the initiation of implosive does not necessarily start with a completely closed glottis.

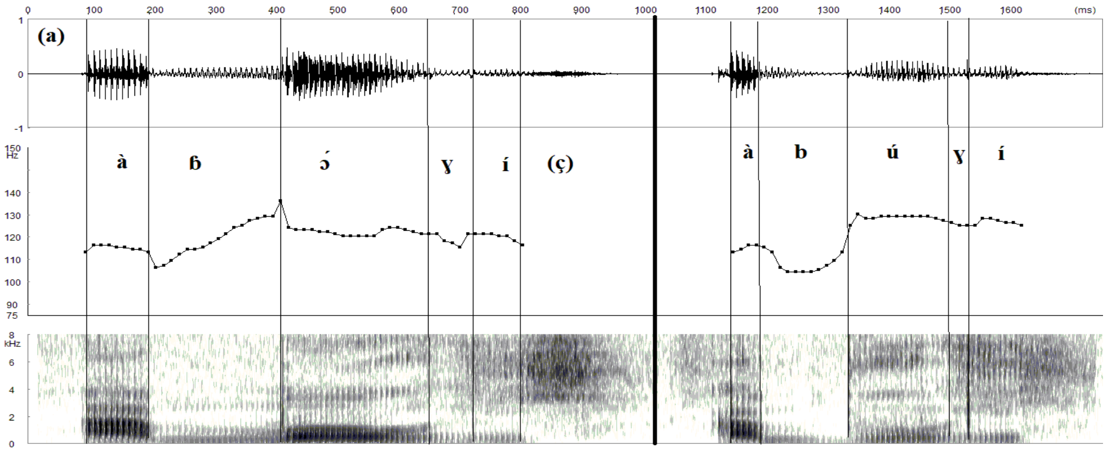

Figure 6. Soundwave, F0, and wideband spectrogram for words **[àɓɔ́ɣí]** ‘harvest (n)’ and **[àbúɣí]** ‘breathlessness (n)’ produced in word isolation form by speaker A.

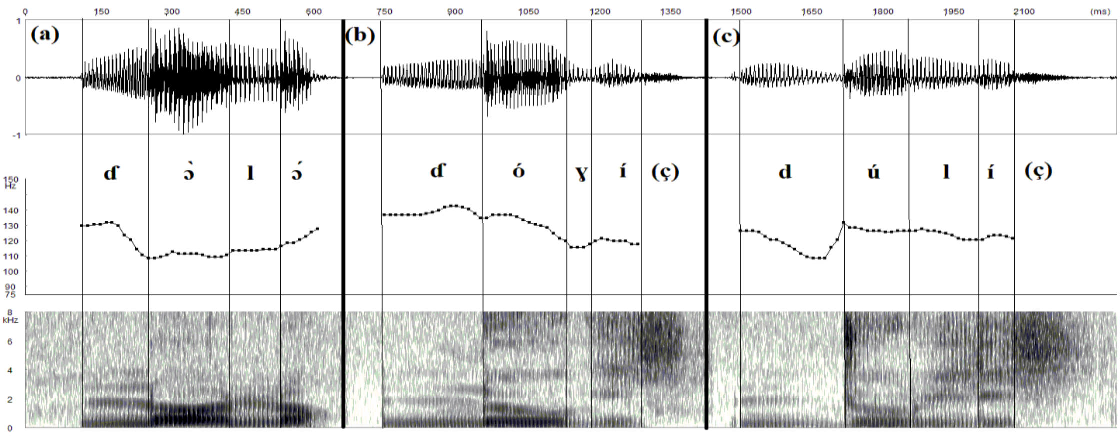

Figure 7. Soundwave, F0, and wideband spectrogram for words **[ɗɔ̀lɔ́]** ‘furuncle (n),’ **[ɗóɣí]** ‘return (v),’ and **[dúlí]** ‘follow (v)’ produced in word isolation form by speaker A.

As for F0 Figures 7(b) and 7(c), they show a representative positive F0 for implosive and a negative F0 for plosive word initially. Figure 7(a) shows a more complex example of F0 for the word-initial implosive [ɗ]. Here, the F0 during the stop closure starts rising but then falls rapidly in the latter half because of the upcoming L tone in the following syllable.

Figure 8 shows the repetition of **[ɗèlí]** ‘bury (v),’ which shows a mild increase in voicing amplitude for implosive and a gradually falling F0 towards the L tone. Figures 9(a) and 9(b) show two HH words containing [b] and [d] in the post-nasal position, for which there are short dips in F0 that are associated with a plosive.

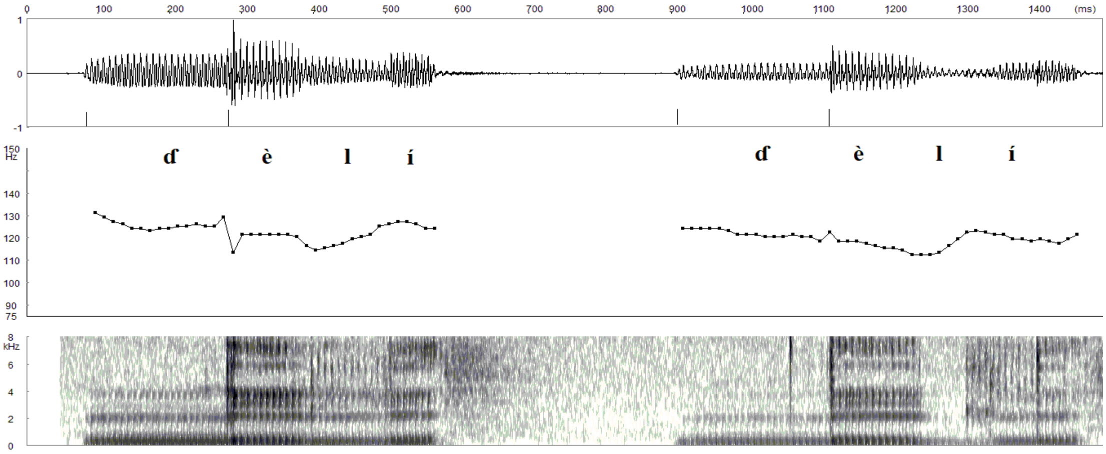

Figure 8. Soundwave, F0, and wideband spectrogram for words **[ɗèlí]** ‘bury (v)’ repeated twice in word isolation form by speaker A

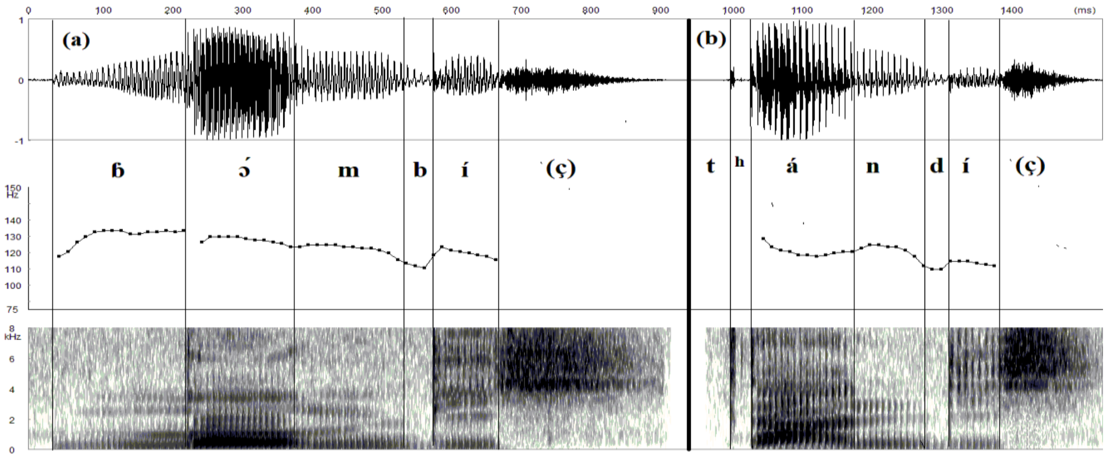

Figure 9. Soundwave, F0, and wideband spectrogram for words **[ɓɔ́mbí]** ‘delight a woman (v)’ and **[tándí]** ‘judge (n)’ produced in word isolation form by speaker A.

Figures 10 and 11 show tokens of [ɓ] and [b] produced by Speaker I. Figure 10(a) shows an increasing voicing amplitude and positive F0 for implosive, while Figure 10(b) shows a constant voicing amplitude and negative F0 for plosive in word-medial position. Both words have the LHH pattern, but the F0 during implosive closure is positive, while it is negative for plosive closure, making a characteristic F0 dip.

In Figures 11(a) and 11(b), the two words with the LLH pattern are compared. In (a), the voicing amplitude for [b] and [ɗ] are very similar, narrow, and level, but the F0 differs clearly. The initial [b] has a negative F0 dip, while the implosive has a positive F0. In (b), the two plosives [b] and [d] have slightly different voicing amplitude types, but both have the same negative F0 dip. F0 during the stop closure of plosives shows a constant F0 dip, whereas that of implosives seems more influenced by tone.

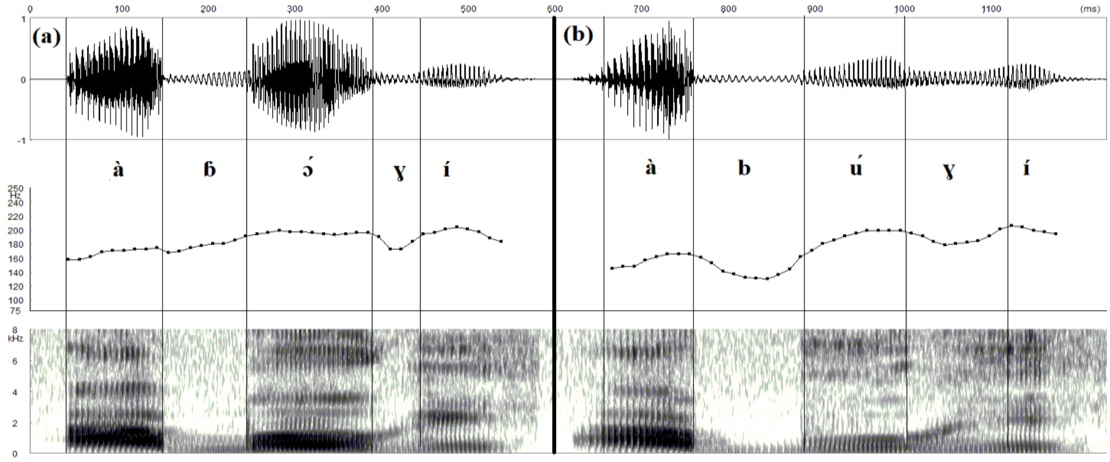

Figure 10. Soundwave, F0, and wideband spectrogram for words **[àɓɔ́ɣí]** ‘harvest (n)’ and **[àbúɣí]** ‘breathlessness (n)’ produced in word isolation form by speaker I.

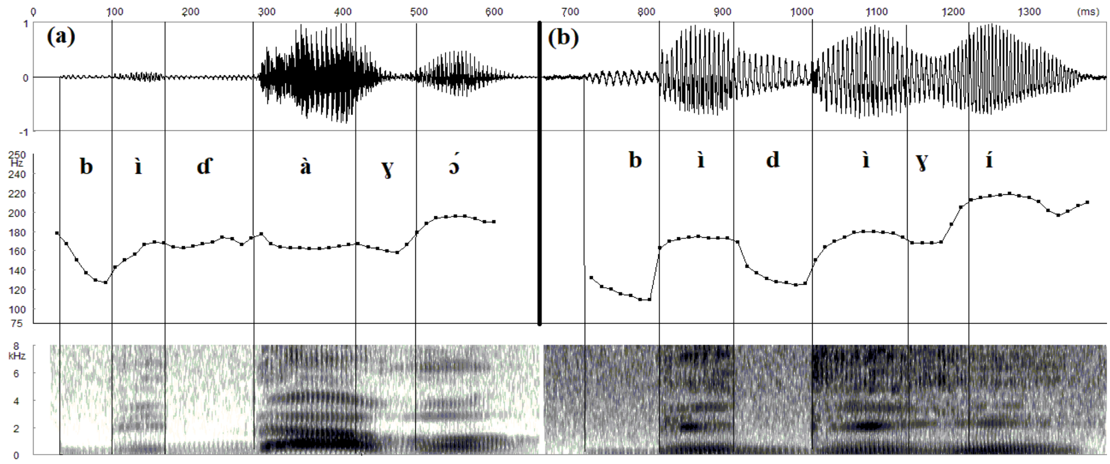

Figure 11. Soundwave, F0, and wideband spectrogram for words **[bìɗàɣɔ́]** ‘nests (n)’ and **[bìdìɣí]** ‘forests (n)’ produced in word isolation form by speaker I.

4. Conclusion

Voicing amplitude is a solid acoustic correlate of implosives and their allophonic plosives in Mpiemo. In our data, increasing voicing amplitude consistently associates with implosives, while decreasing voicing amplitude consistently associates with plosives. A constant or level voicing amplitude is typically found for implosives produced in a career sentence. The F0 change during the stop closure is also a solid acoustic correlate for implosives and plosives in Mpiemo; increased (positive) F0 during the stop closure associates with implosives, while decreased (negative) F0 associates with plosives. We note that the F0 during the stop closure shows an influence of upcoming tone and utterance intonation in some cases.

Since the analysis parameters used for implosives differ across languages and researchers, comparing our data with other works is difficult. However, comparing voicing and voicing amplitude with other African languages indicates that Mpiemo implosives and their allophonic plosives are phonetically more similar to those in a language like Degema, an Edoid language spoken in Nigeria. Not many similarities are found with those in Xhosa (S41) and Zulu (S42), which are Southern Bantu languages.

For future studies, it is desirable to have more aerodynamic and physiological studies combined with acoustic characteristics and, hopefully, to examine the role of the laryngeal muscles and glottis more closely. It would also be helpful to include more natural running speech as material.

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Appendix

Wordlist (L tones are unmarked in this list)

[ɓ] word/stem-initial

	Phonetic transcription	gloss
1	**ɓɛ́gɔ**	'shoulder (n)'
2	**ɓɛ́nyo**	'snakes (n)'
3	**ɓɛlúlí**	'blacksmiths (n)'
4	**ɓágá**	'separation (n)'
5	**ɓɔ́gí**	'bring up (v)'
6	**ɓɔ́mbí**	'delight a woman (v)'
7	**ɓɔyá**	'last (v)'
8	**ɓoá**	'woman (n)'
9	**ɓóri**	'persons (n)'
10	**ɓoróm**	'men (n)'

[ɗ] word/stem-initial

	Phonetic transcription	gloss
1	**ɗelí**	'bury (v)'
2	**ɗema**	'approach (v)'
3	**ɗɛ́ɣi**	'chair (n)'
4	**ɗɛ́ɣɔ**	'so (adv.)'
5	**ɗáɣí**	'lift (v)'
6	**ɗali**	'village (n)'
7	**ɗɔlɔ́**	'furuncle (n)'
8	**ɗɔ́ri**	'friendship (n)'
9	**ɗóɣí**	'give back (v)'
10	**oɣɔ**	'go out (v)'

[ɓ] word-medial, but stem-initial

	Phonetic transcription	gloss
1	**aɓenɔ́**	'anger (n)'
2	**aɓaɣí**	'misstep (n)'
3	**aɓɔɣí**	'melon (n)'
4	**aɓɔ́ɣí**	'harvest (n)'
5	**aɓóɣí**	'pelvis (n)'
6	**aɓóɣi**	'wall (n)'
7	**aɓóɣɔ**	'pipe (n)'

[ɗ] word-medial, but stem-initial

	Phonetic transcription	gloss
1	**biɗaɣɔ́**	'nests (n)'
2	**biɗáɣɔ́**	'sticks to decorticating cucumber seeds (n)'
3	**biɗóɣɔ́**	'kind of tree (Myrianthus arboreus P. Beauv. Cecropiaceae) (n)'
4	**biɗó**	'noses (n)'

[b] word-initial, but not stem-initial

	Phonetic transcription	gloss
1	**bijáɛ**	'relatives (n)'
2	**biká**	'leaves (n)'
3	**biɗó**	'noses (n)'
4	**biló**	'heads (n)'
5	**bilɔ́**	'fall (v)'
6	**búɣi**	'be broken (v)'
7	**búɣɔ**	'break (v)'
8	**buɔ́**	'be much (v)'

[d] word-initial

	Phonetic transcription	gloss
1	**diβí**	'open (v)'
2	**díβɔ́**	'river, water (n)'
3	**dínɔ́**	'name (n)'
4	**dímbɔ́**	'place where certain plants grow (n)'
5	**dúlí**	'follow (v)'
6	**dulɔ́**	'pull (v)'
7	**duí**	'remove (v)'

[b] post-nasal, word-medial

	Phonetic transcription	gloss
1	**bɔ́mbí**	'delight a woman (v)'
2	**kémbí**	'shout (n)'
3	**tumbí**	'light (v)'
4	**kémbe**	'grooving-plane (n)'
5	**lámbá**	'lamp (n)'
6	**kambɔ**	'fear (v)'
7	**jambɔ**	'cook (v)'
8	**gwɔ́mbɔ́**	'lemograss (n)'
9	**kombo**	'kind of tree (Musanga cecropioides R.Br. Ex Tedli (CECROPIACEAE) (n)'
10	**timbó**	'kind of tree (Trilepsisium madagascariense (Schuhmach. & Thonn) Taub (n)'

[d] post-nasal, word-medial

	Phonetic transcription	gloss
1	**tándí**	'judge (v)'
2	**cíndi**	'beach of the river (n)'
3	**hándá**	'last bottle of wine (n)'
4	**kándá**	'country (n)'

5	**gwóndɔ́**	‘voice (n)’
6	**jándɔ́**	‘walk (v)’
7	**póndɔ́**	‘push back (v)’
8	**nkándó**	‘crocodile (n)’
9	**ntúndú**	‘kind of grass (n)’