Chapter 1

Acoustic analysis of implosives in the Rɨ̀kpàʔ language

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This study analyzes the acoustic properties of implosives and voiced and voiceless stops in the Rɨ̀kpàʔ language, located in the Center Region of Cameroon (Guthrie Zone A.53). Three female native speakers produced lexical items with word-initial and word-medial bilabial and alveolar implosives /ɓ/ and /ɗ/, voiced plosives /b/ and /d/, and voiceless plosives /p/ and /t/. We measured and compared the fundamental frequency *(f0)* of the vowel following the target consonant, the plosive prevoicing or closure duration, and closure intensity between the three segment types. Overall, vowels following implosives have a significantly higher *f0* than those following voiced plosives and slightly lower *f0* than those following voiceless plosives. We also find that implosives, contrary to previous studies, have shorter closure durations than voiced plosives in word-initial position, though this pattern was reversed in word-medial position. Finally, while these implosives show no overall difference in intensity of prevoicing in word-initial position compared to voiced plosives, we see that implosives, unlike voiced plosives, have a rising intensity slope. In word-medial position, implosives have a significantly higher prevoicing intensity than voiced plosives, but a more uniform intensity profile.

1 Introduction

A variety of studies have considered the phonetic patterning of implosive consonants in the world's languages both from a theoretical perspective and from an acoustic-instrumental perspective. Descriptions of implosive production traditionally posit a *glottalic ingressive airstream mechanism* in which the speaker's larynx moves downward while the oral cavity is closed, causing a decrease in air

Lindsay Hawtof, Fridah Gam & Kathryn Franich. 2024. Acoustic analysis of implosives in the Rɨ̀kpàʔ language. In James Essegbey, Brent Henderson, Fiona McLaughlin & Michael Diercks (eds.), *Pushing the boundaries: Selected papers from the 51–52 Annual Conference on African Linguistics*, 1–19. Berlin: Language Science Press. DOI: 10.5281/zenodo.14038731

pressure within the oral cavity and a subsequent ingressive airflow into the oral cavity once opened. This is in contrast with the more common pulmonic egressive airstream mechanism, in which sound is created through subglottal pressure buildup and airflow from the lungs outward through the larynx and either the oral or nasal cavity.

In spite of the glottalic ingressive label given to implosives as a class of sounds, studies have found that implosives have different means of production across Sub-Saharan Africa, resulting in variable acoustic patternings in fundamental frequency, prevoicing intensity, durational value, etc. This variability suggests the potential for differences in key articulatory variables such as larynx lowering, glottal constriction, and vocal fold tension when it comes to the production of implosives (Ladefoged 1968, Lindau 1984, Wright & Shryock 1993). Understanding the acoustic and articulatory patterns of implosives in a wider variety of languages will help to paint a more complete picture of their phonetic typology, and to help us better situate them in terms of their phonological status. The present work aims to explore phonetic and phonological patterns of implosives in Rɨkpàʔ, a Cameroonian Bantu language. The primary aim of our study is therefore to understand the acoustic patterns of implosives in Rɨkpàʔ from an instrumental perspective. To that end, we present acoustic data from three native female Rɨkpàʔ speakers in order to determine how fundamental frequency (*f0*), closure duration, and closure intensity differs between Rɨkpàʔ implosives, voiced plosives, and voiceless plosives. A secondary goal of our paper is to use these acoustic results in conjunction with observed distributional patterns of implosives in order to gain a better understanding of their phonological status in the language.

1.1 Acoustic and articulatory patterns of implosive production

A number of different acoustic variables have been examined in an effort to understand the primary cues which differentiate implosive consonants from pulmonic egressive stops, as well as to better understand the articulatory mechanisms involved in implosive production. Fundamental frequency is one variable which has been considered in some depth. As previously mentioned, implosives have been described as having a glottalic ingressive airstream which overlaps with an egressive airstream flow. According to Wright & Shryock (1993), this transition from ingressive to egressive flow of air creates a burst of atmospheric pressure, subsequently increasing the velocity of the airflow. This should theoretically correlate with a higher fundamental frequency in implosive production. Additionally, implosives are thought to be produced with greater vocal fold tension, which also should relate to a higher acoustic measure of fundamental frequency (Painter 1978). On the other hand, implosives generally involve larynx lowering to produce the characteristic ingressive airflow. This, theoretically, should cause a slight *decrease* in the fundamental frequency of an implosive or surrounding segments. Therefore, the articulatory mechanisms involved in implosive production have potential opposing effects on fundamental frequency.

Voiced and voiceless plosives, conversely, are both pulmonic egressive consonants, meaning that the airstream involved in production is only traveling out through the oral cavity. Voiced and voiceless plosives differ, however, in that "true" voiced plosives (of the kind that are found in Rɨkpàʔ) are produced with prevoicing, which can be associated with a host of articulatory maneuvers which serve to increase supraglottal volume, such as larynx lowering (Bell-Berti 1975, Westbury 1983). As mentioned previously, larynx lowering can lead to f0 lowering. In contrast, voiceless plosives do not have prevoicing, so the fundamental frequency should be significantly higher than for voiced plosives (House & Fairbanks 1953). Past studies have presented results in accordance with these theories of implosive production. For example, Wright & Shryock (1993), conducting a study on SiSwati, a Southern Bantu language (region S.43), found that vowels following implosives were significantly higher in f0 than those following voiced plosives, but still lower than those following voiceless plosives. It appears, therefore, that although larynx lowering is attested for both implosives and voiced plosives, its effect on f0 lowering is less pronounced in implosives, perhaps due to competing effects of vocal fold stiffening and velocity of egressive airflow following implosive release. Assuming that Rɨkpàʔ implosives are produced similarly to those in SiSwati, we hypothesized that implosive fundamental frequency should be between that of voiced and voiceless egressive plosives.

In addition to predicted differences between implosive and explosive f0, studies have provided evidence that implosives involve longer prevoicing or closure duration than voiced plosives. Studies by Nagano-Madsen & Thornell (2012) on the Bantu language Mpiemo (A.86) and by Sande & Oakley (2020, 2023) for Guébie, a Kru language, found overall longer duration of closure/prevoicing for implosives than for voiced plosives. These authors also found that intensity of voicing during closure increases over time in implosives while staying relatively stable or even decreasing for voiced plosives. These acoustic variables can be indirectly attributed to the extent of cavity expansion and laryngeal constriction; therefore, these results are consistent with traditional theories of implosive production with rapid larynx lowering and increased laryngeal constriction leading up to the release. If Rɨkpàʔ implosives are produced in this same fashion, we should ideally see these acoustic patterns in our results as well.

1.2 Phonological patterning of implosives

In terms of their phonological patterning, implosives are intriguing in that they have been difficult to situate within the sonority hierarchy (1).

(1) Sonority Hierarchy per Clements (1990); ">" indicates "more sonorant than"

vowels > glides > liquids > nasals > obstruents

Catford (1939) description refers to implosives as "glottal suction stops," suggesting that implosives fit directly into an obstruent classification, on the rightmost side of the hierarchy. This account was well-established for many years; however, newer studies showed that implosives vary considerably across languages. There is the potential for modifications in which the atmospheric pressure can be zero, slightly negative, or slightly positive, meaning that implosives in some languages may not involve any ingressive airflow (Ashby 1990). These phonetic variations consequently put Catford's account into question, which led to Clements & Osu's study on the Ikwere language (2002). In this analysis, Clements and Osu proposed that these implosives had features that fit both sonorant and obstruent phonological qualities due to an absence of oral air pressure. Because of this, they concluded the implosives should be labeled as nonexplosive stops, classified as [−obstruent, −sonorant] within a binary feature system.

Recent work by Sande & Oakley (2020, 2023) has looked closer at the phonological patterning of implosives in order to better understand this cross-linguistic variation. They found that certain phonological patterning was characteristic of more obstruent-like implosives cross-linguistically vs. more sonorant-like implosives. For example, a large proportion of languages from their study which allow implosives in coda position tended to pattern phonologically with obstruents. Similarly, if implosives could be prenasalized in a language, they tended to form a natural class with obstruents. Based on these and other results, they concluded that in some languages, like Hausa, implosives pattern phonologically like obstruents, while in other languages, such as Guébie (Sande & Oakley 2020), implosives pattern phonologically like sonorants. Finally, a third group of languages, exemplified by Ikwere (Clements & Osu 2002), show mixed patterning between obstruent and sonorant. Instead of placing implosives within the class of obstruents, Sande and Oakley approach the treatment of implosives from a gradient features perspective (c.f. Smolensky & Goldrick 2016). Specifically, they argue that implosives should be located between obstruents and sonorants on the sonority scale, and that cross-linguistic variation in phonological patterning of implosives could be captured through language-specific constraint weighting.

Our work seeks to examine how distributional patterns of implosives in Rɨkpàʔ align with phonetic measurements in order to understand how the language might fit into such a typology.

2 Language background and distribution of implosives

Rɨkpàʔ, Kpɑ̀ʔ, or Bafia is a Bantu language (region A.53) spoken in the Center Region (Mbam and Inoubou divisions) of Cameroon. Rɨkpàʔ is classified as a Northwest Narrow Bantu language and is surrounded by Lefa, another Bantu language from the A.50 group, and Yambeta, and Gunu, two Southern Bantoid languages in the Mbam subgroup. Rɨkpàʔ has approximately 25,000 speakers and has four different dialects: Kpàʔ, Bape, Bə̀kpàk, and Rɨpéy. All participants in our study (as well as the second author of this paper) speak the Kpàʔ dialect.

Consonant and vowel charts are given in Tables 1 and 2 reproduced from Guarisma (2003: 308).

Table 1: Consonants of Rɨkpàʔ, based on Guarisma 2003: 308

	Anterior		Central			Posterior	
ORAL	Bilabial	Labio-dental	Apical	Post-apical	Palatal	Velar	Labio-velar
Implosives	ɓ		ɗ				
−voice	p	f	t	s	c	k	kp
+voice	b	v	d	z	j	g	gb
Continuants	w		l	r	y	ɣ	
NASAL	m		n		ɲ	ŋ	

Rɨkpàʔ is analyzed as having a two-way tonal contrast between high and low, though low tones before pause are realized with one of two surface patterns: low-falling, or low-level. These patterns are thought to be remnants of formerly L.L and L.H disyllabic stems, respectively (Guarisma 2003).

Zooming in to the set of plosive and implosive consonants, Rɨkpàʔ has two implosives, the bilabial /ɓ/ and alveolar /ɗ/, which contrast with voiced /b/ and /d/ and voiceless /p/ and /t/, respectively (2).

(2) Near-minimal triplets with implosives, voiced plosives, and voiceless plosives by place of articulation.

a.	ɓàm	‘bag’	bàn	‘town’	pán	‘dish’
b.	ɗú	‘fire’	dúŋ	‘mold’	tú	‘spit’

Table 2: Vowels of Rɨ̀kpàʔ, based on Guarisma 2003: 308

[−back]		[+back]
i	ɨ	u
e	ə	o
ɛ	ʌ	ɔ
a		ɑ
[−round]		[+round]

Word stems in Rɨ̀kpàʔ are largely monosyllabic, though prefixation is common, with prefixes used to express noun class and concord within various types of constructions (e.g., possessives, demonstratives, and diminutives/augmentatives), as well as tense and aspect on verbs (see Guarisma-Popineau 1992 and Guarisma 2000, 2003 for further details). A number of verb extensions and suffixes can also be used to express tense, aspect, and mood.

Syllable structure in the language is (N)CV or (N)CVC. Distributional patterning of implosives in Rɨ̀kpàʔ is quite varied: in addition to initial position, we find that both implosives may occur in medial position, and bilabial implosives may also occur in final positions (3).

(3) Implosives can occur in word-medial and word-final positions

a. ɓé**ɓ**è**ɓ**
   'ugly'
b. ʀɨ̀**ɗ**í
   'to eat'
c. tù**ɓ**
   'pour from a can'

Of interest is the fact that the other consonants allowed in coda position in Rɨ̀kpàʔ are mostly obstruents; nasals are the only sonorant consonants allowed in coda position (4).

(4) Other possible coda consonants include obstruents and nasals

a. kò**p**
   'partridge'

b. tú**ʔ**
'pull'

c. ŋwó**s**
'day/sun'

d. ntè**n**
'stubbornness'

Our findings are consistent with Guarisma (2003) in showing that several sonorants, such as /w/, /ʁ/, /j/, occur in onset position only, as in (5).

(5) Sonorants /w/, /ʁ/, and /j/ limited to onset position

a. ɓəŋ**w**í
'moons'

b. **ʁ**ɨ̀ɗí
'to eat'

c. pé**j**ɨ́
'pay (habitual imperative)'

Both implosives and plosives can be prenasalized in Rɨ̀kpàʔ (6), one of the strongest indicators of "obstruent-like behavior" in Sande and Oakley's typology. We note, however, that most sonorants in Rɨ̀kpàʔ can also be prenasalized (7).

(6) Prenasalization of implosives and plosives

a. **nɗ**óŋ
'lock'

b. **m̀ɓ**àŋ
'red brown colour'

c. **nd**ém
'heart'

d. **nt**èn
'stubbornness'

e. **mp**ó
'wait'

(7) Prenasalization of sonorants

a. **mj**ɔ́m
'mouths'

b. **ŋw**ós
‘day/sun’

We have seen that Rɨ̀kpàʔ implosives show quite flexible distribution in the language in terms of word position. Implosives are found to display two distributional properties associated with the phonological status of implosives as obstruents per Sande & Oakley, Sande & Oakley’s (2020, 2023) typology, including occurrence in coda position and propensity for prenasalization. However, we also find that at least some sonorant consonants can also occur as codas and be prenasalized. We now move on to explore phonetic properties of implosives through an acoustic analysis of these speech sounds.

3 Acoustic study design and method

3.1 Participants and procedure

This study included three female native Rɨ̀kpàʔ speakers, ages 22, 29, and 43. Each speaker produced three repetitions of each target word in isolation and in a sentence context. Example (8) shows a sample of how each word was consistently recorded across all participants for /kɨ̀dén/ ‘meat.’

(8) Lexical and sentence elicitation contexts

a. Lexical context
kɨ̀dén, kɨ̀dén, kɨ̀dén
‘meat, meat, meat’

b. Sentence context

mə	ǎ	ɣɛ́	kɨ̀dén	kɨ́	dʒè	á	fjè.
1SG	SM	saw	meat	ASSOC	pig	PREP	market

‘I saw a piece of pig meat at the market.’

Table 3 summarizes the list of stimuli in terms of segment type, word position, and place of articulation; Table 4 summarizes stimuli by position and tone of the vowel following the target segment.

Attempts were made to balance the number of segments of each type in each position in terms of the following tone, though there were somewhat fewer voiceless segments preceding low tones, perhaps a result of a depressor effect in the language (Kingston & Diehl 1994). Most target segments preceded back vowels [u] and [o], though there were a few tokens where the segment preceded a front vowel [e] or [i]. Examples of stimuli with target consonants in word-initial and word-medial position are shown by tone in Table 5.

Table 3: Frequency of target segments in corpus, by word position (initial vs. medial) and place of articulation

Initial			Medial		
ɓ / ɗ	b / d	p / t	ɓ / ɗ	b / d	p / t
3 / 4	13 / 6	5 / 5	8 / 4	2 / 2	5 / 8

Table 4: Frequency of target segments in corpus, by word position (initial vs. medial), place of articulation, and tone of following vowel

	Initial		Medial	
	Preceding high	Preceding low	Preceding high	Preceding low
Implosive	4	4	7	5
Voiced	10	7	3	3
Voiceless	7	3	9	3

Table 5: Stimuli in word-initial vs. word-medial positions, high vs. low tone

Word-initial position				Word-medial position			
High Tone		Low Tone		High Tone		Low Tone	
***ɗ**ú*	'fire'	***ɗ**ùm*	'belly'	*ʀɨ̀**ɗ**óŋ*	'to lock'	*ʀɨ̀**ɗ**ù*	'to struggle
***d**úŋ*	'mold'	***d**ùŋ*	'bush'	*ʀɨ̀**d**úʀɨ́*	'tomorrow'	*ɓɨ̀**d**ìlàʔ*	'food'
***t**újá*	'to pull'	***t**ɨ̀ɓɨ́ʔ*	'excrements'	*ʀɨ̀**t**úʔ*	'to pull'	*ʀɨ̀**t**ùɓ*	'to pour from can'
***ɓ**óŋá*	'wait' (imperative form)	***ɓ**òʀá*	'bra'	*ʀɨ̀**ɓ**óŋ*	'to wait'	*tɨ̀**ɓ**òmí*	'brain'
***b**ú*	'dog'	***b**ù*	'hole'	*bô**b**ó*	'medicine'	*kɨ̀m**b**òŋ*	'prisoner'
***p**éjɨ́*	'to pay' (imperative form)'	***p**ɨ̀ɣá*	'to launch' (imperative form)'	*ʀɨ̀**p**úpsɨ̀*	'to pay' (infinitive form)	*ʀɨ̀**p**ùʀɨ̀*	'to launch' (infinitive form)

3.2 Data processing and statistical analysis

After recording, data were segmented in Praat. We segmented and annotated the plosive/implosive closure, release, and the vowel following each target segment. Closure duration for voiced plosives and implosives was measured based on the period of prevoicing. For voiceless plosives, closure duration was only measured in word-medial position and was measured in terms of the silent portion following a preceding vowel and preceding plosive release. Figure 1 below depicts the acoustic landmarks used to annotate the word *bàm* 'button.'

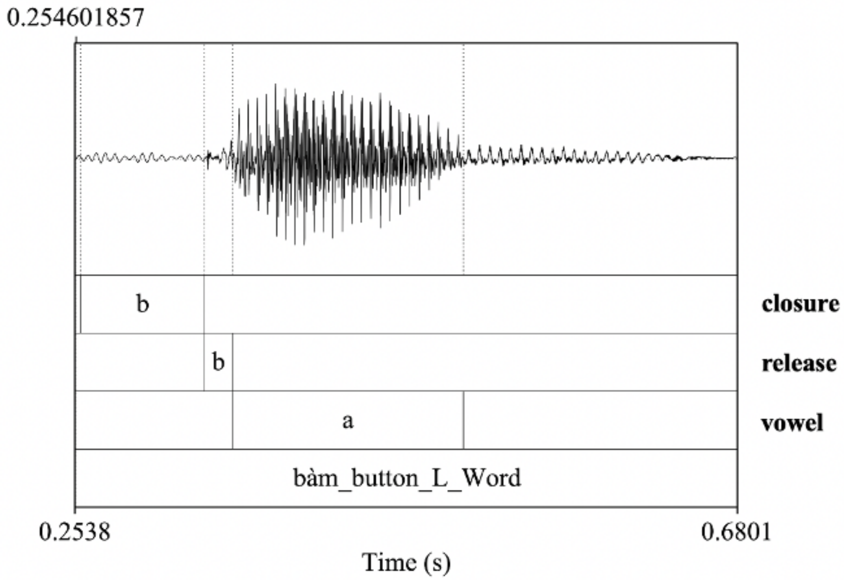

Figure 1: Sample acoustic annotation for the word *bàm* 'button,' including plosive closure (prevoicing), plosive release, and following vowel

Next, Praat scripts were used to extract acoustic measures of fundamental frequency (f0) of the vowel following the target plosive/implosive in Hertz (Hz), plosive closure duration in milliseconds (ms), and plosive closure intensity value in decibels (dB). In order to control for inter-speaker differences in vocal tract size, f0 values were z-scored by subject.

Data were analyzed with linear mixed effects models using the *lmer* package for *R* statistical software (Bates et al. 2015). Two separate models were run to test the effects of the variables' *segment type* (three levels: implosive vs. voiced plosive vs. voiceless plosive) and *position* (two levels: initial vs. medial) on intensity during the segment closure and closure duration. Models included by-subject random slope for position. A third model was run to test the effects of the variables' segment type and tone (two levels: high vs. low) on vowel fundamental frequency following the target consonant. This model included a by-subject random slope for tone. Given the as yet relatively small scale of this study, data were collapsed over place of articulation and context (isolation vs. sentence context). Categorical variables were treatment-coded. Posthoc paired comparisons were carried out using the *emmeans* package in R (Lenth 2021).

4 Results

4.1 Intensity

Our results revealed no main effect of segment type on intensity during closure between implosives and voiced plosives in initial position ($F(2, 839) = 3.00$, $p = 0.05$), but, consistent with previous studies (Lindau 1984, Nagano-Madsen & Thornell 2012), a rising intensity slope for implosives compared with voiced plosives (Figure 2).

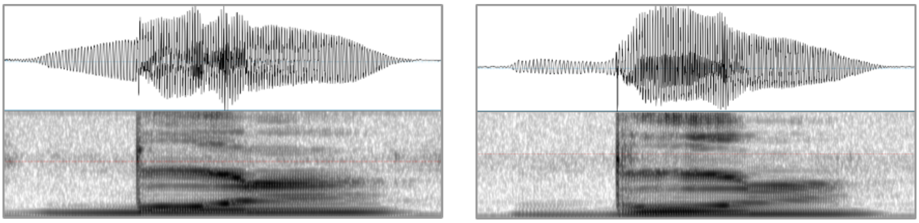

Figure 2: Acoustic signal for *ɓúl* 'snail' (left) and *búl* 'goat' (right); initial implosive shows a steady intensity rise into the release, while initial voiced plosive shows slight decrease.

There was a significant interaction between segment type and word position ($F(2, 776) = 18.54$, $p < 0.0001$). Posthoc testing confirmed that while there was no difference in closure intensity in initial position, implosives had slightly higher intensity than voiced plosives in medial position ($\beta = 3.03$, $t = 2.19$, $p < 0.05$, Figure 3), though intensity slope was flatter for implosive segments in this position (Figure 4). Voiced plosives had significantly higher closure intensity than voiceless plosives in medial position ($\beta = 4.01$, $t = 2.12$, $p < 0.05$).

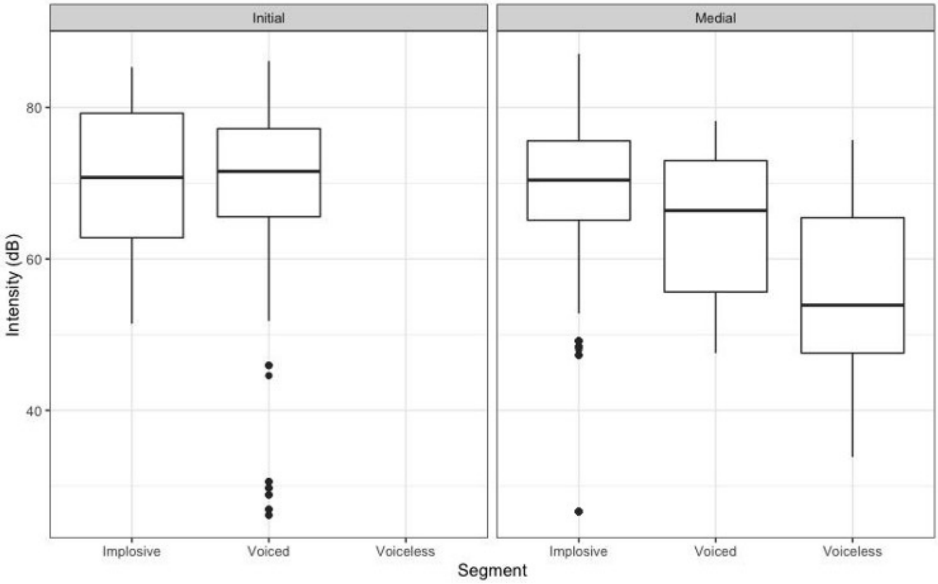

Figure 3: Intensity by segment type and position

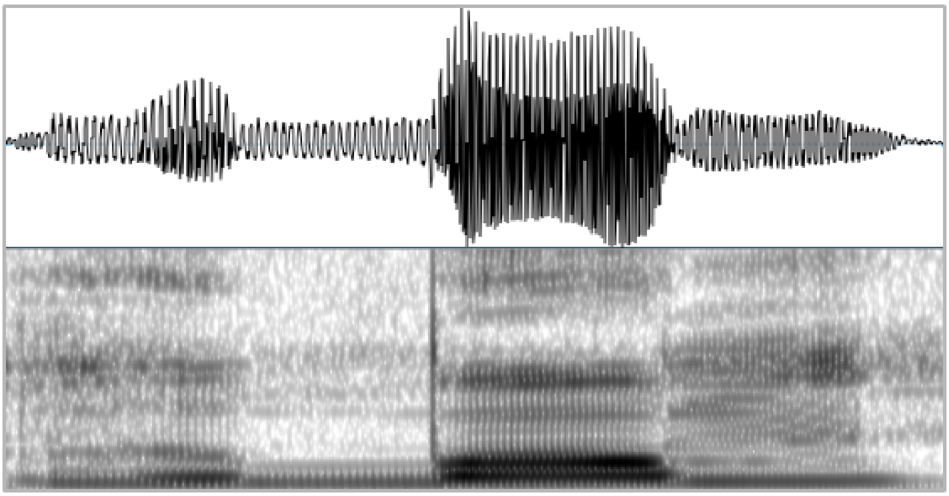

Figure 4: Acoustic signal for *ʀìɓóm* ‘furrow’; implosive in medial position shows relatively flat intensity profile

4.2 Closure duration

While there was a main effect of segment type on closure duration ($F(2, 332) = 3.84$, $p < 0.0001$), contrary to some prior research (Nagano-Madsen & Thornell 2012, Sande & Oakley 2020), closure duration was shorter for implosives than voiced plosives in initial position ($\beta = -20.04$, $t = -5.75$, $p < 0.0001$). A significant interaction between segment type and position was also found ($F(2, 403) = 25.67$, $p < 0.0001$), and posthoc tests revealed that voiced plosives trended toward having shorter closure duration compared with implosives in medial position, though this difference did not reach significance ($\beta = -10.00$, $t = -1.75$, $p = 0.08$). In medial position, voiceless plosives showed longer closure duration than implosives or voiced plosives ($\beta = 22.26$, $t = 4.05$, $p < 0.001$) (Figure 5)

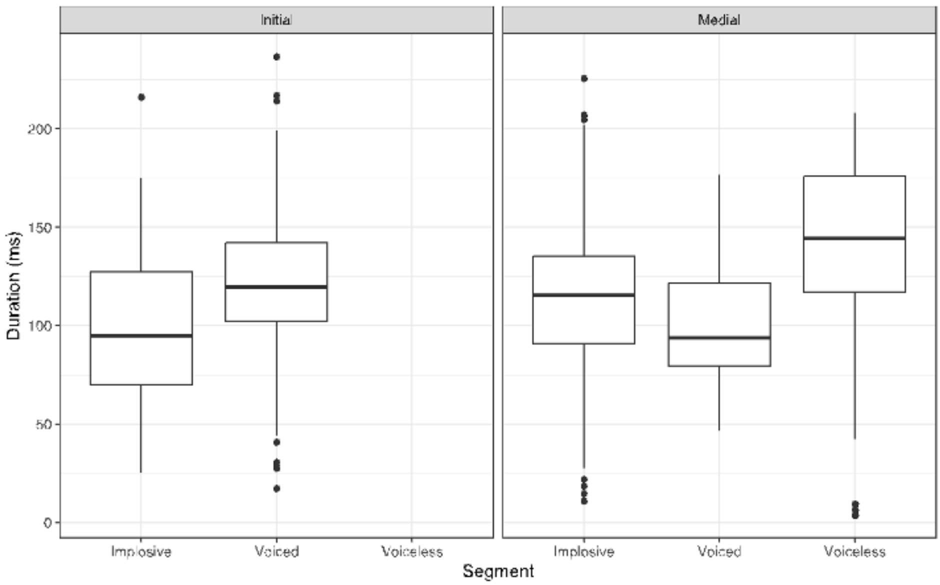

Figure 5: Closure duration by segment type and position

4.3 Vowel fundamental frequency

Finally, a main effect of segment type was found for vowel fundamental frequency ($F(2, 780) = 7.47$, $p < 0.001$), as well as an interaction between segment type and tone ($F(2, 781) = 3.12$, $p < 0.05$). For high-toned syllables, vowels following implosives were realized with significantly higher f0 than vowels following voiced plosives ($\beta = 9.55$, $t = 3.66$, $p < 0.001$), while no difference was observed between vowels following implosives and those following voiceless plosives ($\beta = 9.24$, $t = 1.92$, $p = 0.05$) (Figure 6). For low-toned syllables, however, vowels following implosives and voiced plosives patterned similarly ($\beta = 0.40$, $t = 0.14$, $p = 0.88$), while vowels following voiceless plosives trended towards having higher f0 than those following voiced plosives, though this difference did not reach significance ($\beta = 8.83$, $t = 1.30$, $p = 0.20$).

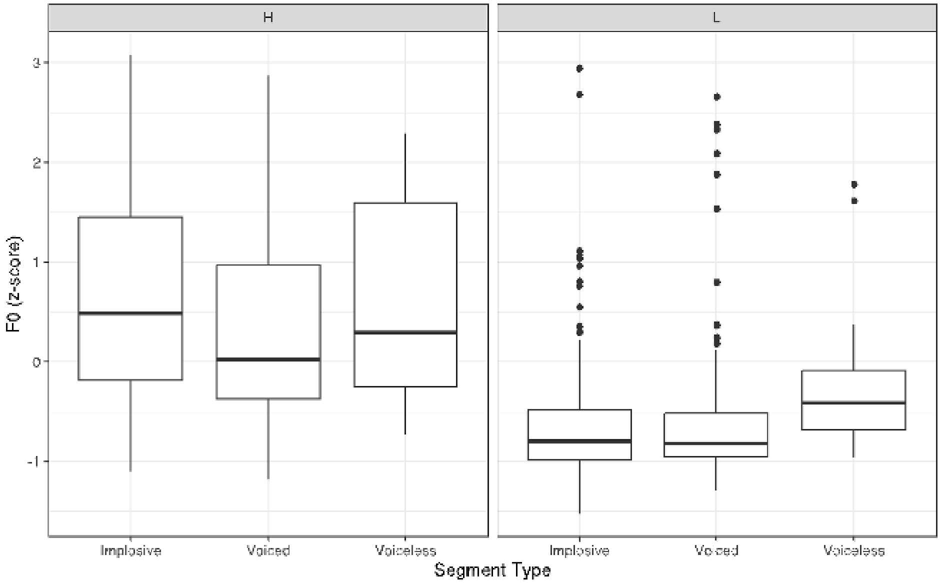

Figure 6: Fundamental frequency of following vowel by segment type and tone

5 Discussion

5.1 Phonetic patterning and articulation of implosives

To sum up, for prevoicing intensity, there was no significant difference in overall intensity during prevoicing between implosives and voiced plosives. However, similar to previous findings, implosives had a rising slope in prevoicing intensity building up to the release in initial position of the word. Voiced plosives, on the other hand, showed no change or a small decrease in intensity leading up to the release. These results are consistent with traditional theories of implosive production, where rapid larynx lowering and increased laryngeal constriction leading up to the release are thought to condition an increase in vocal intensity. Interestingly, in word-medial position, implosives had a significantly greater closure intensity compared to voiced plosives; however, both implosives and voiced plosives had relatively flat intensity slopes for intensity closure leading up to the stop release in this position. It appears, therefore, that the way in which intensity acts as an acoustic cue to implosive production varies across word positions. This is possibly a result of aerodynamic factors restricting prevoicing intensity in word-initial position vs. word-medial position, where (in our stimuli) the vocal folds were already vibrating from the preceding vowel when the implosive was initiated.

Initial prevoicing duration for implosives was found to be significantly shorter than for voiced plosives in word-initial position. This contrasts with past findings from Nagano-Madsen & Thornell on the Mpiemo language (2012), as well as from Sande & Oakley on the Guébie language (2020), both of which found that implosives had a significantly longer duration than voiced plosives. In word-medial position, implosives did have a slightly longer closure/prevoicing duration than voiced plosives; however, this was not a significant difference. Voiceless plosives had significantly longer closure duration than both implosives and voiced plosives. We take up this issue in more depth in §5.2.

As for fundamental frequency of the vowel following target consonants, f0 was higher overall after implosives than voiced plosives, similar to some previous studies. We also found that there was no significant difference between f0 following implosives and voiceless stops. It has been suggested that implosives involve relatively high vocal fold tension, which may counter the effects of larynx lowering in implosives, leading to similar values of f0 following implosives and voiceless plosives. Our overall results suggest that this is also the case in Rɨkpàʔ. However, an interaction between segment type and tone revealed that differences in f0 after implosives and voiced stops were diminished in the context of low tone vowels; both had relatively lower following f0 as compared with voiceless stops. We hypothesize that the larynx lowering and vocal fold slackening necessary for low tone production may override any potential tensing of the vocal folds during implosive production; further articulatory studies will be necessary in order to fully understand the ways in which these articulatory mechanisms operate across segment types and tones.

5.2 Distributional patterns of implosives in Rɨkpàʔ

Sande & Oakley (2020, 2023) propose, through an analysis of a diverse array of Sub-Saharan African languages, that implosives should be analyzed in terms of gradient features, allowing them to behave relatively more like obstruents or like sonorants. As mentioned in §1, there are various aspects of phonological patterning of Rɨkpàʔ implosives that suggest more consistent patterning with obstruents, per Sande & Oakley's diagnostics. For example, Rɨkpàʔ allows implosive codas, and most other segments allowed in coda position in the language are obstruents (with the exception of nasals). Furthermore, implosives in Rɨkpàʔ can be prenasalized, which is one of the strongest predictors of obstruent-like patterning in Sande & Oakley's typology.

Various aspects of our acoustic results are also consistent with the status of implosives in Rɨkpàʔ as more obstruent-like. For example, contrary to findings from Guébie, a language in which implosives are thought to behave more like sonorants, closure duration of implosives in Rɨkpàʔ was shorter, not longer, than that of voiced plosives. We also found that intensity profiles of medial implosives in Rɨkpàʔ revealed only slightly greater intensity than for voiced plosives. Medial implosives also had a similarly flat intensity slope to voiced plosives, rather than the characteristic steady increase in intensity during prevoicing. Sande & Oakley point out that intensity and duration are correlates of resonance more generally, with longer/louder segments tending to fall toward the more sonorous side of the sonority continuum. It is therefore striking that Rɨkpàʔ showed somewhat more obstruent-like patterning of these two variables.

Additional phonetic evidence for more obstruent-like behavior of implosives in Rɨkpàʔ comes from f0 patterning: in low tone contexts, implosives showed similar patterning of f0 on the following vowel to what was found for voiced stops. This would seem to suggest that some characteristic articulatory features of implosives–such as increased vocal fold tension–are sacrificed preceding a low tone vowel, leading to a greater level of acoustic similarity between implosives and other voiced obstruents.

6 Conclusion

All in all, our analysis of implosives from the Rɨkpàʔ language gave us insight into their phonetic patterning and phonological tendencies. Our acoustic results showed certain traditional markers of implosive production such as lowering of the larynx through observations of a rising intensity slope for implosive prevoicing. Also, we saw through our analysis that these implosives are produced with relatively stiff vocal fold tension, shown through the f0 analysis where implosives were significantly higher than voiced plosives and equivalent to voiceless plosives in high tone conditions.

However, we also saw that these implosives tended to be produced more similarly to voiced plosives in certain environments through our acoustic analysis. First of all, implosive f0 dropped to similar levels in comparison to voiced plosives in low tonal conditions. Also, we saw certain acoustic similarities in word-medial positions such as similar prevoicing durations and no rising intensity slopes. Along with these phonetic results, we observed certain phonological patterns in accordance with obstruent-like patterning. We found that Rɨkpàʔ implosives can occur in coda syllable positions, a common trait of other languages that have obstruent-like implosives based on Sande & Oakley's study. Furthermore, we observed that implosives were able to be prenasalized, another predictor of obstruent-like behavior from their study.

Based on these phonetic and phonological patterning observations, our assessment is that implosives in Rɨkpàʔ pattern mainly with obstruents. We note, however, that our study has some limitations. First off, we have thus far only examined implosives' phonetic patterning relative to obstruents in Rɨkpàʔ, but have not yet taken sonorants into consideration. Second, our word-medial implosives were largely stem-initial, following a CV prefix. Therefore, there may be additional prosodic considerations which we have not captured here in the patterning of implosive consonants in Rɨkpàʔ

Although further investigation into the acoustic and articulatory properties of implosives and a more in-depth survey of their phonological patterning will be important for corroborating this observation, these preliminary results support the idea that implosives do not form a unified class across languages either phonetically or phonologically; future research into the historical roots of this variation will also be useful in establishing a more comprehensive typology for implosives.

Acknowledgements

We are grateful to the Rɨkpàʔ speakers who participated in this study and to two anonymous reviewers for their helpful feedback on our paper. We are also grateful to Madeleine Oakley and Hannah Sande for helpful feedback on the paper.

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