# Features of implosives: Emergent or universal?*

Hannah Sande · Madeleine Oakley
Georgetown University
hannah.sande@georgetown.edu · mo643@georgetown.edu

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## 1 Introduction

- **Observation 1:** Implosive segments are conspicuously absent from typological studies of phonological sound patterning sound similarity.
  - Mielke (2012)'s acoustic and articulatory investigation of the level of similarity of 58 segments to understand why certain sounds tend to form natural classes.
  - Parker (2002, 2011)'s 'complete' sonority hierarchy.
- **Observation 2:** Implosives pattern with different groups of sounds in different languages.
  - With obstruents: Hausa (Afro-Asiatic), Fula (Atlantic)
  - With sonorants: Kwa, Kru
  - With both: Ijo, Ikwere
- **Driving questions:**
  - What phonetic and/or phonological traits do implosives share with obstruents?
  - What phonetic and/or phonological traits do implosives share with sonorants?
  - What phonological features of implosives account for their mixed patterning within and across languages?
- **Goal:** We examine the cross-linguistic phonological patterns of implosives, as well as their acoustic and perceptual patterning within a single understudied language, to better understand what set of phonological features might account for the mixed patterning of implosives.

**Roadmap**



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# 2 Phonological patterning of implosives

## 2.1 Previous literature

- The distribution of implosives across the world's languages, based on the 2,155 languages in the Phoible database, is provided below.

| | ɓ | ɗ | ʄ | ɠ |
|---|---|---|---|---|
| **Count** | 293 | 241 | 45 | 19 |
| **Percent of languages** | 14% | 11% | 2% | 1% |

  - Implosives are not very common as contrastive sounds in general, but the bilabial implosive is more common than the alveolar, which is more common than the palatal or velar.
  - Languages containing implosives in their inventories are primarily concentrated in subsaharan Africa, with some representation in southeast Asia and Central and South America as well (Moran et al. 2014).

- There has been very little work on the phonological patterning of implosives across languages. Implosive patterning in six languages or language families are considered here.

## 2.2 Implosives pattern with obstruents

### 2.2.1 Hausa

- In Hausa, there is a set of glottalized consonants [ɓ, ɗ, 'y, k, kw, ky] (Newman 2000, p. 392).
- These contrast with voiced and voiceless plosives, and sonorant consonants (nasals, liquids, glides).
- Sonorants do not co-occur in a word in Hausa, but implosives (like obstruents) co-occur with sonorants: ɗàri, 'hundred'
- Similarly, in CC clusters where the first is an obstruent or implosive, the cluster surfaces as a geminate with the features of the second consonant (Newman 2000, 2004).
  - Sonorants do not show this pattern (1c)

(1) **Geminate simplification in Hausa**

| | *Underlying* | *Surface* | *Gloss* |
|---|---|---|---|
| a. | zàaf-zàafáa | zàazzàafáa | 'hot' |
| b. | káɗ-kàɗáa | kákkàɗáa | 'keep beating' |
| c. | fàrkáa | fárkáa, *fákkáa | 'paramour' |

- There is no evidence that implosives in Hausa ever pattern with sonorants.

### 2.2.2 Fula

- In Fula, in coronals CC sequences, the first C must be more sonorous than the second. Implosives pattern with obstruents in this distributional requirement.
  - Liquids, glides, and nasals precede stops and implosives.
  - Stops and implosives never precede other stops or implosives.
- A suffix /-dV/ surfaces as [dV] after a sonorant but [-VrV] after an obstruent. Implosives again pattern with obstruents.

(2) *Fula implosives pattern with obstruents in affix selection* (Paradis 1992, p. 121)

| | | |
|---|---|---|
| a. | fal-dɛ | 'bank' |
| b. | tul-dɛ | 'mountain' |
| c. | ton-du | 'lip' |
| d. | con-di | 'flour' |
| e. | ser-du | 'rifle butt' |
| f. | hiir-dɛ | 'evening' |
| g. | hus-ɛrɛ | 'cube' |
| h. | nad-ɛrɛ | 'belt' |
| i. | sɛɛd-ɛrɛ | 'cowrie' |
| j. | yiit-ɛrɛ | 'eye' |
| k. | fuʃ-ɛrɛ, *fuʃ-dɛ | 'pimple' |
| l. | ɗaaʃ-ɛrɛ, *ɗaaʃ-dɛ | 'bulb' |

- Additionally, obstruents and implosives pattern together in assimilating to following coronal suffixes, while sonorants do not.

(3) *Implosives pattern with obstruents in triggering assimilation*(Paradis 1992, p. 122)

| | | | |
|---|---|---|---|
| a. | /mut-n-a/ | munna | 'to make s.o dive' |
| b. | /hɔɗ-n-a/ | hɔnna | 'to make s.o. inhabit' |
| c. | /fad-t-a/ | fatta | 'to wait again' |
| d. | /tiiɗ-t-a/ | tiitta | 'to harden again' |
| e. | /yul-n-a/ | yulna, *yunna | 'to make s.o. pierce' |
| f. | /ɓir-n-a/ | ɓirna, *ɓinna | 'to make s.o. milk' |
| g. | /hɛl-t-a/ | hɛlta, *hɛtta | 'to break again' |
| h. | /ɓir-t-a/ | ɓirta, *ɓitta | 'to milk again' |

- According to Paradis (p. 119), 'In Pulaar [...] there are no arguments favoring an analysis of implosives as sonorants. The behavior of these consonants in Pulaar suggests that the should be classified as stops.'

## 2.3 Implosives pattern with both obstruents and sonorants

### 2.3.1 Ijo

- Williamson (1978) describes the patterning of implosives in Ijo, spoken in southern Nigeria.
- In Ijo, implosives pattern with sonorants in some respects, but with obstruents in others.
- **Patterning with sonorants:** In some Ijo varieties, initial sonorants and implosives are produced as nasalized before nasal vowels, while obstruents are not (4) (Williamson 1987).

(4) **Ijo nasalization** (Williamson 1987)[1]

| | Kalabari | Nemba | Biseni | Oporoza | Proto-Ijo | |
|---|---|---|---|---|---|---|
| a. | mĩɲɟi | mĩndí | mĩnĩ | bẽnĩ | * ɓẽdĩ́ | 'water' |
| b. | mãŋgí | mãŋgí | mɛ̃ɛ̃ | bãĩ | *ɓãgĩ́ | 'run' |
| c. | pãmba | pãmbá | – | pĩmã | *pãbá́ | 'wing' |

[1]Additional data to fill out this paradigm is not available, so we rely on the analysis provided by the source of the data, Williamson (1987).

- **Patterning with obstruents:** Consonants cannot be 'stronger' than a preceding consonant in the word. The strength divisions are provided below (Williamson 1978).

| | |
|---|---|
| **Strong** | p, t, k, kp, f, s |
| **Medium** | b, d, g, gb, ɓ, ɗ |
| **Weak** | m, l, r, w, y, ɣ |

  - Note that the two implosives in the inventory, /ɓ, ɗ/, pattern with voiced plosives.
  - This pattern is illustrated by a set of Proto-Ijo forms in (5) (Williamson 1978, 245), though note that the same pattern also holds in the majority of synchronic forms across Ijo.

(5) **Proto-Ijo consonants decrease in strength throughout a word**

| | | | |
|---|---|---|---|
| a. | */o-kosi/ | 'old (person)' | strong, strong |
| b. | */kodmu/ | 'waist' | strong, medium, weak |
| c. | */akalʊ/ | 'moon' | strong, weak |
| d. | */ɗigi/ | 'rope' | medium, medium |
| e. | */ɓeri/ | 'ear' | medium, weak |
| f. | */o-molmi/ | 'slave' | weak, weak, weak |

- Implosives pattern with obstruents with respect to distribution in a word, but sonorants with respect to nasalization in Ijo.

### 2.3.2 Ikwere

- Clements and Osu (2002) describe a set of non-explosive stops in Ikwere which are articulatorily similar to implosives in that they correlate with negative air pressure and ingressive airflow, but differ in that they do not involve lowering of the larynx.
  - Despite their articulatory differences, I refer to the Ikwere non-explosives as implosives here, for lack of a better term.
- **Patterning with sonorants:**
  1. Ikwere implosives and sonorants have nasal realizations before nasals, but obstruents do not.
     - [àbà̀], 'jaw', but *[ãɓà̀]
     - There are no cases of a surface implosive followed by a nasal vowel, but there are cases of [m] followed by a nasal vowel. /ɓ/ is analyzed as surfacing as [m] before nasal vowels: the strong subject pronoun /ɓɛ̃/ surfaces as [mɛ̃].
  2. Implosives and sonorants do not have a depressing (lowering) effect on surrounding tones.
- **Patterning with obstruents:** Obstruents and implosives are more often present in onset than coda position in Ikwere. They may precede liquids in onset clusters, while other sonorants cannot.
  - Similar distributional restrictions are found in other African languages with implosives: Lendu, Hausa, Fula. See (Clements and Osu 2002, 337) for an overview.

## 2.4 Implosives pattern with sonorants

### 2.4.1 Ebrié

- In Ebrié (Bole-Richard 1983, 327) (Kwa, Côte d'Ivoire), implosives pattern with sonorants.
- After a nasal vowel, all vowels, sonorants, and implosives surface as nasal.

(6) *Ebrié nasalization affects implosives* (Bole-Richard 1983, 328)

a. àká ɓà lé ɓá
Aka FUT NEG come
'Aka will not come'

b. à̀ mà̀ né́ má́
She FUT NEG come
'She will not come'

- Similarly, the plural morpheme in Ebrié is a nasal feature, which affects all vowels and sonorants and implosives in the word (7).

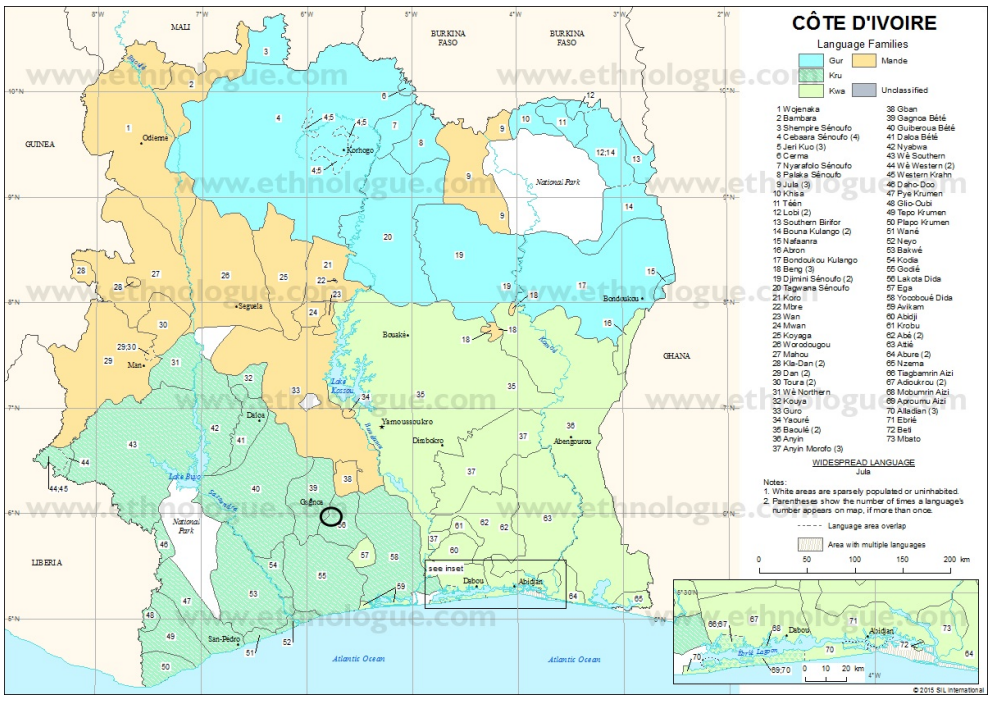
(7) *Ebrié nasalization in plural contexts* (Bole-Richard 1983, 328)

| | *Singular* | *Plural* | |
|---|---|---|---|
| a. | ájá | ɛ́ɲá́ | 'trees' |
| b. | áɓɛ́ | ɛ́mɛ́ | 'ropes' |
| c. | álɛ́ | ánɛ́ | 'tongues' |
| d. | àwɔ́ | à̀ŋwɔ́ | 'cats' |

- Implosives and oral sonorants do not co-occur with nasals. Fricatives and plosives, on the other hand, can co-occur with nasal vowels: ɛ̀zɔ́, 'shell species'.

### 2.4.2 Guébie

- Number of speakers: ∼7,000
- One remaining monolingual speaker
- Most Guébie speakers speak French, many also speak other neighboring Kru languages.




- The data in this section was collected over the past six+ years in Sande's work with the Guébie community (Sande 2017).

- There is one implosive sound in Guébie, /ɓ/, which constrasts with other labial(ized) consonants, /p, b, kp, gb, $k^w$, $g^w$, w/.
  - /ɓ/ patterns with sonorants in four respects, and never patterns with obstruents.
    1. CVCV reduction to CCV is highly likely if the second C is /l/ or /ɓ/, but not otherwise.

(8) **CVCV → CCV**

| | *CVCV* | *CCV* | Gloss |
|---|---|---|---|
| a. | jɪla$^{2.3}$ | jla$^{23}$ | 'ask' |
| b. | duɓu$^{3.3}$ | dɓu$^{3}$ | 'mourn' |
| c. | bete$^{3.1}$ | *bte$^{31}$ | 'break' |

    2. Vowel hiatus is avoided by inserting /j/, /w/, or /ɓ/.
    3. In reciprocal reduplication, /ɓ/ is reduplicated as [l].
       * See Kaye et al. (1981) on a similar historical change in Dida and Bete, two neighboring Kru languages.

(9) [l] ∼ [ɓ] **alternation in reduplication**

| | *(Particle-)Verb* | *Reciprocal* (verb-RED-li) | *Gloss* |
|---|---|---|---|
| a. | ɓɔ | ɓɔ-l̲ɔ-lɪ | 'finish each other' |
| b. | ji-ɓe | ji-ɓe-l̲e-li | 'know each other' |
| c. | la | la-la-lɪ | 'call each other' |
| d. | ɟu | ɟu-ɟu-li | 'respect each other' |

    4. Distributionally, implosives and sonorants fail to co-occur in monomorphemic words containing nasals, while obstruents co-occur freely with nasals.
       * Of the 165 disyllabic words containing an implosive, only 2% of them co-occur with a nasal.
       * Similarly, only 10 of the 686 disyllabic words containing /l/ (1%) also contain a nasal consonant.
       * On the other hand, obstruents regularly co-occur with nasals; between 12 and 30% of the disyllabic words containing each obstruent also contain a nasal. (Since nasals make up 20% of the consonant inventory of Guébie, this is the expected proportion of co-occurrences.)

- Like Guébie, implosives pattern with sonorants to the exclusion of obstruents across Kru languages (Kaye et al. 1981).
  - Tone spreading rules apply to implosives in the same way as sonorants. Obstruents block tone spreading (10c) while implosives and sonorants do not (10a,b). Tones spread onto following low-toned words. Relevant data from Vata is provided in (10).

(10) **Tone spreading in Vata** (Kaye et al. 1981, 80)

| | *Underlying* | *Surface* | *Gloss* |
|---|---|---|---|
| a. | n$^{3}$ li$^{1}$ | n$^{3}$ li$^{3}$ | 'I ate' |
| b. | n$^{3}$ ɓuɓie$^{1.1.2}$ | ɓuɓie$^{31.1.2}$ | 'I pardoned' |
| c. | n$^{3}$ bada$^{1.1}$ | n$^{3}$ bada$^{1.1}$ | 'I hung' |

  - As in Guébie, laterals and implosives across Kru fail to co-occur with nasals.
    – Some Kru languages are analyzed as not having contrastive nasal consonants. Instead, surface nasals are derived from underlying sonorants and implosives in words that contain nasal vowels.

# 3 Acoustic properties of implosives

We determine whether language-specific phonetics might be responsible for the mixed cross-linguistic patterning of implosives by examining whether implosives pattern phonetically with sonorants in Guébie.

- In a series of perception experiments, Sande and Oakley (2018a,b) found that implosives are more often confused with obstruents than with sonorants, and in a forced choice similarity task, speakers are more likely to choose obstruents than sonorants as most similar to implosives.
  - These results hold in English, where listeners do not have a contrastive implosive in their L1, and in Guébie where speakers have a contrastive implosive in their L1, which patterns phonologically with obstruents.
- In order to test whether the phonological patterning of implosives as sonorants in Guébie is related to their phonetic characteristics, here we present results from a production task.
- **Acoustic expectations:**
  - Catford (1939) describes implosives in Nama as ingressive stops with a glottal closure, a lowering of the larynx, and implosion when the glottal closure is released.
    - However, not all implosives are produced with glottal closure or ingressive airflow (Ladefoged 1968; Ladefoged and Maddieson 1996).
    - Not all implosives are produced with larynx lowering or negative oral air pressure (Clements and Osu 2002).
    - Similarly, effects of implosives on F0 of the following vowel differ across speakers and languages (Wright and Shryock 1993; Nagano-Madsen and Thornell 2018)
  - Clements and Osu (2002) determine that the most reliable feature to differentiate an implosive is the lack of an increase in oral air pressure during production.
- In this section we examine intensity slope (an acoustic measure of oral air pressure change), as well as average intensity and duration of implosives, sonorants, and obstruents in Guébie.
  - If implosives pattern with sonorants on any of these measures, it may give us a clue as to why implosives pattern with sonorants in Guébie, and what phonological features might be leveraged to model the natural class of sonorants and implosives.

## 3.1 Methodology

- Participants: 5 Guébie speakers
  - Speaker 1 and Speaker 2: male, age 25-40
  - Speaker 3, Speaker 4, Speaker 5: female, age 20-30
- Task and Procedure
  - Elicitation: prompted by phrases in French that the speakers translated into Guébie
  - Each phrase was repeated three times
  - Target words in phrase initial position, designed to elicit obstruents and sonorants with every combination of vowel and tone pair
  - In total, 456 obstruent tokens, 162 sonorant tokens, and 73 implosive tokens included in analysis

- Analysis
  - In Praat, each target consonant was measured for duration, average intensity (dB), intensity at 25% of the consonant, intensity at the end of the consonant, and intensity slope (measured as change of intensity at 25% and end of consonant divided by consonant duration)
  - In R, Anova to compare individual acoustic measures between obstruents, sonorants, and implosives

## 3.2 Results

- Intensity (measured in dB)
  - Average intensity: Anova's comparing mean dB for obstruents, sonorants, and implosives
    - Main effect of consonant category (p=2e-16)
    - Post-hoc Tukey HSD shows obstruents, sonorants, and implosives are all significantly different in average intensity

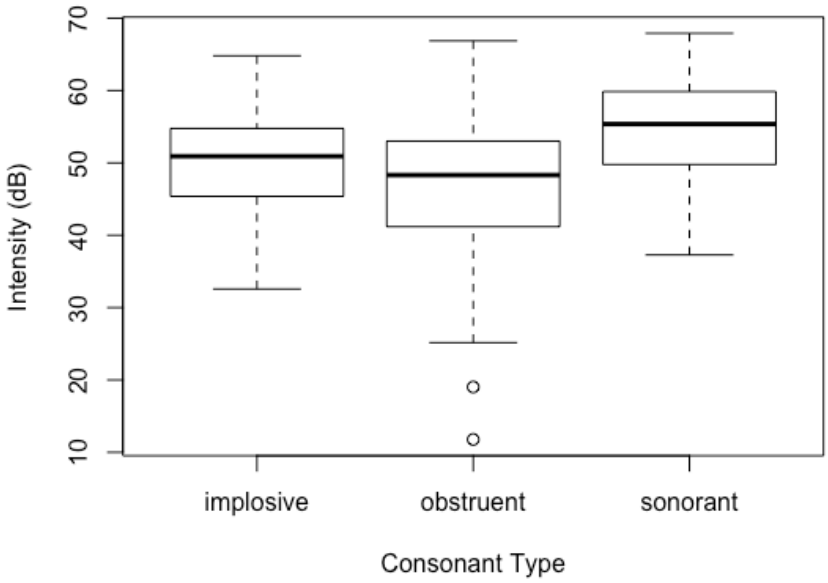



Figure 1: Average Intensity (dB) of consonants in initial position

  - Intensity slope: Chi-Square comparing the number of tokens with rising or falling intensity slope, by consonant category
    - Obstruents, sonorants, and implosives have different number of tokens with positive and negative intensity slope (p=2.55e-8)
    - Implosives and sonorants tend to have rising intensity slope, while obstruents tend to have negative intensity slope

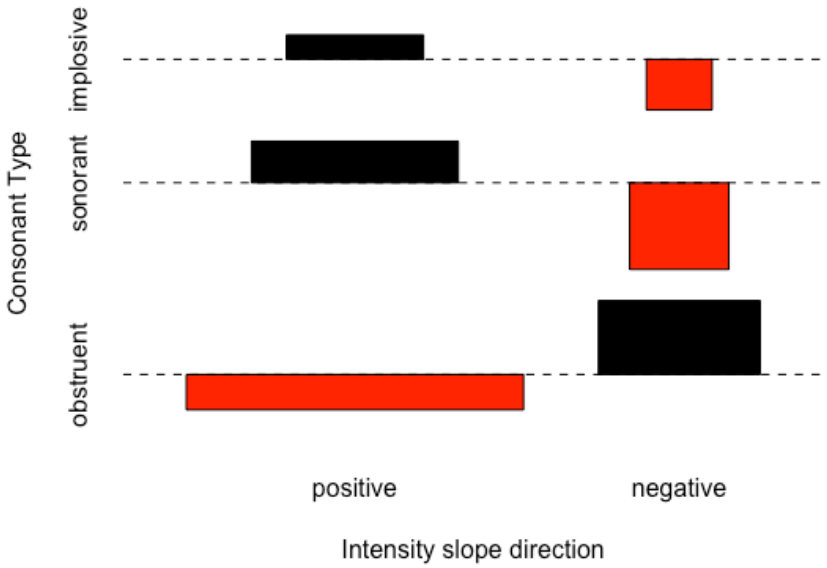



Figure 2: Association plot of occurrences of implosives, sonorants, and obstruents with a negative or positive intensity slope for all speaker's consonant productions

- Duration: Anova's comparing duration measures of obstruents, sonorants, and implosives
  - For all speakers: main effect of consonant category (p=2.46e-5)
  - Post-hoc Tukey HSD shows obstruents differ from sonorants and implosives in average duration, but sonorants and implosives do not differ from each other

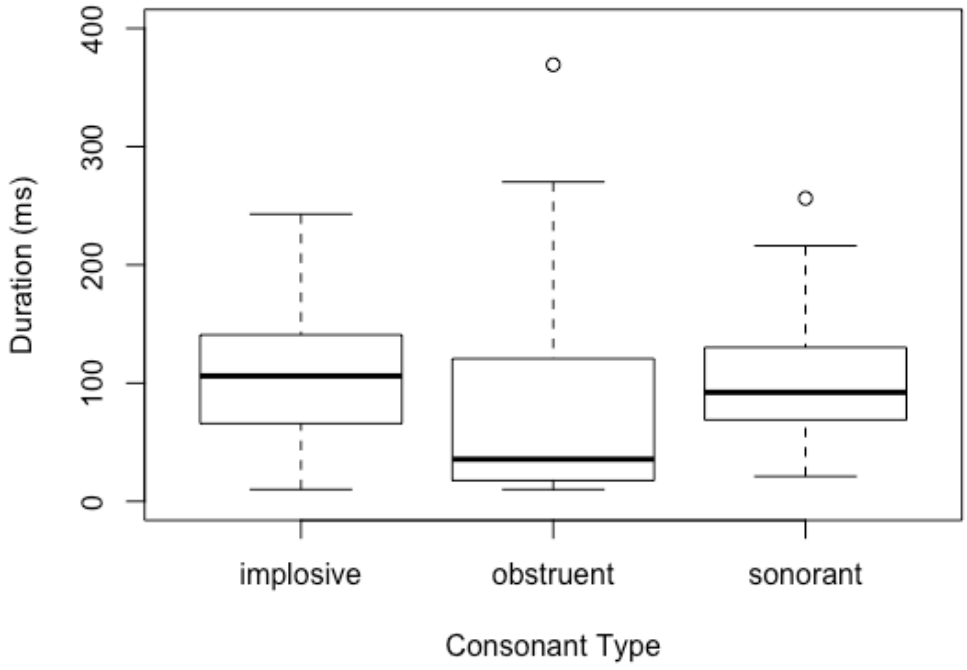



Figure 3: Duration (ms) of consonants in initial position produced by all speakers

To summarize: implosives and sonorants are phonetically similar in terms of duration and direction of intensity slope throughout the production of the consonant. Implosives differ from obstruents in terms of average intensity, intensity slope direction, and duration.

### 3.3 Discussion

- Results from previous perception tasks show that implosives are perceived as more similar to obstruents than sonorants, despite the phonological patterning implosives with sonorants in Guébie.
- In the production task, implosives were found to differ from both obstruents and sonorants in their average intensity.
- However, implosives pattern with sonorants in Guébie in having a negative intensity slope over the duration of the consonant, and in their average duration.
- **Remaining questions:**
  - How do implosives pattern acoustically in a language like Hausa where they pattern phonologically with obstruents?
  - What phonological features account for the patterning of sonorants in some languages but obstruents in others?
    - Should the relevant phonological features correspond to intensity slope and duration, because those are the acoustic features that seem to differentiate implosives and sonorants from obstruents in Guébie?

## 4 Possible phonological analyses

- Distinctive feature theories make predictions about the sounds that we expect to see patterning together phonologically across languages.
  - Sounds that share features, such as vowels with a [-back] feature (front vowels), for example, form a natural class.
  - These natural classes can be the targets or triggers of phonological alternations.
- In most feature theories, individual distinctive features are phonetically defined, grounded in acoustics, articulation, or perception (Jakobson et al., 1951; Chomsky and Halle, 1968; Clements and Hume, 1995).
  - Even in Emergent Feature Theory (Mielke, 2004, 2008), phonetic similarity is predicted to motivate phonological natural classes: 'phonologically active classes are accounted for in part as the result of generalizations to groups of phonetically similar segments' (Mielke, 2004, p.230).
- The majority of the literature on the features of implosives assumes that they are obstruents, and focuses on the laryngeal features which distinguish implosives from plosives and ejectives.
  - Chomsky and Halle (1968); Greenberg (1970); Halle and Stevens (1971); Keating (1984); Lombardi (1995); Hall (2007)
  - An exception: (Clements and Osu 2002) propose that implosives in Ikwere are both [-obstruent] and [-sonorant], based on language-specific articulatory, acoustic, and phonological properties.
  - With the exception of Clements and Osu (2002), all prior work on features of implosives predicts that implosives are obstruents and should pattern with obstruents to the exclusion of sonorants.

- We see three possible types of feature-based solutions to the question of how to account for the cross-linguistic behavior of implosives.

  1. Implosives universally have features in common with both obstruents and sonorants (cf. Clements and Osu (2002)).

     (11) **Possible universal features of obstruents, implosives, and sonorants**

     | | *+obstruent* | *-obstruent* |
     |---|---|---|
     | *[+sonorant]* | – | Sonorants |
     | *[-sonorant]* | Obstruents | Implosives |

     – *Potential problems*:
       * Over-predicts that we should find a set of sounds that is both [+obstruent] and [+sonorant].
       * Requires binary [obstruent] and [sonorant] features, which is different than what most extant universal feature theories assume.
       * In languages like Guébie and Ebrié, there is no phonological evidence for a [-sonorant] feature of implosives.
       * In languages like Hausa and Fula there is no phonological evidence for a [-obstruent] feature of implosives.

  2. Features are not universal, but emergent, and learners of different languages will learn a different set of features for implosive sounds based on language-specific phonetics and phonology (Pierrehumbert 2001; Johnson 2007).
     – Instances of production and perception (exemplars) experienced by the speaker/hearer are stored (in clusters) as they occur, not necessarily associated with an abstract feature set.
     – There are a number of benefits of adopting an emergent feature approach, in particular for segments who pattern with different classes of sounds in different languages.
     – *Potential problem:* An emergent feature approach does not make clear predictions about possible natural classes. What sounds sounds do we expect implosives to pattern with across languages?
     – Though perhaps for cognitive or other functional reasons there are explanations for why some segments/exemplars are clustered together.
       * Within emergent feature theory, phonetically natural classes are the result of common sound changes, while phonetically unnatural classes are the result of less likely sequences of events (Mielke 2008, 87-88). Further historical investigation is needed to determine the sequence of events most likely to have resulted in the current Guébie system (and other cross-linguistic systems with contrastive implosives).

  3. Features are universal but gradient, and implosives fall in between obstruents and sonorants on a universal sonority scale.
     – Gradient Symbolic Representations assume that input segments can be gradiently activated (Smolensky and Goldrick 2016).
     – Following more recent work, we assume that features can be gradiently activated (Rosen 2016; McCollum 2019; Walker 2019).
     – On this approach, the sonority hierarchy could be built into the grammar with a universal gradient activity scale for the feature [sonorant] (we take the combined acoustic measures of duration and intensity to be related to sonorousness):

(12) **The sonority hierarchy** (Parker 2011)
vowels[2] ≫ glides ≫ rhotic approx. ≫ flaps ≫ laterals ≫ trills ≫ nasals ≫ voiced fricatives ≫ voiced affricates ≫ voiced stops ≫ voiceless fricatives ≫ voiced affricates ≫ voiced stops

(13) **Proposed gradient sonority features** vowels: $[\text{Son}]_{1}$ ≫ glides: $[\text{Son}]_{.9}$ ≫ rhotic approx.: $[\text{Son}]_{.8}$ ≫ flaps: $[\text{Son}]_{.75}$ ≫ laterals: $[\text{Son}]_{.7}$ ≫ trills: $[\text{Son}]_{.65}$ ≫ nasals: $[\text{Son}]_{.6}$ ≫ **implosives**: $[\text{Son}]_{.5}$ ≫ voiced fricatives: $[\text{Son}]_{.35}$ ≫ voiced affricates: $[\text{Son}]_{.3}$ ≫ voiced stops: $[\text{Son}]_{.25}$ ≫ voiceless fricatives: $[\text{Son}]_{.15}$ ≫ voiced affricates: $[\text{Son}]_{.1}$ ≫ voiced stops: $[\text{Son}]_{.0}$

- In a MaxEnt-Harmonic Grammar model (Goldwater and Johnson 2003; Hayes and Wilson 2008), language-specific constraint weights interact with this universal sonority activity scale to result in mixed patterning of implosives within and across languages.
- In an upcoming BLS talk, we flesh out the details of this latter approach and argue that it is preferred:
  * The proposed gradient representations account not just for the patterning of implosives, but other sonority-related patterns across languages.

# 5 Conclusions

- **Cross-linguistic findings**
  - Implosives pattern with obstruents in some languages, sonorants in some languages, and with obstruents and sonorants in different alternations in other languages.
- **Acoustic findings for implosives in Guébie**
  - We describe the acoustics of consonant sounds in an understudied languages.
  - Implosives are differentiated from other sounds in their average intensity.
  - Implosives are similar to sonorants, to the exclusion of obstruents, in their average duration and intensity slope.
- **Phonological findings:**
  - We weigh the pros and cons of three possible phonological feature systems: universal binary features, emergent features, and universal gradient features.
    - Future historical work may show that an emergent feature account is well suited to model the cross-linguistic patterning of implosives.
    - We tentatively conclude that universal gradient features (discussed further in Sande and Oakley (2020)) provide the best explanation for the patterning of implosives within and across languages.
  - More concretely, we conclude that implosives have an intermediate status on the sonority hierarchy, between obstruents and sonorants.

[2]Parker breaks down vowel sonority into 5 parts, which I've simplified here.

# References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