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A typological survey of the phonological behavior of implosives: Implications for feature theories

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This paper presents the first cross-linguistic investigation into the phonological behavior of implosive sounds. In many feature theories, implosives share features with obstruent sounds, plus some implosive-specific laryngeal feature. These feature theories predict, then, that implosives should pattern phonologically as a natural class with obstruents, to the exclusion of sonorants. We take a detailed look at the phonological patterning of implosives in six languages, and present results of a typological survey of implosives in 88 languages where implosives contrast with sonorants and obstruents at the same place of articulation. We find that, despite previous feature-based proposals which assume that implosives are obstruents, implosives pattern with sonorants to the exclusion of obstruents in 38% of languages in our sample. Another 32% of languages show mixed behavior, where implosives pattern with both obstruents and sonorants, depending on the specific phonological process involved. We discuss the implications of our results for the phonological featural representation of implosives, and propose future historical and phonetic studies to further illuminate the cross-linguistic behavior of implosive sounds.

Keywords: implosives; typology; obstruents; sonorants; distinctive features

1 Introduction

Implosive consonants are found in about 14% of the world's languages, yet we know very little about their phonological patterning. To fill this gap, this paper closely examines the behavior of implosives in six African languages, and presents the results of a typological survey on the phonological behavior of implosives across 88 languages. While previous phonological feature theories treat implosives as obstruents, we find that implosives pattern with obstruents to the exclusion of sonorants in only about about 30% of the languages in the sample. In other languages with implosive sounds, they pattern with sonorants, to the exclusion of obstruents (38%), and in still another set of languages, implosives pattern with obstruents with respect to some processes but with sonorants for others, showing mixed phonological behavior (32%). These results have implications for phonological representations of implosive sounds.

We begin by surveying previous literature on implosives (Sections 1.1 and 1.2), and developing a definition of these for our purposes, §1.3. A full roadmap of this paper can be found in §1.4.

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1.1 The areal distribution of implosives

Implosives are present in about 14% of the world's languages, based on the sample of 2,155 languages in the Phoible database (Moran & McCloy 2019).

Table 1: Languages with implosives

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

The bilabial implosive is more common than the alveolar, which is more common than the palatal or velar. While most languages with only one implosive have a bilabial implosive, there are a few languages, concentrated in East Africa, which have only an alveolar implosive. Languages containing implosives in their inventories are primarily found in subsaharan Africa, with some representation in southeast Asia and Central and South America (Moran & McCloy 2019). Most languages with implosive sounds outside of Africa do not have contrastive plosives at the same place of articulation. The areal distribution of implosives as found in our typological sample will be elaborated on more fully in §3.2.3.

1.2 Predicted patterning of implosives

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, for example, form a natural class. These natural classes can be the targets or triggers of phonological alternations, i.e. velars become palatal before [-back] vowels in Modern Greek. A rule referring to the natural class of [velar] or [dorsal] sounds allows us to avoid stating two separate rules, one for the velar stop and one for the velar fricative, both which surface as palatal before front vowels. Similarly, front vowels in general trigger this change. The natural class of front vowels can be specified with a single [-back] feature, rather than a list of all front vowels, or a separate rule for each front vowel.

In most feature theories, individual distinctive features are phonetically defined, grounded in acoustics, articulation, or perception (Jakobson, Fant & Halle 1951; Chomsky & Halle 1968; Clements & 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. This predicts that a model of phonetic similarity should be able to predict likely phonologically active classes at least as well as any phonetically-based feature theory.' (Mielke 2004:230).

In universal feature theories (Jakobson et al. 1951; Chomsky & Halle 1968; Clements & Hume 1995), phonetically dissimilar segments are not predicted to pattern together. Thus, 'crazy classes' (as Mielke (2004) calls them) like the famous Sanskrit /s/ alternation before only /r, u, k, i/ (Zwicky 1970; Kiparsky 1973; Vennemann 1974), or Evenki /v, s, g/ nasalizing before nasals in a system with a full series of voiced and voiceless stops and fricatives (Nedjalkov 1997:320, 175), are difficult to account for. In the same way, a segment that appears to pattern with segments of opposite feature values in different languages, say, [-sonorant] in some languages but [+sonorant] in others, is not predicted, though see Bjorndahl (2018) for just such a case regarding the sound /v/. Here we present data in Sections 2 and 3, that this type of mixed cross-linguistic patterning is also characteristic of implosive sounds with respect to their behavior as obstruent versus sonorant.

Some sounds are less well represented in feature theories than others. Relevant for our purposes, some feature theories, often those found in textbooks, for example, leave implosives out entirely (Zsiga 2012:Chapter 12). Many feature theories, though, do include implosives. The remainder of this section explores the predictions of the phonological behavior of implosive sounds given extant feature theories.

The majority of the literature on the features of implosives focuses on the laryngeal features which distinguish implosives from plosives and ejectives. Halle & Stevens (1971/2013) propose a series of features including binary [stiff, slack, spread], and [constricted] features to distinguish voicing, aspiration, and glottalization (also see Hall (2007) who uses [+constricted] to differentiate implosives and ejectives from plosives). As Keating (1984) and Lombardi (1995) show, Halle and Stevens' feature set overpredicts the number of laryngeal contrasts we see across languages, for example, predicting a contrast between laryngealized voiced stops and implosives, which is not found cross-linguistically (Greenberg 1970). Lombardi instead proposes a privative constricted glottis feature, which we call [CG] here, to distinguish glottalized from pulmonic consonants. While the [CG] and earlier [+constricted] features pick out glottalized consonants as a distinct class, they do not make predictions about whether implosives, which have a [CG] feature, are expected to pattern with pulmonic obstruents or pulmonic sonorants, both of which lack the [CG] feature. Keating (1984) and Lombardi (1995) treat implosives as having the features of stops, with the addition of a [CG] feature; this predicts that implosives should be able to pattern with obstruents, but not with sonorants.

Similarly, while Chomsky & Halle (1968) do not provide a full list of feature values for implosive sounds, implosives are argued to be differentiated from other stops with the addition of an implosion feature (p. 322), again predicting that implosives will pattern with obstruents.

For Lombardi (1995:46), implosives are differentiated from ejectives in having a [voice] feature where ejectives lack one.[1] In a language like Guébie (Kru, Côte d'Ivoire), discussed in §2.2.2, where there is an implosive and a series of contrastive voiced plosives alongside a series of voiceless ones, the [voice] feature would predict a natural class of implosives, voiced obstruents, and sonorants (see also the discussion in Clements & Osu (2003)). However, with this feature set there is no way to pick out a class of implosives and sonorants that does not also include voiced plosives. Thus, we cannot pick out the class of segments /ɓ, l, j, w/, which we will see do, in fact, pattern together in Guébie and other languages.

Building on feature-based theories, implicational hierarchies such as the sonority hierarchy make predictions about how sounds are expected to pattern within a language (Sievers 1893; Jespersen 1904; De Saussure 1916). However, even in Parker's 'complete sonority hierarchy', implosives are not discussed (Parker 2002, 2011). The theory makes no predictions about how implosives across languages are expected to pattern: are they more, less, or of equal sonority to plosives? To sonorants? Similarly, confusion matrices and other studies of sound similarity do not include implosives, and thus do not make explicit predictions about the patterning of implosives across languages (Miller & Nicely 1955; Wang & Bilger 1973; Mielke 2012).

Greenberg (1970:123-124) states, "the phonological opposition in individual languages between ejectives and injectives (implosives) applies effectively only to obstruents, and is neutralized for sonorants and semi-vowels," and, "the typical injective (implosive) obstruent is, on the other hand, a voiced stop". With the exception of Clements & Osu (2002), who propose that implosives (or non-explosive stops) in Ikwere are both [-obstruent] and [-sonorant], based on language-specific articulatory, acoustic, and phonological properties, each of the above theories treat implosives as a subset of voiced stops, but with an additional (unary) feature specifying that they are produced with implosion. That is, implosives are treated, with little to no evidence or discussion, as voiced obstruents, and thus are predicted to pattern with voiced sounds and obstruents phonologically. We will see that this prediction is not borne out. As shown in Sections 2 and 3, in a number of languages, implosives pattern with sonorants to the exclusion of (voiced) obstruents.

1.3 Defining a category of implosives

Sounds described as implosives are not always produced the same way across languages. Catford (1939) describes implosives in Nama as ingressive stops with a glottal closure, a lowering of the larynx, and im-

[1] Note that this approach cannot account for languages like Sereer-Siin, which have a set of voiceless implosives (McLaughlin 2005).

plosion when the glottal closure is released. However, Ladefoged (1968) and many others have found that implosives are not always produced with glottal closure or an ingressive airstream mechanism. Building on this work, Ladefoged & Maddieson (1998:82) conclude that there are three possible glottal configurations that can result in implosive consonants: modal voicing, tense voice, and complete glottal closure. As for airflow, Ladefoged & Maddieson (1998) find that implosive and explosive stops cannot be categorically distinguished by ingressive airflow.

If neither glottal closure nor ingressive airflow is enough to distinguish implosives from other consonants articulatorily, then the question becomes whether there is a single phonetic articulation or acoustic property that corresponds to what we call 'implosive' consonants across languages. One option is that implosives might raise F0 of the following vowel (Hombert 1978; Ohala 1976); however, this, too, has been shown to vary across languages (cf. Wright & Shryock (1993) on Siswati where implosives do not raise F0, but Nagano-Madsen & Thornell (2018) on Mpiemo where they do.). On top of lack of consistent glottal closure, ingressive airflow, and F0 effect, Clements & Osu (2002) show that neither negative oral air pressure nor larynx lowering distinguishes implosives from other sounds (p. 304-305). They propose that instead the distinguishing property of implosives is a lack of air pressure build-up in the oral cavity. This definition does not necessarily imply negative oral air pressure, but simply the lack of an increase in oral air pressure during production, the opposite of what we expect from an obstruent (Stevens 1983). We adopt this lack of an increase in oral air pressure as a defining phonetic characteristic of implosive sounds, as per Clements & Osu (2002), acknowledging that there is a range of possible realizations of an implosive consonant. However, we do not have phonetic data for all, or even most, sources in the typological survey in §3. In such cases, we take the word of language experts who have written descriptive material on each language that what they call an "implosive" meets the definition discussed here.

The fact that articulatory strategies for producing implosive stops differ both across and within languages (Ladefoged 1968) may help to explain their phonologically mixed patterning across languages, discussed in Sections 2 and 3. This connection between phonetics and phonological behavior is returned to in §5.2.

1.4 Roadmap

The remainder of this paper examines the cross-linguistic distribution of implosives, and the ways in which implosives pattern with obstruents and sonorants across languages. The survey herein represents the first cross-linguistic study of the phonological behavior of implosive consonants, and we hope it serves as a starting point for continued work on the phonological status of implosives across languages.

§2 provides detailed case studies from six languages with contrastive implosive consonants. In two of the six languages implosives pattern with obstruents, in two others implosives pattern with sonorants, and in the remaining two languages implosives pattern with sonorants with respect to some processes but with obstruents for others.

§3 takes a broader view, examining the phonological behavior of implosives in a typological survey of 88 languages. The results suggest that there is a connection between the overall phonological behavior of implosives and 1) areal distribution, 2) phonological inventory, and 3) the specific phonological processes implosives are involved in.

§4 discusses the implications of the typological results for phonological feature theories, ruling out certain possible sets of universal features for distinguishing sonorants from obstruents. §5 discusses connections between the typological results and phonetics, diachrony, and language contact, and suggests directions for future work on better understanding the behavior of implosive sounds.

2 Case studies

This section provides data from two languages where implosives pattern with obstruents to the exclusion of sonorants (§2.1), as predicted by previous feature theories discussed in §1.2. We also provide data from two languages where implosives pattern with sonorants to the exclusion of obstruents (§2.2), and from two languages where implosives display mixed phonological behavior (§2.3). As each phonological process or alternation is described, the set of features necessary to pick out the targeted or triggering class of sounds is discussed. §2.4 summarizes the three types of patterns found across languages.

Throughout, for each pattern involving implosives that we describe, we consider what minimal set of features might be used to pick out the class of segments that patterns together. We consider whether a [+/-sonorant] feature is necessarily involved, or whether other features, those that do not distinguish obstruents from sonorants, could be used to pick out the same class. For the classes of sounds that can only be picked out with a [+/-sonorant] feature, we consider whether implosives pattern together with the [+sonorant] or [-sonorant] sounds.

2.1 Implosives patterning as obstruents

2.1.1 Hausa

Hausa is a Chadic (Afro-Asiatic) language spoken primarily in northern Nigeria, with additional speakers in Chad, Benin, and Cameroon. The consonant inventory is given below.[2]

Table 2: Hausa consonant inventory

	Labial	Alveo-palatal	Palatal	Velar	Lab. vel.	Pal. vel.	Laryngeal
Plosive	b	t d	c ɟ	k g	kʷ gʷ	kʲ gʲ	
Glottalized	ɓ	ɗ	ʔj	ƙ	ƙʷ	ƙʲ	ʔ
Fricative	f fʲ	s z	ʃ ʒ				h
Nasal	m	n					
Approx		l,ɾ,r̃	j		w		

There is a set of glottalized consonants in Hausa [ɓ, ɗ, ʔj, ƙ, ƙʷ, ƙʸ] (Newman 2000:392). These contrast with voiced and voiceless plosives, and sonorant consonants (nasals, liquids, glides). Newman describes [ɓ, ɗ] in Hausa as phonetically laryngealized and sometimes implosive, while [ƙ] is ejective and [ʔj] is a glottalized palatal semivowel. In Hausa, the glottalized consonants, which include implosives, always pattern together with obstruents, and never with sonorants.

Coronal sonorants cannot co-occur within a word in Hausa. Specifically, /l/ and /n/ do not co-occur, nor do /l/ and /ɾ/ (1c). The flap /ɾ/ can regularly appear before /n/ in a word, [ɾinà] 'dye', but not the other way around, *[niɾà].

(1) a. ɗàɾi 'hundred'
b. naɗà̀ 'install'
c. tùlu 'water pot'
d. *làɾi, *nulu

Implosives also rarely co-occur with other implosives (Newman 2000:410); however, the implosive restriction must be a separate restriction on word shape from the co-occurring sonorant restriction, because coronal implosives (1a), (1b), like coronal obstruents (1c), do freely co-occur with coronal sonorants, in contrast with (1d).

[2] The palatalized labial fricative and glottalized palatal semivowel are rare. The /r̃/ represents an apical tap or roll, while /ɾ/ represents a retroflex flap, as in (Newman 2000:394).

The fact that implosives and obstruents can co-occur with sonorant consonants, but sonorants cannot co-occur shows that implosives and obstruents pattern phonologically together in this respect. To account for the co-occurrence restrictions in (1), one could refer to the class of coronal sonorants, which must necessarily exclude coronal implosives, since coronal implosives freely co-occur with coronal sonorants as seen in (1a), (1b). This means that implosives must lack a [+sonorant] feature.[3]

In clusters of two consonants, CC, where the first is underlyingly an obstruent (stops and fricatives, voiced or voiceless) or implosive, the cluster typically simplifies to surface as a geminate with the features of the second consonant (Newman 2000, 2004), as in Table 3-a,b. In this way, implosives again pattern with obstruents, to the exclusion of sonorants, Table 3-c,d.

Table 3: CC assimilation in Hausa

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

We have already seen that to account for co-occurrence restrictions of sonorants, implosives must not have a [+sonorant] feature in Hausa. This assimilation pattern seems to target all non-sonorant (obstruent) sounds, including implosives. Thus, we have evidence that implosives share a [-sonorant] feature with obstruents. The class of plosives, fricatives, and implosives and other glottalized sounds cannot be picked out with another set of features. For example, a [-continuant] feature could pick out plosives and implosives, but not fricatives. A [-voice] feature could pick out voiceless obstruents, but without voiced obstruents or implosives. Thus, in order to capture the generalization that all obstruents, including implosives, assimilate to the following sound in a CC cluster, but sonorants do not, implosives must share the [-sonorant] feature with obstruents.

In addition to cluster simplification and co-occurrence restrictions, implosives pattern with obstruents in surfacing as a sonorant allophone in particular phonological positions. Velar obstruents, including the glottalic /ƙ/, /k, g, ƙ, kʷ, gʷ/, surface as [w] or [u] syllable-finally. This can be seen most clearly across a paradigm: /ɓaunaa/ 'buffalo', /ɓakàanee/ 'buffalo (pl)'. Coronal obstruents /t, d/ and the implosive /ɗ/ surface as [r̃] syllable finally, particularly before nasals. In some dialects, this alternation also applies word-finally. In Eastern Hausa, labial obstruents /b, f/ and the implosive /ɓ/ surface as [w] in coda position. Labials are unaffected in Western Hausa. Newman (2004) shows that for labials, this is a change in progress, where lenition is most common syllable-finally before [ɾ, n], and does not apply before obstruents like [t]. Because /ƙ/ is described as an ejective, not implosive, in Hausa, the /velar/ → [w] change may not be relevant for our purposes. However, the bilabial implosive [ɓ] patterns with other bilabial obstruents in surfacing as [w] in coda position in Eastern Hausa. To target the relevant segments in the labial alternation, a set of features such as [labial, -sonorant] is needed, which picks out [f,b,ɓ] to the exclusion of other obstruents and other labials. [labial] alone is not enough, since it would also predict that /m/, /w/, and perhaps also the labialized velar sounds would pattern with the labial obstruents and implosives, but they do not.

In a variety of phonological domains, implosives in Hausa pattern with obstruents, and not with sonorants. There does not seem to be any evidence that they ever pattern with sonorants. In order to account for the alternations we see in Hausa, we need implosives to be included in the [-sonorant] class of sounds (as evidenced by the assimilation pattern and alternation with /w/), and not in the [+sonorant] class (as evidenced

[3] The separate restriction on multiple co-occurring implosives could refer to a laryngeal feature that picks out glottalized consonants, but this must be a distinct restriction from the restriction on co-occurring sonorants, since implosives and sonorants *do* co-occur.

by co-occurrence restrictions with conoral sonorants).

2.1.2 Fula

We see similar patterning of implosives with obstruents in other languages with phonemic implosives, such as Fula (Senegambian), also known as Pulaar. The consonant inventory of Fula is given in 4 (Paradis 1992:123).[4]

Table 4: Fula consonant inventory

	Labial	Alveo-palatal	Palatal	Velar	Laryngeal
Plosive	p b	t d	c ɟ	k g	
Implosives	ɓ	ɗ	ʔj		
Fricative	f	s			
Nasal	m	n	ɲ	ŋ	
Approx	w	l,r	j, ɥ		h

In word-internal consonant clusters, CCs, when both Cs are coronal, the first C must be more sonorous than the second. If one of the consonants is non-coronal, this sonority restriction no longer holds: *fɔɔɓ-rɛ* ‘stump’, *caak-ri* ‘couscous’. We see clusters of liquids, glides, or nasals preceding stops and implosives, but never stops or implosives preceding other stops or implosives (Paradis 1992:Ch. 4). Specifically, glides and /r/ pattern as the most sonorous, in that they can be followed by any coronal consonant in a CC cluster, including each other, but never surface as the second C of a coronal CC cluster. /l/ can follow /j, r/ but no other coronal sound in a CC cluster. The nasal /n/ can precede obstruents and implosives but not sonorants. Clusters of only coronal obstruents or implosives do not occur: *td, dt, dɟ, ɟd, ɗd, dɗ, etc. Thus, the relevant sonority of coronal consonants in Fula seems to be /j, r/ ≫ /l/ ≫ /n/ ≫ obstruents + implosives. This could be accounted for by a series of markedness constraints on sonority, where implosives and obstruents (including both plosives and fricatives) are part of the same class in terms of sonority.

Also in Fula, a /-dV/ suffix surfaces as [-dV] after a sonorant, but as [-VrV] following an obstruent. Implosives pattern with obstruents in taking the [-VrV] suffix, as in Table 5. To pick out the class of sounds that triggers the suffix alternation – oral plosives, fricatives, and implosives, but not sonorants – a feature such as [-sonorant] would need to be shared among implosives and other obstruents, but not sonorants.

Additionally, when an obstruent or implosive precedes the causative suffix /-n/ or repetitive suffix /-t/, they assimilate fully to the features of the following suffix consonant, Table 6a-d. This assimilation does not occur when the preceding consonant is a sonorant, Table 6e-h.

For obstruents and implosives to be targeted for this assimilation process to the exclusion of sonorants, they must have some feature in common that sonorants do not have, such as [-sonorant].

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 they should be classified as stops.’ We have seen that in assimilation patterns, as triggers of suffix allomorphy, and in co-occurrence restrictions, implosives must have a feature in common with obstruents that sonorants do not also share: [-sonorant].

[4] Paradis (1992) notes that the /h/ could be classified as a fricative or a glide, but in any case it displays special behavior. As it is not relevant to the discussion of implosives, we recreate the consonant inventory as in Paradis (1992:123), with the /h/ as a glide. Also note that there are surface prenasalized voiced plosives and a surface glottal stop, but Paradis analyzes these as allophones rather than as phonemic.

Table 5: Fula implosives pattern with obstruents in affix selection, (Paradis 1992:121)

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.	fuʄ-ɛrɛ, *fuʄ-dɛ	‘pimple’
l.	ɗaaʄ-ɛrɛ, *ɗaaʄ-dɛ	‘bulb’

Table 6: Implosives and obstruents trigger assimilation, (Paradis 1992:122)

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’

2.2 Implosives patterning with sonorants

2.2.1 Atchan

In Atchan (Bole-Richard 1983:327) (Kwa, Côte d’Ivoire; also called Ebrié), unlike in Hausa and Fula, implosives pattern with sonorants to the exclusion of obstruents. The data presented in this section comes from Bole-Richard (1983) and was confirmed by the first author with a native Atchan speaker in Abidjan in Summer 2019. Additional data comes from fieldwork carried out by Katherine Russell and described in Russell (2023). The consonant inventory of Atchan is given in Table 7. /h/ is in the velar column as in Bole-Richard (1983:327).

Table 7: Atchan consonant inventory

	Labial		Dental		Palatal		Velar		Lab.vel.	
Plosive	p, p^h	b	t, t^t	d	c, c^t	ɟ	k, k^k	g	kp	gb
Fricative	f		s				h			
Approx		ɓ		l		j			w	

There are voiceless, voiceless aspirated, and voiced plosives at the labial, dental, palatal, and velar places of articulation, as well as voiced and voiceless velar plosives. The bilabial implosive is listed as an approximant because of its phonological patterning with other approximants. There are no contrastive nasal consonants in Atchan. Rather, all surface nasal consonants are derived from underlying approximates or implosives in the context of a nasal vowel.

Both in nasalization and tone depressing patterns, implosives pattern with sonorants.

After a nasal vowel in the verbal domain, vowels and sonorants surface as nasal (except the final vowel of the verbal word, which is always oral). Consonants that otherwise surface as oral implosives and sonorants (2a) surface as nasals of the same place of articulation in (2b), (2c) in the context of a nasal pronoun (1SG or 3SG). Obstruents, including voiced and voiceless plosives and fricatives, do not nasalize (2d), though plosives become prenasalized (2e).

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

b. ã̀ mã̀ nẽ́ má
She FUT NEG come
'She will not come'

c. mɛ̃̀ mã̀ nɛ̃́ má
1SG.NOM FUT NEG come
'I will not come.'

d. mɛ̃̀ fĩ́ bɔ̀prɔ̀
1SG.NOM sweep.PFV floor
'I swept the floor.'

e. mɛ̃̀ mã̀ ᵐbò
1SG.NOM FUT wait
'I will wait.'

In nasal contexts, /l/ surfaces as [n], /w/ as [ŋʷ], /j/ as [ɲ], and /ɓ/ as [m]. In other words, all consonants in the approximant row of Table 7 fully nasalize, including sonorants and the bilabial implosive.

Similarly, the plural morpheme in Atchan is a nasal prefix, which triggers nasalization of neighboring vowels and sonorants (Table 8-a,b,c), including implosives (Table 8-d). Oral plosives become prenasalized (Table 8-e,f), and fricatives do not alternate (Table 8-g).

Table 8: Atchan nasalization in plural contexts, (Bole-Richard 1983:328)

	Singular	*Plural*	
a.	álɛ́	ã́nɛ́	'tongues'
b.	àwɔ́	ã̀ŋʷɔ́	'cats'
c.	ájá	ɛ̃́ɲá	'trees'
d.	áɓɛ́	ɛ̃́mɛ́	'ropes'
e.	ã́kú	ɛ̃́ᵑkú	'houses'
f.	gɔgɔ	ɛ̃ⁿgɔgɔ	'mice'
g.	sɛ	ɛ̃́-sɛ	'men'

Implosives and oral sonorants do not co-occur with nasals; the following sequences are unattested: *ãja, ajã, ãjã, ãɓa, aɓã, ãɓã, alã, ãla, ãlã, awã, ãwa, ãwã. Fricatives and (prenasalized) plosives, on the other hand, can co-occur with nasal vowels: *ɛ̃̀zɔ̃́*, 'shell species', and as in Table 8-e,f,g.

Implosives pattern with sonorants in Atchan in becoming fully nasal segments in the context of a nasal harmony trigger. Plosives do not fully nasalize, but prenasalize, and fricatives do not alternate. To target the class of sonorants and implosives, to the exclusion of plosives and fricatives, implosives and sonorants must share a feature that obstruents lack. These are not the only voiced sounds in the language (recall that Atchan has contrastive voiced obstruents /b, d/, for example). This set of sounds does not share other properties like being [+continuant], since the implosive is [-continuant]. Thus, the best candidate for a shared feature picking out this class of sounds seems to be [+sonorant]. This feature seems to be the right one because all of the sounds that do not undergo this alternation in Atchan are unambiguously obstruents, [-sonorant].

To target the class of sounds that prenasalize in nasal contexts, the feature set [-sonorant, -continuant] picks out only voiced and voiceless plosives, as long as implosives are not [-sonorant] in this language.

In addition to nasalization, sonorants and implosives pattern together in their interaction with tone. Voiced obstruents, but not implosives or sonorants, act as tone depressors in Atchan (Bole-Richard 1983:320); tones surface with a lower pitch after voiced obstruents than in other contexts. For example, Bolé-Richard describes the low tone surfacing as 'very low' after depressor consonants, but not other consonants. This pattern has been confirmed in recent work by Katherine Russell (Russell 2023). If implosives lack a [-sonorant] feature in Atchan, we can pick out the class of depressor consonants with the features [-sonorant, +voice].

The bilabial implosive is the only underlying implosive sound in Atchan, though a surface alveolar implosive is an allomorph of /l/ (Bole-Richard 1983:329-331), showing an alternation between implosives and sonorants. Note that an alternation from /l/ to [ɗ] does not necessarily imply a shared feature between the two sounds. One could easily write a rule or apply a process where /l/ $\rightarrow$ [ɗ] in a given environment; a target underlying sound and its surface realization need not share features. Thus, this alternation alone does not provide information about the whether [ɗ] patterns as a sonorant or obstruent in Atchan. Though note that it is perhaps simpler in a feature-based theory for an alternation to involve changing fewer features between the underlying and surface form (in a constraint-based approach, fewer IDENT-FEATURE violations would occur).

To account for Atchan nasalization, implosives must share a [+sonorant] feature with other sonorants. To account for the fact that voiced obstruents but not implosives act as tone depressors, implosives must lack the [-sonorant] feature that picks out obstruents. This is the opposite of what we saw in Hausa and Fula (§2.1) where implosives must share a [-sonorant] feature with obstruents.

2.2.2 Guébie

Guébie is a Kru language spoken in southwest Côte d'Ivoire (Sande 2017). There is a single implosive phoneme in Guébie, the bilabial /ɓ/, which contrasts with voiced and voiceless plosives /b, p, m/, as well as voiced and voiceless labiovelars and labialized velars /gb, kp, gʷ, kʷ/, and approximants /j, w, l/. The implosive patterns in every respect with sonorants, and never patterns with obstruents. The same sonorant-like patterning is found for implosives in other Kru languages (Marchese 1979:42; Kaye et al. 1981), which are discussed further in §2.2.3.

The Guébie data presented in this section comes from work by the first author with the Guébie community in Côte d'Ivoire from 2013-2022. The patterns discussed here are described in more detail in (Sande 2017:Ch. 2) and in (Sande 2022). The Guébie consonant inventory is given below.

Table 9: Guébie consonant inventory

	Bilabial	Lab. dent.	Alveo-palatal	Palatal	Velar	Labialized	Labio-velar
Plosive	p b		t d	c ɟ	k g	kʷ gʷ	kp gb
Nasal	m		n	ɲ	ŋ	ŋʷ	
Fricative		f (v)	s (z)				
Approx	ɓ		l	j			w

The /v/ is in parentheses because it is present in very few words, primarily loan words. The /z/ is only found in ideophones, proper names, and loans.

The implosive /ɓ/ can be seen to pattern with sonorants in at least four distinct ways. First, there is a process of vowel deletion, where some CVCV words regularly surface CCV (Sande 2017:Ch. 5). This process is highly likely if the second consonant of a word is /l/ or /ɓ/, and possible if the second consonant is a glide, but not otherwise. Other than these surface CCV forms derived from underlying CVCV, there are no instances of consonant clusters in the language. Examples of reduction when the second consonant is /l/ or /ɓ/ are given in Table 10. Reduction is impossible for the obstruent-internal root in Table 10f.

Superscripted numbers represent tone heights, where 4 is high and 1 is low. Tones on different syllables are separated with a '.', and multiple numbers within the same syllable represent a contour tone.

Table 10: CVCV → CCV

	CVCV	CCV	Translation
a.	jɪla$^{2.3}$	jla^{23}	'ask'
b.	bala$^{3.3}$	bla^{3}	'hit'
c.	duɓu$^{3.3}$	dɓu^{3}	'mourn'
d.	ɓili^{31}	ɓli^{31}	'fall'
e.	kpala$^{3.3}$	kpla^{3}	'be.sharp'
f.	bete$^{3.1}$	*bte^{31}	'break'

The identity of the first consonant in the word does not seem to affect whether a CCV form is possible; for example, an initial glide (Table 10a), obstruent (Table 10b,c,e), or implosive (Table 10d) before /l/ or /ɓ/ can surface as CCV.

In Table 10 and other CVCV/CCV alternating forms, the first vowel is not predictable given the phonological context, and so is proposed to be present in the underlying form (Sande 2017). The first vowel can be deleted only in the context of a following sonorant or implosive, and not in the context of a following obstruent. In other words, in CC onset clusters, only implosives and sonorants / ɓ, l, j, w/ can surface as the second consonant. For this phenomenon to be accounted for in a unified way, the implosive must share a feature or set of features with (non-nasal) sonorants, to the exclusion of obstruents.[5] A [+sonorant] feature must be shared between the implosive and sonorants to pick out only this class of sounds as possible C2s.

Second, distributionally, implosives and sonorants do not appear after nasals in monomorphemic words, while obstruents co-occur freely with nasals. /ɓ/ occurs as the second consonant in a CVCV word 95 times in a corpus of 2068 disyllabic Guébie words. However, zero of those occurrences show a nasal in initial C position. /ɓ/ surfaces initially in 70 of 2068 disyllabic words, only two of which (3%) contain a nasal in the second C slot. In total, 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 proportion of co-occurrences we would expect if there were no restrictions. It seems, then, that implosives and sonorants pattern together in not co-occurring with nasals. There is a related nasal harmony alternation in morphologically complex words, where suffixes that begin with /l/ have an [n]-initial form after roots whose final consonant is nasal. There are no suffixes containing /ɓ/ in Guébie, so we cannot see a synchronic alternation; however, given the distributional facts, one might predict a ɓ∼m alternation if such a suffix did exist.

Restricting the co-occurrence of oral sonorants and implosives with nasal consonants in Guébie is straightforward if implosives and sonorants share a [+sonorant] feature, which is already necessary to account for CVCV words which surface as CCV. A rule requiring sonorants to surface as nasal in the envi-

[5] A nasal may also be the second consonant in a CCV word, though in all such cases the first consonant is also nasal, and the surface nasals in C2 position can be analyzed as underlyingly oral, undergoing a regular nasalization process.

ronment of other nasals, or a constraint against co-occurring sonorants and nasals, accounts for the shared behavior of implosives and sonorants, as well as for the behavior of non-sonorants (obstruents), which freely co-occur with nasals. If implosives were [-sonorant], as predicted by the feature theory literature, we would need a disjunctive rule, or multiple rules, to account for the fact that the implosive and sonorants are both subject to the same set of co-occurrence restrictions with nasals; one of these could target [-nasal, +sonorant] sounds and the other could target [+implosive] or [+cg] sounds, picking out only the implosive. Because the implosive patterns together with sonorants in multiple distinct ways in Guébie, we would need to separately pick out this same disjunctive set of sounds for multiple different processes or rules. A shared feature between the implosive and sonorants is clearly preferable.

A third way in which implosives pattern with sonorants is in vowel hiatus resolution. All roots end in vowels; there are no syllable codas in the language. Certain suffixes begin with vowels, which means that when a root is followed by a V-initial suffix, there is a sequence of two adjacent underlying vowels. Hiatus can be resolved via deletion of a vowel or insertion of a consonant, dependent both on the identity of the vowels present, and the identity of the adjacent morphemes. The consonants inserted to resolve hiatus are /j, w,/ and /ɓ/. /w/ and /ɓ/ are inserted interchangeably when one of the two vowels is round. In this way, the bilabial implosive patterns with glides.

Table 11: Vowel hiatus avoidance

	Underlying VV	Surface VCV	Translation
a.	/dibo-ə$^{3.1.2}$/	[dibowə$^{3.1.1}$] or [diboɓə$^{3.1.1}$]	‘the plantain’
b.	/ɟɔk^{w}ɪ-a$^{2.3.3}$/	[ɟɔk^{w}ɪja$^{2.3.3}$]	‘the bird’

Note that while it is possible to produce the form in Table 11-a with either a [w] or [ɓ] between the underlyingly adjacent vowels, /w/ and /ɓ/ are otherwise contrastive in the language: /wi^{3}/ ‘cry’, /ɓi^{31}/ ‘plates’.

If implosives and glides share a feature, that feature can be leveraged in deriving the hiatus resolution pattern in Table 11. Notably, though, /l/ is not used to break up vowel hiatus in Guébie, so we would need to exclude /l/ from this process with something like a [-lateral] feature.[6] Another alternative is to say that glides are inserted to break up vowel hiatus, and that /w/ then optionally strengthens to [ɓ]. In the latter approach, one could certainly derive [ɓ] from /w/ by changing multiple features, including the value of a [sonorant] or [obstruent] feature, though the change is intuitively simpler and more economical if fewer features are changed between the two. Thus, this hiatus resolution pattern can be derived without requiring the bilabial implosive to have a [+sonorant] feature, but the simplest feature-based approaches involve shared features, and specifically a shared [+sonorant] feature, between the implosive and glides, and other processes in the language (nasalization and CVCV/CCV alternations) already suggest that implosives have a [+sonorant] feature.

Lastly, in certain morphosyntactic environments when a sequence of two identical CV’s both beginning with /ɓ/ would be adjacent, the second /ɓ/ surfaces as [l]. One such environment is reduplication in reciprocal contexts, where a reduplicated /ɓ/-initial CV surfaces with [l], as in Table 12. Here we see an [l/ɓ] alternation. See Kaye et al. (1981) on a related historical change in Dida and Bete, two neighboring Kru languages.

The examples in 12-a,b show that /ɓ/-initial roots are reduplicated with [l], while 12-c shows that /l/-initial roots surface with a faithful [l]-initial reduplicant. 12-d provides an example of reduplication of a root without /l/ or /ɓ/.

[6] Blevins (2008) argues that the most natural consonant epenthesis patterns are glide epenthesis, and that other epenthetic consonants are the diachronic result either of subsequent glide strengthening (w→ɓ) or restructuring of consonant deletion. There is little convincing evidence in Guébie that the implosive insertion patterns are the result of restructuring of implosive deletion, though they may very well be the historical result of glide strengthening.

Table 12: Liquid/implosive alternation in reduplication

	Particle-Verb	Reciprocal (reduplicated verb + /-li/)	Gloss
a.	ɓɔ^{32}	ɓɔ-l̠ɔ-lɪ$^{3.2.2}$	'finish each other'
b.	ji-ɓe$^{3.1}$	ji-ɓe-l̠e-li$^{3.1.2.2}$	'know each other'
c.	la^{3}	la-la-lɪ$^{3.2.2}$	'call each other'
d.	ɟu^{3}	ɟu-ɟu-li$^{3.2.2}$	'respect each other'

This could be analyzed as an OCP effect for implosive consonants, where the result is an alternation between the implosive and [l]. On its own, this pattern does not suggest that implosives need have a [+sonorant] feature in Guébie, though given the other evidence in favor of implosives as members of the sonorant class in Guébie, the derivation of /ɓ/ to [l] in Table 12 becomes simpler in that fewer features need to change to derive one from the other. An example rule could target [labial, -nasal, +sonorant] sounds, picking out only /ɓ/. By changing only the place feature from [labial] to [coronal], the result is a ɓ∼l alternation; whereas, if /ɓ/ were [-sonorant], multiple features would need to change to derive [l] from /ɓ/.

To summarize, while the hiatus and /ɓ/∼/l/ alternations in Guébie could be accounted for without assuming that the implosive shares a feature with sonorants to the exclusion of obstruents, the distributional restriction of nasals with non-nasal sonorants or implosives, and the reduction of CVCV to CCV only when the second consonant is a sonorant or implosive, are straightforwardly accounted for by assuming that the implosive in Guébie is [+sonorant], and are difficult to account for if the implosive does not share a feature with sonorants to the exclusion of obstruents. The next section discusses additional data from other Kru languages that support this conclusion.

2.2.3 Other Kru languages

As in Guébie, implosives across Kru languages pattern with sonorants to the exclusion of obstruents (Kaye et al. 1981).

Tone spreading rules apply to implosives in the same way as sonorants. That is, obstruents block tone spreading as in Table 13-c, while implosives and sonorants do not, Table 13-a,b. Tones spread onto following low-toned words that begin with a sonorant or implosive. Relevant data from Vata is provided in Table 13.

Table 13: 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$^{1.1.2}$	n^{3} 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, as for Atchan, surface nasals are derived from underlying sonorants and implosives in words that contain nasal vowels.

Diachronically, Proto-Kru sequences of lVlV and nVnV (coronals in general, in some languages) underwent a dissimilation process (Kaye et al. 1981:78). In these cases, proto-/l/ becomes [ɗ] in some languages and [ɓ] in others, Table 14. It is not yet known whether this is the only source of implosives in Kru languages. Reconstructions of tones and vowels are tentative, according to Kaye et al. (1981). This historical analysis may help explain why implosives pattern with sonorants in Guébie and other Kru languages, since, according to Kaye, at least some implosives in Kru are derived from the sonorant /l/.

Table 14: Dissimilation across Kru

	Proto	*Vata*	*Dida*	*Bété*	*Guéré*	*Gloss*
a.	$*\text{lala}^{3.4}$	dla^{4}	ɓla^{4}	$\text{lɔɓɔ}^{3.4}$	ɗɓa^{3}	‘kill/strike’
b.	$*\text{nɛnɛ}^{2.2}$	nnɛ^{2}	$\text{mnɛ}^{2.2}$	$\text{nɛmɛ}^{2.2}$	nmi^{2}	‘animal/meat’
c.	$*\text{lilu}^{2.2}$	dli^{2}	ɓlu^{2}	$\text{liɓi}^{2.2}$	ɗu^{2}	‘mash’
d.	$*\text{zili}^{2.2}$	zle^{2}	$\text{jili}^{2.2}$	$\text{ziɓi}^{2.2}$	$\text{zimiɛ}^{1.1.1}$	‘fish’

Across Kru, there is no evidence that implosives ever pattern with obstruents. A clear synchronic explanation for how a Kru speaker generates sound patterns where implosives pattern with sonorants rather than with obstruents is a shared [+sonorant] feature.

2.3 Implosives with mixed patterning

2.3.1 Ijo

Ijo, also spelled Ijaw, is a family of languages spoken in southern Nigeria. There are two implosive sounds in Ijo, /ɓ, ɗ/, which contrast with voiced and voiceless plosives /p, b, t, d/ (Williamson 1978). The implosive sounds in Ijo languages show mixed phonological behavior, patterning with obstruents in some respects and sonorants in others.

In Ijo languages, consonants in a word must not increase in ‘strength’ from left to right, where the strength divisions are given in Table 15. All phonemic consonants in the language are represented in the table.

Table 15: Strength divisions in Ijo

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

This pattern is illustrated by a set of Proto-Ijo forms in Table 16 (Williamson 1978:245), though note that the same pattern also holds in the majority of synchronic forms across Ijo. The star on the examples in this table means that these are reconstructed for the proto-language, not that they are ungrammatical forms.

Table 16: 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 can surface earlier in a word than voiced obstruents, as in Table 16-d, but cannot be preceded by sonorants, and cannot be followed by voiceless obstruents. In this way, implosives pattern with voiced plosives. Note that Williamson finds a few exceptions to this pattern, including an example where an implosive surfaces after a sonorant: [jaɓi], ‘mother’s brother’, weak medium. Out of 252 Proto-Ijo words, only 20 exceptions to the above pattern were found, meaning that the strength generalization accounts for more than 90% of the sample (Williamson 1978:345). Implosives pattern with obstruents with respect to their distribution within morphemes.

In a distinctive feature approach, the strong consonants all share the features [-voice, -sonorant], the weak consonants all share the feature [+sonorant], and, if the implosives are considered to be obstruents, then the medium-strength consonants all share the features [+voice, -sonorant]. However, if the implosives are considered sonorants, with a [+sonorant] feature, there is no obvious set of features that picks out the medium-strength consonants without also picking out some of the weak or strong consonants, too. For this process, it seems that implosives in Ijo pattern with voiced obstruents and must be [-sonorant].

However, despite patterning with obstruents in their distribution within words, in some Ijo varieties (Kalabari, Nembe, and Biseni (Williamson 1987:405)) implosives pattern with sonorants in the domain of nasalization. Initial sonorants and implosives are produced as nasalized before nasal vowels, while obstruents are not, Table 17.[7]

Table 17: Ijo nasalization, (Williamson 1987)

	Kalabari	Nemba	Biseni	Oporoza	Proto-Ijo	
a.	mĩnɟi	mĩndí	mĩnĩ	bẽnĩ	*ɓẽdĩ́	‘water’
b.	mãŋgí	mãŋgí	mɛ̃ɛ̃	bãĩ	*ɓãgĩ́	‘run’
c.	pãmba	pãmbá	–	pĩmã	*pãbã́	‘wing’

Synchronically, there is a distributional restriction on the position of oral sonorants and implosives. We do not see oral sonorants or implosives preceding nasal vowels in Kalabari, Nemba, or Bisemi. However, we do see nasals and oral plosives surfacing before nasal vowels, Table 17-c. Nasalization of implosives and sonorants, but not obstruents, before nasal vowels occurs synchronically in other West African languages as well, such as Atchan, described in §2.2.1. Similarly, in four Bua (Adamawa) languages, implosives /ɓ, ɗ/ surface as glottalized nasals before a nasal vowel; see (Palayer (1975:146-147) on Tunia, Boyeldieu (1985:44) on Lua, and Florian Lionnet (p.c.) on Ba and Kulaale), and Laal (isolate, Chad) (Florian Lionnet, p.c.).

As in Atchan, we can pick out the consonants that undergo nasalization in the context of a nasal vowel by targeting [+sonorant] segments. Implosives must also be targeted by this feature. This presents a paradox in a binary feature theory, since implosives in Ijo pattern as [-sonorant] with respect to their strength and position in a word, but as [+sonorant] with respect to nasalization.

The Ijo data shows that within a single language, implosives have inconsistent patterning: they pattern with obstruents in ‘strength’, but with sonorants in surfacing as nasalized before nasal vowels.

2.3.2 Ikwere

Ikwere, also spelled Ikwerre, is a language spoken near Port Harcourt, Nigeria that has a series of contrastive voiced and voiceless plosives, as well as a set of two non-explosive sounds both at the bilabial place of articulation (Clements & Osu 2002). Clements and Osu show that the non-explosive stops in Ikwere are articulatorily similar to implosives in other languages in that they correlate with negative air pressure and ingressive airflow, but they differ from what are traditionally called implosives in that they do not involve lowering of the larynx. Despite the lack of larynx lowering, we refer to these non-explosive stops as implosives here, given our definition in §1.3.

As in Ijo, Ikwere implosives and sonorants pattern together in some respects. Namely, both sets of sounds have nasal realizations before other nasal sounds, while obstruents do not alternate before nasals (Clements & Osu 2002, 2003, 2005). Distributionally, we see obstruents before nasal vowels, but implosives never

[7] Additional data to fill out the paradigm in Table 17 is not available, so we rely on the description and analysis provided by the source of the data, Williamson (1987).

surface in this position: [àbã̀], 'jaw', but *[ã̀ɓã̀]. While there are no cases of a surface implosive followed by a nasal vowel, there are cases of [m] followed by a nasal vowel. These are analyzed as underlying implosives, which are nasalized preceding nasal vowels; for example, the strong subject pronoun /ɓɛ̃/ surfaces as [mɛ̃]. Additionally, neither implosives nor sonorants have a depressing (lowering) effect on surrounding tones, while voiced obstruents do. See Clements & Osu (2002:327) for a phonetic discussion about why implosives might show different behavior with respect to tone depression than voiced obstruents. If implosives have a [+sonorant] feature and lack a [-sonorant] feature, then the nasalization process can be analyzed as targeting all [+sonorant] sounds and the tone depressing process as triggered by [-sonorant] sounds.

On the other hand, implosives tend to pattern with obstruents rather than sonorants in their position within a word. Obstruents and implosives are more often present in onset than coda position in Ikwere. Both can precede liquids in CC onset clusters, while sonorants cannot. These distributional restrictions are similar to those found for implosives in other African languages, including Lendu, Hausa, and Fula (Clements & Osu 2002:337). In order to limit the distribution of the initial C in CC clusters to obstruents and implosives, the two must share a feature that sonorants lack: [-sonorant].

Again, as in Ijo, we see mixed patterning of implosive sounds within a single language; they pattern together with obstruents in some respects (suggesting a [-sonorant] feature) but sonorants in others (suggesting a [+sonorant] feature).

2.4 Interim summary

Implosives pattern exclusively with obstruents in Hausa and Fula (§2.1), which is predicted by previous proposed featural representations of implosives. However, in Guébie and Atchan (§2.2), implosives pattern exclusively with sonorants, and never with obstruents. And in Ijo and Ikwere, while implosives pattern with obstruents in some respects, they also pattern with sonorants to the exclusion of obstruents for certain processes (§2.3). The behavior of sonorant-patterning languages and mixed patterning languages is unpredicted based on previously proposed distinctive features of implosives.

Implosive sounds do not pattern consistently with either obstruents or sonorants within or across languages. This inconsistent phonological behavior may well be due to mixed or intermediate phonetic properties of implosives across languages, as briefly discussed in §1.3, and similar to Mielke (2005)'s analysis of laterals and nasals with respect to the feature [continuant]. We suggest phonetic studies that may illuminate this connection in §5.2. Another possibility, discussed further in §5.1 is that there are historical or areal influences on implosive patterning across languages.

§3 presents a typological survey of implosive behavior, beginning to address the questions of how common sonorant- versus obstruent-patterning languages are, and whether implosives are more likely to pattern with obstruents versus sonorants in certain types of alternations. Broadly, we examine how implosives pattern phonologically across languages, how wide-spread are the three types of implosive patterning discussed here, and why the cross-linguistic patterns are distributed the way that they are.

3 Typological survey

§2 layed out the phonological patterning of implosives in six languages, showing that implosives pattern differently in different languages, and that even within a single language implosives can pattern with sonorants with respect to some processes but with obstruents with respect to others. This section expands on these observations to examine the phonological patterning of implosives across 88 languages. We find that languages like Guébie, Atchan, Ijo, and Ikwere, discussed in §2, in which implosives pattern with sonorants in at least one process, are not unusual as feature theories where implosives are assumed to be obstruents might predict. Rather, implosives pattern with sonorants or show mixed patterning in the majority of languages with contrastive implosive sounds. This behavior suggests the need for a novel featural representation of implosive sounds.

3.1 Methods

The Phoible database (Moran & McCloy 2019) and P-Base (Mielke 2008) were consulted for a list of languages that contain implosives. Phoible listed 293 languages that have implosives in their consonant inventories, and P-Base listed 66 languages with implosives in their consonant inventories at the time the survey was conducted.

Languages were excluded from the present analysis if implosives did not contrast with voiced plosives at at least one place of articulation.[8] This inclusion criterion was necessary to meet the goals of the typological survey. If a language does not have voiced obstruents but has implosives, and implosives pattern as sonorants with respect to certain phonological processes, the feature [+voice] could pick out sonorants and implosives to the exclusion of obstruents, and a shared [+sonorant] feature would not be necessary. This then would not tell us anything about the status of implosives as sonorant-like or obstruent-like. Because the goal of this survey is to observe the cross-linguistic phonological patterning of implosives as patterning with sonorants and/or obstruents, the sample was limited to languages with voiced obstruents at the same place of articulation as implosives. Most languages with phonemic implosives outside of Africa lack a contrast between implosives and voiced plosives at the same place of articulation, as exemplified by Ese Ejja (Tacanan, Bolivia and Peru) in Table 18 (Vuillermet 2006) and Eastern Cham (Austronesian, Cambodia and Vietnam) in Table 19 (Smith 2013). For this reason, our survey includes almost exclusively languages of Africa.

Table 18: Ese Ejja consonant inventory

	Labial	Alveo-palatal	Palatal	Velar	Lab. vel.	Laryngeal
Plosive/Affricate	p	t	tʃ	k	kʷ	ʔ
Glottalized	ɓ	ɗ				
Fricative		s	ʃ		x	h
Nasal	m	n	ɲ			
Approx			j		w	

Table 19: Eastern Cham consonant inventory

	Labial	Alveo-dental	Palatal	Velar	Glottal
Plosive	p, pʰ	t, tʰ	c, (cʰ)	k, kʰ	ʔ
Glottalized	ɓ	ɗ			
Fricative		s			h
Nasal	m	n	ɲ	ŋ	
Approx		l/r	j		w

Of the 293 languages listed in Phoible with implosives in their inventories, 228 languages have implosives that are phonemic and constrast with voiced plosives of the same place of articulation. Of the 66 languages with implosives listed in P-Base with implosives in their inventories, 51 languages have implosives that contrast with voiced plosives. There is overlap in the two groups such that 22 of the 51 languages listed in P-Base are also listed in Phoible, meaning there is a total of 257 distinct languages listed in either database that have contrastive implosive consonants. Beginning with this set of 257 languages, two researchers consulted available descriptive materials of the phonology of each of the languages. Of these

[8] In Basaa (Bantu, Cameroon), implosives contrast with prenasalized voiced plosives at the same place of articulation, but not with plain voiced plosives.

257 languages with contrastive implosives, 95 languages were found to have sources with sufficient descriptive material to analyze the phonological patterning of implosives, and 161 languages either had sources that were unavailable or did not contain enough information about implosives to make claims about their phonological patterning.

The remaining 95 languages each had a minimum of one source available that described the phonological behavior of implosives as sonorants or obstruents. Using a bottom-up approach, two researchers recorded all the described phonological processes involving implosives for each language. That is, all of the phonological processes that involve implosives were listed for each language, along with which other sounds undergo the same processes, and those which do not. All of the phonological processes were reviewed and grouped into the following categories in order to compare across languages. These categories were determined in a bottom-up manner; as we encountered descriptions of implosives participating in a particular process, we added that process to the list of categories.

- Meta-data
  - Language family, implosive segments in the inventory, and continent
- Syllable structure
  - if implosives pattern with sonorants to the exclusion of obstruents with respect to their distribution in onset position, nucleus position, in consonant clusters, or in coda position; or, if implosives pattern with obstruents to the exclusion of sonorants with respect to their distribution in onset position, in nucleus position, in clusters, and in coda position
- Nasalization
  - whether implosives nasalize with sonorants in nasal environments (to the exclusion of obstruents), whether implosives prenasalize with voiced obstruents (to the exclusion of sonorants), or whether implosives (and sonorants) do not prenasalize with voiced obstruents
- Alternations
  - if there are alternations with implosives and voiced obstruents to the exclusion of sonorants, if there are alternations with implosives and sonorants to the exclusion of obstruents, if there is implosive/plosive harmony or assimilation, if implosives devoice word-finally with voiced obstruents to the exclusion of sonorants, if obstruents undergo some alternation that implosives and sonorants do not, if sonorants undergo some alternation that implosives and obstruents do not, if implosives and sonorants undergo some alternation that obstruents do not, if implosives and obstruents undergo some alternation that sonorants do not
- Tonal patterns
  - if implosives act as depressor consonants with voiced obstruents (to the exclusion of sonorants) or not, if implosives pattern with obstruents in blocking tone spreading or not
- Historical relationship
  - if there is a clear historical relationship between implosives and sonorants or obstruents

All phonological processes involving implosives for each language were described by the categories of the coding scheme. Next, if any phonological process did not show evidence for implosives patterning with obstruents to the exclusion of sonorants, or vice versa, that pattern was excluded. Each category in the coding scheme was subsequently labeled as showing evidence for implosives as sonorant patterning or obstruent patterning. A pattern was excluded if a sonorant or obstruent feature was not necessary to describe the implosive behavior.

For example, in Igbo (Igboid, Nigeria) a set of sounds including /r,l,v,s,z,ɣ,h/ nasalize in nasal contexts, but implosives and other sounds do not. This set of sounds can be picked out with a [+continuant] feature, and in fact that feature [+continuant] picks out all and only this set of sounds in Igbo. The feature [+sonorant] or [-sonorant] is not needed to pick out the set of sounds that nasalize in nasal contexts in Igbo, so it was not included in our survey. Removing processes that do not show evidence of implosives patterning with obstruents or sonorants resulted in removing some languages from the sample. Specifically, after removing such processes, seven languages no longer had enough information available to say anything about patterning with sonorants or obstruents. This left 88 languages in the sample that show some positive evidence that implosives pattern with obstruents to the exclusion of sonorants or vice versa. A list of these languages is available in Appendix A. A spreadsheet of the languages included in the sample, the descriptive materials consulted, and the coding for patterning in each language is included in a supplementary document.

If a language only showed evidence for phonological processes where implosives pattern as obstruents, the language was labelled as 'obstruent patterning'. If a language only showed evidence for phonological processes where implosives pattern as sonorants, the language was labelled as 'sonorant patterning'. If a language showed evidence for implosives patterning with obstruents to the exclusion of sonorants in at least one category and evidence for implosives patterning with sonorants to the exclusion of obstruents in at least one category, the language was labelled as 'both patterning'.

Here we refer readers to one sonorant-patterning and one obstruent-patterning example of each major category listed above. With respect to sonorant-patterning syllable structure, readers are directed to the Guébie CVCV/CCV pattern where only sonorants and implosives /l,w,j,ɓ/, but not obstruents, can surface as the second C of an onset cluster (Table 10). On the other hand, in Wan (wan, Mande, Côte d'Ivoire) only oral sonorants /l,w,j/ can surface as the second C of an onset cluster, while implosives and obstruents cannot (Ravenhill 1982). For consonants in coda position, in Palor (fap, Senegambian, Senegal) (Thornell 2016) we see sonorant-patterning, where implosives and sonorants can surface in coda position, while voiced obstruents cannot. On the other hand, in Mbay (myb, Bongo-Bagirmi, Chad and Central African Republic) (Keegan 1997) we see obstruent-patterning; all sonorants can be codas, while implosives and obstruents cannot.

For examples of implosives showing sonorant-like patterning in nasalization, readers are referred to the Atchan 2, Guébie, Ijo (Table 17), and Ikwere discussions in §2. There are also a number of languages in our sample where sonorants nasalize in nasal contexts, but implosives and obstruents do not. Such examples include Epie (epi, Edoid, Nigeria) (Elugbe 1989) and Pagibete (pae, Bantu, Democratic Republic of Congo) (Reeder 1998).

In many languages in our sample, implosives and obstruents trigger or undergo a phonological processes that sonorants do not undergo, and vice versa. These include OCP patterns, harmony, voicing alternations, interactions with tone, and more. In Bade (bde, West Chadic, Nigeria) (Tang 2008), obstruents block tone spreading, but sonorants and implosives do not (sonorant-patterning). In Tirmaga (suq, Surmic, Ethiopia) (Bryant 1999), implosives and obstruents devoice word-finally, while sonorants do not (obstruent-patterning).

For the languages described in Sections 2.1, 2.2, and 2.3, and for most languages in our sample, it was very clearly diagnosable whether implosives patterned with obstruents or sonorants, or showed mixed patterning. However, the situation is not always as clear cut. We eliminated languages without clear evidence in one direction or the other from the sample.

We now turn to the results of our typological study. The analysis of this study has three primary goals. The first goal is to determine the frequency distribution of languages where implosives pattern with obstruents versus sonorants (§3.2.1). The second goal is to examine whether specific phonological processes are active in predicting the phonological patterning of implosives with sonorants or obstruents (§3.2.2). The third goal is to determine whether there are any areal patterns in the phonological behavior of implosives. §3.2.3 presents an overview of the geographic regions where the languages of each type are spoken, and whether implosives patterning as sonorants and/or obstruents correlates with the location of the speech community.

3.2 Results

3.2.1 Distribution of implosive patterning

Overall in the sample, there are 34 languages with implosives that pattern only with sonorants (38.63%), 26 where they pattern only with obstruents (29.54%), and 28 where they show mixed patterning (31.81%). In other words, 62 of the 88 languages in the sample show at least one phonological process in which implosives pattern with sonorants, and 54 of the 88 show at least one phonological process in which implosives pattern with obstruents. This is a remarkably even distribution across these three types, and perhaps an unexpected one given the phonological features previously proposed for implosives, discussed in §1.2. A test of equal proportions shows that there is no meaningful difference between the number of languages in the sample that have implosives that are exclusively sonorant patterning, exclusively obstruent patterning, or show evidence for both patterning (X-square=1.77; df=2; p=.41).

A closer look at the phonological systems of languages in the sample shows that languages where implosives pattern exclusively as sonorants are slightly more likely to have only one implosive in the phonological inventory than languages where implosives pattern as obstruents. Table 20 shows this pattern. If a language has implosives that pattern with obstruents (either exclusively, or if the language has mixed-patterning), then that language is likely to have more than one implosive in the inventory. If implosives pattern *exclusively* as sonorants in a language, then it is more likely that the language will only have one implosive. Of the 24 languages included in this sample that have only one implosive in their inventory, 22 languages contain only /ɓ/, and 2 languages contain only /ɗ/. However, a chi-square test comparing the languages where implosives pattern *exclusively* with sonorants, *exclusively* with obstruents, or both, and whether the language has one or more implosive in the inventory shows that this trend does not reach significance (X-square=4.43; df=2; p=.109). This may be due to the small number of languages that are obstruent patterning or both patterning that only have one implosive consonant.

Table 20: The relationship between the number of languages surveyed which contain implosives that pattern with sonorants, obstruents, or both, and the number of implosives in the inventory

	One implosive segment	More than one implosive
Sonorant patterning	12	22
Obstruent patterning	3	23
Both	8	20

The relationship between the number of implosives in the phonological inventory and the phonological patterning of implosives as obstruents and sonorants may be related to several factors. First, this observation may be caused by the areal distribution of languages with one implosive segment. Many Kru, Kwa, and Mande languages have only one implosive segment (typically, only /ɓ/) and are overwhelmingly sonorant patterning. Thus, the fact that languages with one implosive segment are more likely to pattern as sonorants may be at least partially an artifact of language family and areal contact. The areal patterns of the phonological behavior of implosives are discussed in §3.2.3. Second, there may also be a historical explanation; it is conceivable that implosives in languages with only one implosive sound have a different historical origin than those in languages with a full series of implosive sounds. This possibility is discussed further in §5.1.

Finally, the relationship between the number of implosives in the phonological inventory and phonological patterning could have a phonetic explanation. A majority of the languages with only one implosive segment have only /ɓ/, and this segment is more likely to pattern with sonorants in such languages. /ɓ/ may be phonetically more similar to sonorants than implosives at other places of articulation. This hypothesis stems from findings that non-coronal fricatives are more phonetically similar to sonorants than coronal fricatives (Mielke 2012), which may extend to implosives as well. More acoustic and articulatory data of cross-linguistic implosive production is necessary to test this hypothesis.

3.2.2 Implicational patterns in results

Next, we examine the possibility that implosives are more likely to pattern with sonorants or obstruents based on certain phonological processes. Implosives may be more likely to pattern with obstruents or sonorants with respect to certain phonological processes for a number of reasons, including phonetic factors. For example, obstruents devoice word-finally in many languages, motivated by several phonetic factors. Notably, it is difficult to maintain the transglottal pressure differential needed to sustain voicing while also building pressure in the oral cavity. Similarly, because implosives are defined by a complete closure in the vocal tract, it may be difficult to maintain the ingressive airflow necessary to sustain voicing on implosives (Blevins 2006). As such, we compare whether certain phonological processes are more likely than others to determine or correlate with whether implosives in a given language are sonorant patterning or obstruent patterning. Recall that each language was coded for whether implosives pattern as obstruents, sonorants, or both based on a wide range of phonological processes. Of the 88 languages included in this analysis, 34 languages have implosives that pattern exclusively with sonorants, 26 languages have implosives that pattern exclusively with obstruents, and 28 languages show phonological processes that indicate implosives pattern with both obstruents and sonorants.

Figure 1 shows the break down for how many times a phonological process was included as evidence for a language containing implosives that pattern as obstruents or sonorants. For each phonological process, across the languages in the sample, how many times did that phonological process show evidence of sonorant patterning (to the exclusion of obstruents), and how many times did that process show evidence of obstruent patterning (to the exclusion of sonorants)?

The specific phonological processes that were coded for each language are described in detail in §3.1, but are briefly defined again here to ease interpretation of the results:

- Word final devoicing: do implosives devoice word-finally with voiced obstruents to the exclusion of sonorants?
- Prenasalization: do implosives prenasalize when obstruents do, or not?
- Nucleus position: do implosives pattern with obstruents or sonorants in whether they can be the nucleus of a syllable?
- Nasalization: do implosives nasalize in nasal contexts when sonorants do, or resist nasalization like obstruents?
- Implosive processes (exclude other cons): do implosives and sonorants trigger or undergo an alternation that obstruents do not? Or do implosives and obstruents trigger or undergo an alternation that sonorants do not?
- Historic patterning: is there a clear diachronic relationship between implosives and sonorants or obstruents?

- Depressor consonant: do implosives and obstruents act as depressor consonants? Or do obstruents (but not implosives and sonorants) act as depressor consonants?
- Coda: can implosives and sonorants (but not obstruents) surface in coda position? Or can sonorants (but not obstruents or implosives) surface in coda position?
- C2 onset: do implosives pattern with sonorants or obstruents in whether they can be in the second consonant position of an onset consonant cluster?
- C Cluster: do implosives pattern with sonorants or obstruents in their co-occurrence restrictions in consonat clusters?
- Assimilation: do implosives show assimilation and/or harmony with obstruents or sonorants?
- Other Processes (exclude implosives): do obstruents trigger or undergo a phonological process that implosives and sonorants do not? Or do sonorants trigger or undergo an alternation that obstruents and implosives do not?
- Alternations: are implosives allophones of sonorants or obstruents? Or do implosives have a sonorant or obstruent allophone?

Although several of the phonological processes show a fairly even distribution as to whether or not they show evidence of implosives patterning as obstruents or sonorants, there are a few differences between obstruent and sonorant patterning. The languages in this sample show implosives patterning with obstruents, but never with sonorants, in word final devoicing and nucleus position. That is, if obstruents devoice word-finally, implosives always do. Neither implosives nor obstruents are reported to be able to surface as the nucleus of a syllable in any of the languages in the sample. For example, in Mambai (mcs, Mbum, Cameroon and Chad) (Anonby 2008), implosives and voiced obstruents devoice word-finally, while sonorants do not. In Dagara (dgi, Gur, Ghana and Burkina Faso) (Nerius 2013), approximants and vowels can be syllable nuclei, while implosives and obstruents cannot.

Figure 1 also shows that more languages in this sample have implosives that pattern with obstruents in terms of coda position (68%) than with sonorants in the coda position (32%). For example, as previously mentioned, in Mbay (myb, Bongo-Bagirmi, Chad and Central African Republic), sonorants can appear in coda position, but implosives and obstruents cannot. More languages in this sample also have implosives that pattern with obstruents (77.77%) in terms of consonant cluster restrictions than sonorants (22.22%). Implosives also pattern with obstruents (87.5%) more often than sonorants (12.5%) in assimilation patterns (see Hausa assimilation in Table 3).

On the other hand, for nasalization, 90% of languages with productive consonant nasalization in nasal environments show implosives patterning with sonorants to the exclusion of obstruents in undergoing nasalization, compared to 10% of instances where sonorants undergo nasalization but implosives pattern with obstruents in not alternating in nasal environments (see §2.2.1 for an example of implosives nasalizing with sonorants in Atchan). Overall, certain phonological processes are more likely to show implosives patterning with sonorants, while others are more likely to show implosives patterning with obstruents, though few of these generalizations are universal.

When the set of obstruents or sonorants not including implosives alternates (in the 14 languages represented in the "Other Processes (Exclude Implosives)" category), this could be because the target set of features is, for picking out only obstruents, [-son, -cg], or simply [-son] where implosives share a [+son] feature with sonorants but no feature with obstruents. Note that the former requires a binary [+/-cg] rather than privative [cg] feature, which many feature theories argue against (Lombardi 1995). If this binary [+/-cg] analysis is adopted, however, patterns where all obstruents trigger are the target of some alternation to

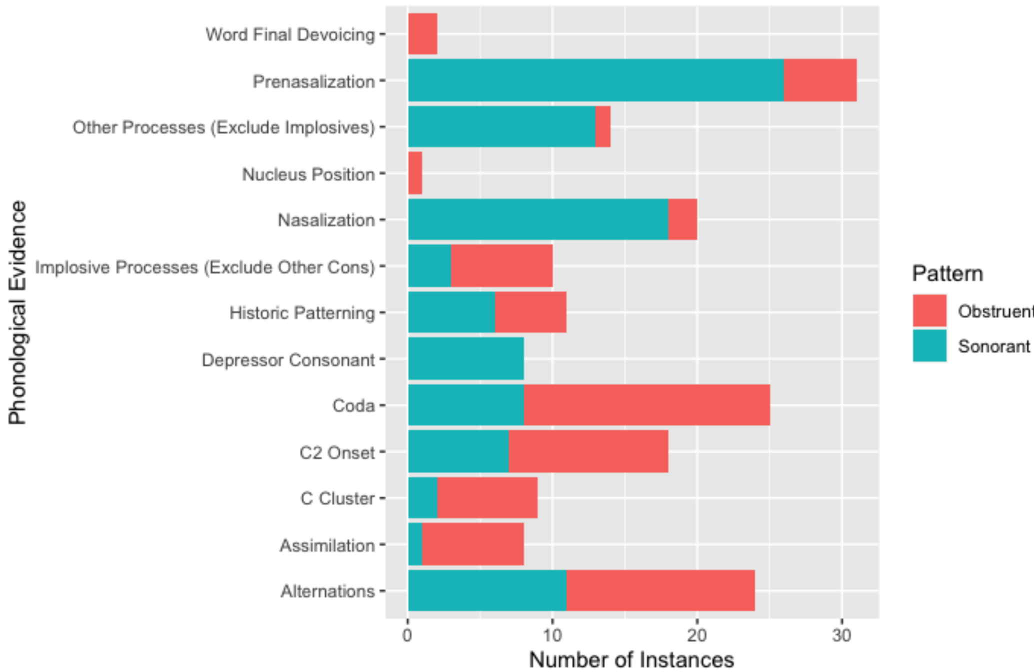

Figure 1: For all languages: the number of times each phonological process was cited to show implosives pattern as obstruents or sonorants

the exclusion of implosives and sonorants may not, in fact, provide evidence about the value of the feature [sonorant] for implosive sounds, because the [-cg] feature rather than a [+/-son] feature rules out implosives from being members of the relevant class. The same is true for alternations that target sonorants but not implosives or obstruents. While we acknowledge that this is the case, we include these properties in our sample for completeness (and because we believe the privative view of laryngeal features makes better typological predictions than a view of all laryngeal features as binary, cf. Lombardi (1995)) and briefly discuss how they impact our results here. If we were to have excluded the ”alternations excluding implosives” patterns, three languages would not have been included in our sample because they did not show other positive evidence of implosives patterning together with either obstruents or sonorants: Aari, Bade, and Pero. All three of these are sonorant-patterning, so the percentage of sonorant patterning languages would have been slightly lower (36.47% of the total as opposed to 38.63%). The overall classification of a given language as mixed, sonorant, or obstruent patterning would have changed for three of the other languages: Dime and Igbo would have been considered obstruent-patterning languages rather than mixed, and Arbore would have been considered sonorant-patterning instead of mixed. This would have lowered the overall count of mixed languages by one and raised the overall count of obstruent-pattenring languages by one, not significantly changing the overall patterns.

Next, we look more closely at the languages where implosives pattern exclusively with obstruents or sonorants, and consider whether specific phonological processes are more likely to show obstruent or sonorant patterning. Figure 2 shows for all 34 languages that are exclusively sonorant patterning, which phonological processes show that implosives pattern as sonorants. Figure 3 shows for all 26 languages that are exclusively obstruent patterning, which phonological processes show that implosives pattern as obstruents. It is important to note here that some language descriptions discuss multiple phonological processes involving implosives, so a language may be represented more than once by different phonological processes, but can never be represented more than once for the same phonological process.

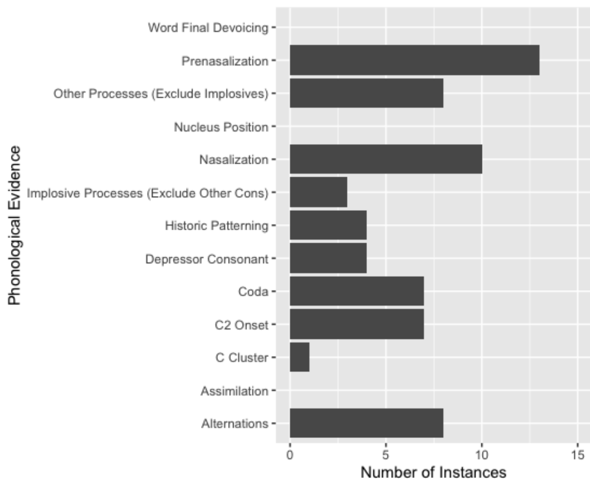

Figure 2: For all sonorant-patterning languages: the number of times each phonological process was cited to show implosives pattern as sonorants

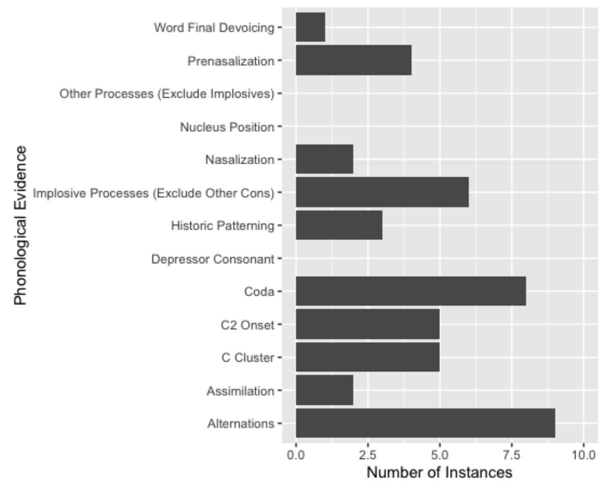

Figure 3: For all obstruent-patterning languages: the number of times each phonological process was cited to show implosives pattern as obstruents

As can be seen in Figure 2, nasalization, prenasalization are the two most common phonological processes that are cited as evidence that implosives pattern as sonorants in a language. This is similar to the aggregate results for all languages in the sample show in Figure 1 that show prenasalization and nasalization to largely show implosives patterning as sonorants. Figure 3 shows that alternations are the most common phonological process that shows evidence for implosives patterning as obstruents in a language to the exclusion of sonorants. Whether implosives are permitted in the coda (coded here as 'Coda') is the second most common phonological process that corresponds to implosives patterning as obstruents in a language.

Although interesting that implosives tend to alternate with obstruents rather than sonorants, sounds do not necessarily need to share features if they alternate with each other. Similarly, sounds that are historically related to one another do not necessarily need to share a feature synchronically. As such, a second set of analyses are run without these two phonological processes in order to only examine processes that could use a sonorant or obstruent feature to explain the pattern.

Removing the 'alternations' and 'historical patterning' processes reduced the number of language in the sample to 78. This means that 10 languages included in the original sample only had alternations or historical evidence to the phonological behavior of implosives. 33 of the remaining languages have implosives that pattern exclusively with sonorants (42.31%), 21 have implosives that pattern exclusively with obstruents (26.92%) and 24 have implosives that pattern with both obstruents and sonorants (30.77%). A test of equal proportions shows that there is no difference between the number of languages in this sample where implosives pattern exclusively with sonorants, exclusively with obstruents, or with both (X-square=4.5; df=2, p=.105). This means that removing alternations and historical patterning as evidence for the phonological patterning of implosives as sonorants or obstruents does not greatly effect the overall trends discussed in this section. There is still a remarkably even distribution between languages where implosives pattern with sonorants, obstruents, or both.

Although alternation patterns and historical evidence do not themselves show evidence that implosives share a feature with either obstruents or sonorants, alternation patterns show similar phonological behavior to the other phonological patterns observed here. Of the 11 languages that have an alternation between implosives and sonorant, 7 of those languages also show implosives patterning exclusively with sonorants in some other regard (i.e. prenasalization, onset posiiton, etc.). Two of the languages that have an alternation between implosives and sonorants show implosives patterning with sonorants in some other regard, but non-exclusvely (i.e. there is another pattern where implosives pattern with obstruents). There is only one language where implosives alternate with a sonorant and the only other evidence of the phonological patterning of implosives shows it to pattern with obstruents; in Aizi (ahi/ahm, debated Kwa or Kru, Côte d'Ivoire) implosives pattern with obstruents in their distribution in CC clusters (only sonorants /l,j,w/ and not implosives or obstruents can surface as the second C in an onset CC cluster) but /l/ as an allophone [ɗ] which surfaces before high front vowels and glides (Herault 1971). The other language that shows implosives to alternate with sonorants does not have any other evidence as to the phonological patterning of implosives. On the other side, of the 13 languages that show implosives to alternate with obstruents, 5 languages also show implosives to phonologically pattern exclusively with obstruents in some other regard. Two languages that have implosives that alternate with obstruents show other patterns of implosives patterning with obstruents and sonorants in at least one other phonological pattern. Only 2 languages that show implosives to alternate with obstruents also show other evidence of implosives patterning exclusively with sonorants. The other 4 languages do not have other evidence of the phonological patterning of implosives as obstruents or sonorants. To summarize, if implosives alternate with sonorants in a given language, they also tend to pattern phonologically with sonorants in some other regard, and if implosives alternate with obstruents, they also tend to pattern phonologically with obstruents in other patterns, for the languages which have enough data to say one way or the other. These trends are small given the small sample size of languages that show alternation patterns.

The historical evidence for implosive phonological behavior affects an even smaller number of languages in the sample. That is, very few of the descriptive resources available make any claims about the historical origins of implosives, making it difficult to determine whether historical evidence of an implosive's phonological status is indicative of synchronic phonological patterning. There are 6 languages in this sample that show historic evidence that implosives come from sonorants. Three of these languages show implosives to pattern exclusively with sonorants with some other synchronic phonological process, and 2 show implosives to pattern with both obstruents and sonorants with respect to different phonological processes. The other language that shows implosives to historically be sonorants does not have other evidence as to the phonological patterning of implosives. No languages that have evidence that implosives were historically sonorants show implosives to exclusively pattern with obstruents synchronically. There are 5 languages that show implosives to be historically related to obstruents. Of these 5 languages, one language has other evidence to show that implosives phonologically pattern exclusively with obstruents, one language has evidence to show implosives pattern exclusively with sonorants, and one language shows evidence of implosives phonologically pattern with both obstruents and sonorants. The other two languages do not have any evidence about the synchronic status of implosives. The trend holds that languages that historically patterned with sonorants show synchronic evidence that implosives pattern with sonorants in at least some respects, but the sample size is too small to indicate whether this is true of obstruents as well.

Taken together, the results of this section have shown that whether implosives pattern as sonorants or obstruents is at least partially dependent on the phonological processes in question. Implosives are more likely to pattern with obstruents than sonorants in terms of syllable position. For example, implosives, like obstruents, cannot be nucleus of a syllable, they often cannot appear in coda position, and they often cannot be the second consonant of an onset cluster. On the other hand, implosives are more likely to pattern with sonorants in terms of nasalization. Many languages in this sample show implosives patterning with sonorants in nasalizing near nasal consonants or vowels, and in whether or not they can surface as prenasalized. One hypothesis that may help explain these facts is that the phonetic properties of implosives may cause them to behave phonologically with obstruents with respect to certain phonological processes, and with sonorants with respect to others. For example, nasalization is compatible with the absence of intraoral pressure buildup found in implosives. Future work on the cross-linguistic phonetic properties of implosives is suggested to address the hypothesis that the phonetic properties of implosives can help to explain their mixed patterning across languages.

3.2.3 Areal results

To determine if there are significant areal patterns with respect to how implosives behave phonologically, we mapped each of the languages in our sample, using the longitude and latitude as well as language family information from Glottolog (Hammarstrom, Forkel, Haspelmath & Bank 2020). Figure 4 shows all languages in our sample, each represented by a dot, where the colors of each dot represent implosive patterning.

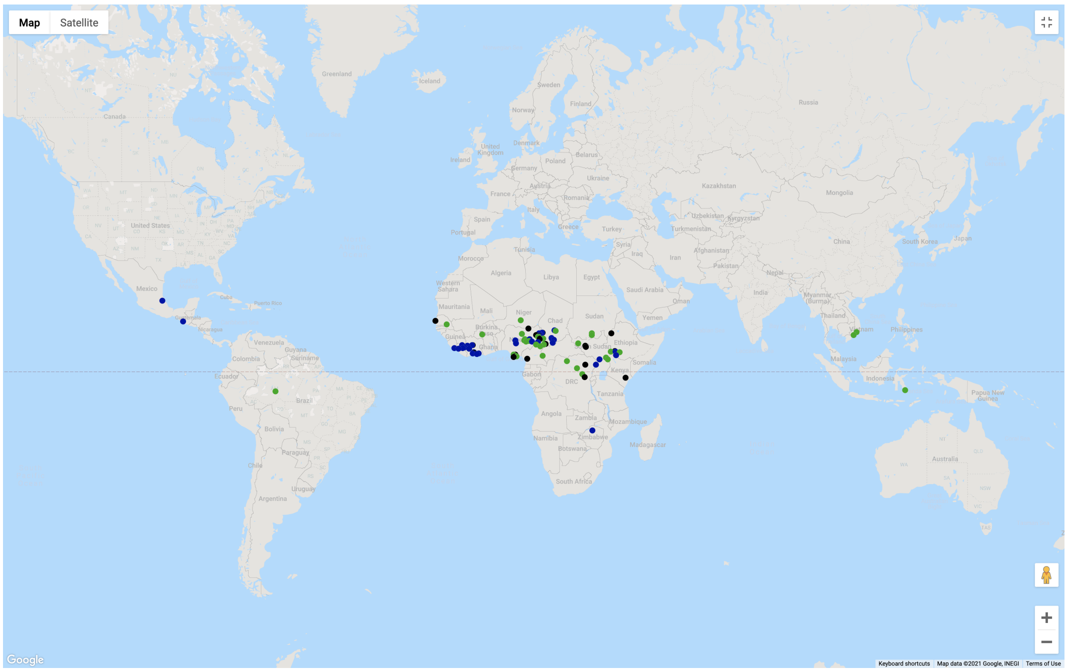

Figure 4: World map of implosive patterning; key: green = obstruent patterning, blue = sonorant patterning, black = mixed patterning

So few languages in our sample come from outside of Africa (reflecting the fact that most languages with contrastive implosive and voiced plosive sounds are found in Africa), that it is difficult to say whether there are relevant areal patterns in the Americas or Asia. For this reason, this section focuses solely on the areal patterns among languages in our sample spoken in Africa. In the maps below, languages are marked by a letter representing language family. Those marked by a dot rather than a letter are either isolates, such as Laal in Chad, or are the only language of a particular family in the sample, such as Ik (Kuliak/Rub) in northeast Uganda.

In Figure 5 we see that most languages in our sample are spoken in the Macro-Sudan Belt (for more on the areal features of the Macro-Sudan Belt, see Güldlemann (2008); Creissels, Dimmendaal, Frajzyngier & König (2008); Clements & Rialland (2008)). Within this area, languages with all three types of patterning–where implosives pattern with sonorants, obstruents, and those that show mixed patterning–are well represented. There are some areal tendencies within this zone. We see that there are gaps in the Macro-Sudan Belt where implosive consonants are not found or not represented in our sample. For example, languages of Ghana, Togo, and Benin either tend to lack implosives, or are less well described and thus not represented in our sample. Further West, in Côte d'Ivoire, Guinea, and Liberia, in particular, there is an abundance of languages where implosives pattern with sonorants, only a few where they pattern with both obstruents and sonorants, and none that pattern with obstruents only, Figure 6. These micro-areas tend to align with micro-areas of the Macro-Sudan Belt that have been identified in investigating the distribution of independent features such as word order (Sande, Baier & Jenks 2019) and vowel inventory (Rolle, Lionnet & Faytak 2020).

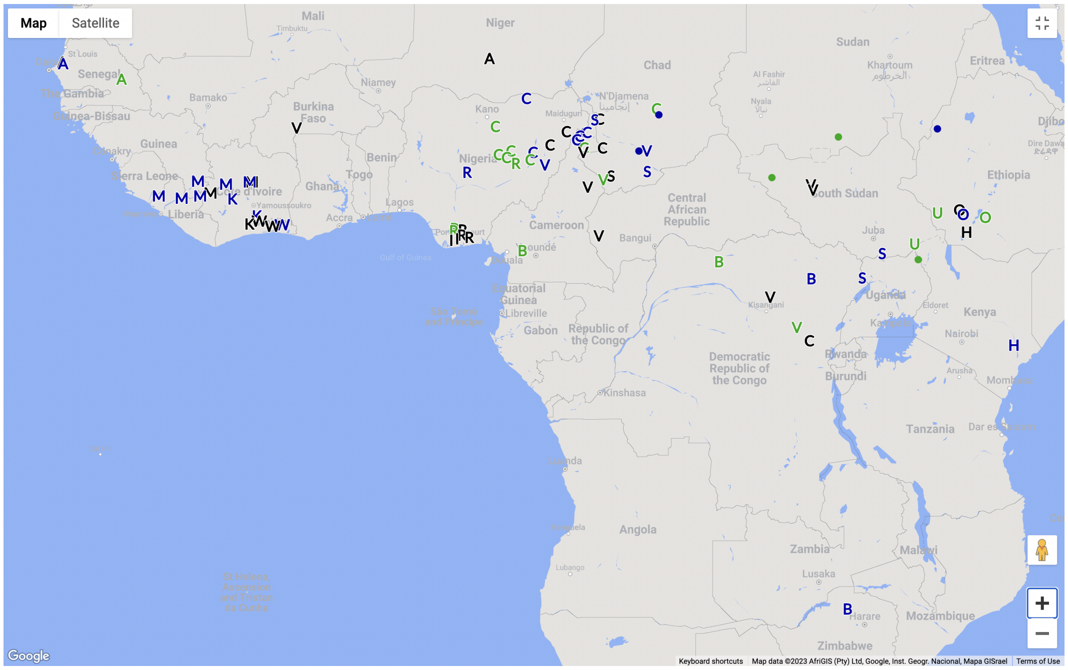

Figure 5: Implosive patterning in Africa; key: green = obstruent patterning, blue = sonorant patterning, black = patterns with both obstruents and sonorants; A = North-Central Atlantic, B = Bantu, C = Chadic, H = Cushitic, I = Ijoid, K = Kru, M = Mande, O = Omotic, R = Benue-Congo, S = Central Sudanic, U = Surmic, V = North-Volta-Congo, W = Kwa

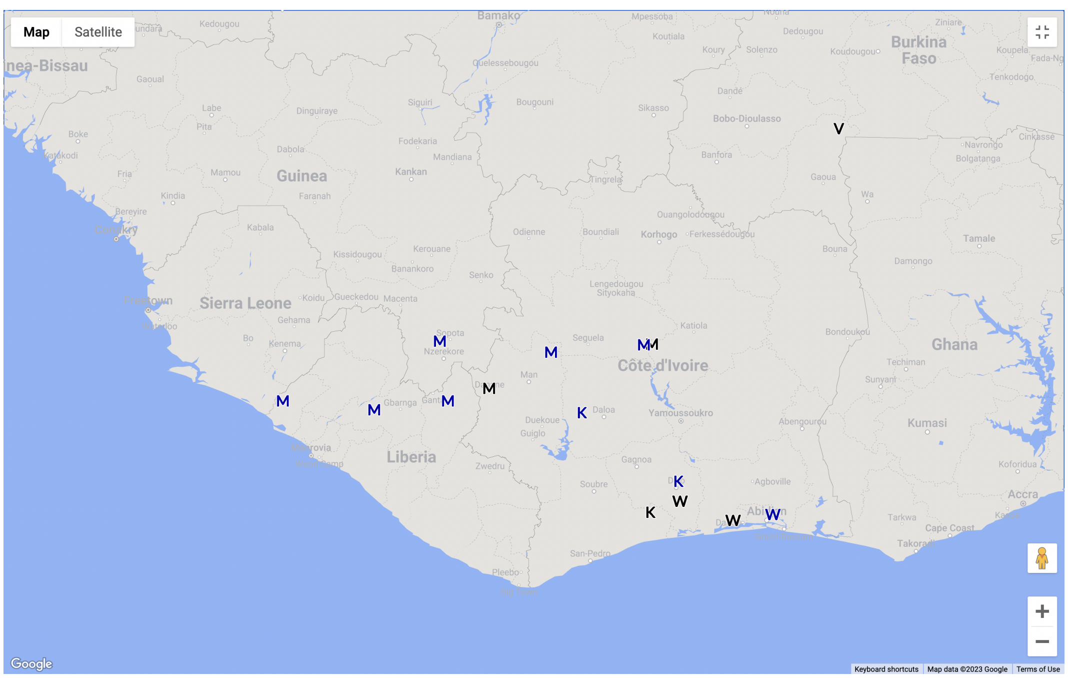

Figure 6: Implosive patterning in West Africa; key: green = obstruent patterning, blue = sonorant patterning, black = patterns with both obstruents and sonorants; K = Kru, M = Mande, V = North-Volta-Congo, W = Kwa

Regardless of language family, languages of Côte d'Ivoire and the surrounding area tend to have implosive sounds that pattern with sonorants. Or, more specifically, implosives in languages in this do not pattern exclusively with obstruents (Figure 6).

In Central Africa we see a different pattern, shown in Figure 7. In Nigeria, Cameroon, and Chad, there seems to be an equal mix of language with implosives that pattern with obstruents, those that pattern with sonorants, and those with mixed patterning. Even within a single language family, such as Chadic (C), there are languages of all three types, sometimes spoken very near to languages of other types. Without a much deeper historical dive, it is difficult to see an areal or historical reason behind these patterns. Rather, all three types of implosive patterning seem to be well represented in Nigeria, Cameroon, and surrounding areas.

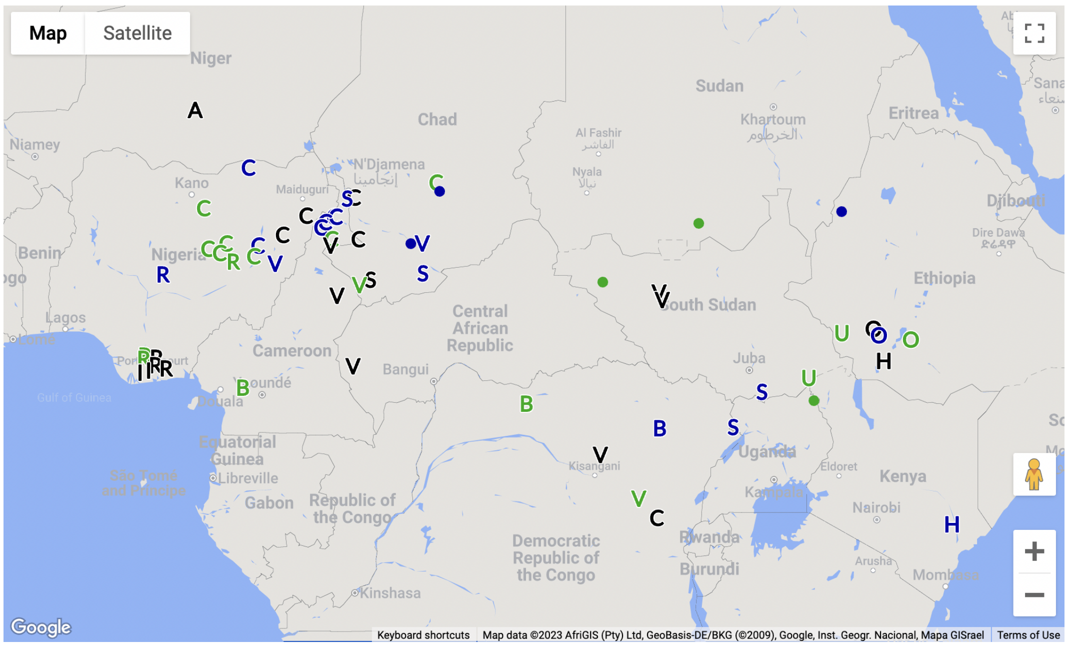

Figure 7: Implosive patterning in Central and East Africa; key: green = obstruent patterning, blue = sonorant patterning, black = patterns with both obstruents and sonorants; A = North-Central Atlantic, B = Bantu, C = Chadic, H = Cushitic, I = Ijoid, K = Kru, M = Mande, O = Omotic, R = Benue-Congo, S = Central Sudanic, U = Surmic, V = North-Volta-Congo, W = Kwa

Further east, the data is more sparse, but we see more patterning by language family than area. Implosives in Cushitic languages (H) tend to pattern with sonorants, while in Surmic languages (U) they pattern with obstruents.

To summarize the areal patterns, there seems to be a strong cluster of sonorant-patterning languages in West Africa, spanning Mande, Kru, and Kwa language families. This is an area that patterns together linguistically with respect to a number of other properties including tone (Hyman, Sande, Lionnet, Rolle & Clem 2020) and word order (Sande et al. 2019), so it is perhaps not unexpected that these languages also pattern together with respect to implosive behavior. Interestingly, the languages of Liberia and Côte d'Ivoire tend to have only one contrastive implosive sound, so perhaps language contact in this area has led to the strong correlation between languages with only a single implosive in the inventory and sonorant patterning, discussed in §3.2.1. Elsewhere in the Macro-Sudan Belt, languages of all three types are well represented. A few language families seem to pattern a particular way regardless of location, such as Ijoid (I, mixed patterning) and Surmic (U, obstruent patterning), while other language families include languages that differ in implosive patterning across languages (North-Central Atlantic, Chadic, Benue-Congo).

3.3 Limitations of the typological survey

One limitation of the typological survey is that the results depend on the available resources for each language. As such, there may be other phonological processes involving implosives in a given language that are not discussed in the available descriptive materials, and thus are not represented in this study. There are two consequences for the interpretation of the results that stem from this limitation. First, there is a possibility that the mixed-patterning languages are underrepresented by this sample. Some sources only listed one or two phonological processes involving implosives. If each source had listed all of the segments that undergo each phonological process, and a complete list of phonological processes, it is possible that more languages would have been classified as having mixed-patterning.

The second consequence of relying on the reporting of each source is that individual processes may be underrepresented as correlating with sonorant or obstruent patterning. For example, authors may have been less likely to report the segments that act as depressor consonants than the segments that undergo nasalization. The relative representation of specific processes in the sample may thus be a consequence of reporting practices.

Despite this limitation to the typological survey, this study contributes valuable insight into the typological phonological patterning of implosives. Although access to more data on each of the 88 languages in the sample, and having access to data on more languages, would improve the validity of our findings, the information gathered from each of these 88 languages contributes to an understanding of the phonological behavior of implosives that has been overlooked in previous phonological literature.

We strongly recommend based on our experience with this survey that authors of phonological descriptions include lists of each sound that undergoes each phonological process in their descriptions, which will make their work more likely to be useful to future typological studies.

4 Implications for feature theories

Phonological feature sets define classes of segments necessary to describe the sound patterns of language (Trubetzkoy 1969 [1939]). Features often have a phonetic definition or basis; however, they must also be able to account for the classes of sounds that pattern together. As discussed in §1.2, previous feature theories attribute a [+obstruent] or [-sonorant] feature to implosive sounds based on articulation. However, the typological survey results presented in §3 have shown that implosives show mixed sonorant/obstruent behavior within and across languages. Thus, previous feature sets which treat them as obstruents are inadequate, and do not account for the phonological patterning of implosives in most of the languages that have contrastive implosive sounds. This section explores a number of possible phonological feature-based analyses of implosives, ruling out some options in favor of others.

4.1 A single [+/-sonorant] feature

One option for how to account for obstruent and sonorant patterning is a single binary [+/-sonorant] feature, without also adopting the existence of a [+/-obstruent] feature. On this approach, we could say that implosives are not universally specified as obstruent or sonorant, but are underspecified for the feature sonorant. Learners can then associate implosives with the [-sonorant] or [+sonorant] set of sounds and can assign the feature its value based on exposure.

This approach could work to account for sonorant-patterning and obstruent-patterning languages, but cannot account for languages where implosives pattern with obstruents with respect to some phonological phenomena, and with sonorants with respect to others, as in §2.3. If there is a single binary feature [+/-sonorant], there are three possible values that implosives could have for this feature in a given language: [+sonorant], [-sonorant], or it could be underspecified. If implosives have a [-sonorant] feature, we expect them to pattern with other obstruents, and not with [+sonorant] sonorants. If implosives have a [+sonorant] feature, we expect them to pattern with sonorants and not with obstruents. If they are not specified for the feature [sonorant] in some language, then any process that targets [+sonorant] or [-sonorant] sounds will not target implosives, so in this case we predict implosives to pattern neither with obstruents nor with sonorants. In none of these three scenarios can implosives pattern with obstruents for some processes but sonorants for others. Thus, a feature theory with a single binary [+/-sonorant] feature (and no [obstruent] feature) cannot account for the cross-linguistic patterns we see.

The opposite assumption, where there is a [+/-obstruent] feature but no [+/-sonorant] feature in the system, encounters the same problems. Additionally, a feature system where both [obstruent] and [sonorant] are present, but are privative, runs into the same set of issues presented here. Any feature system where there is a single sonorant/obstruent distinction (a single binary feature or two privative features) is insufficient in accounting for the cross-linguistic behavior of implosives, and in particular for implosive behavior in mixed-patterning languages.

4.2 Implosives as [-obstruent, -sonorant]

As discussed in §1.2, most of the literature on features of implosives focuses on the laryngeal features which distinguish implosives from plosives and ejectives (Chomsky & Halle 1968; Greenberg 1970; Halle & Stevens 1971/2013; Keating 1984; Lombardi 1995; Hall 2007). These feature theories treat implosives as obstruents, plus an extra implosive- or glottalic-specific feature. Such theories predict that we should find languages like Hausa or Fula (§2.1) in which implosives pattern with obstruents. However, they do not predict that we should find systems like Guébie or Atchan where implosives pattern exclusively with sonorants (§2.2), or languages like Ijo and Ikwere where implosives show mixed phonological behavior (§2.3). This prediction comes from the fact that there is no feature in these theories which picks out sonorants and implosives to the exclusion of (voiced) obstruents.

Clements & Osu (2002) propose, based on the mixed phonological patterning of implosives in Ikwere, that implosives have both [-obstruent] and [-sonorant] features.[9] In being [-obstruent], implosives form a natural class with sonorants, and in being [-sonorant] implosives form a natural class with obstruents. In Ikwere, these feature specifications account for the dual patterning of non-explosive consonants with sonorants on one hand and obstruents on the other.

We could adopt the approach of Clements & Osu (2002), which assumes two binary features [+/-obstruent] and [+/-sonorant]. If we do, we can say that all implosives across languages are associated with [-sonorant, -obstruent] features, as proposed for Ikwere. Then in Guébie and Atchan the [-sonorant] feature would be inactive, playing no role in the phonological patterning in the language (otherwise, we'd expect to see some scenarios where implosives pattern with obstruents, which are not attested in the language). Similarly, in Hausa and Fula, where implosives pattern in every way with obstruents, the feature [-obstruent] would never be active. This approach seems to work, but may overpredict. First, there is no evidence that implosives ever pattern as [-sonorant] in Guébie or Atchan, or as [-obstruent] in Hausa or Fula, though in a universal feature theory, they would be specified as such anyway. Second, not only does this approach predict a class of [-obstruent, -sonorant] sounds (implosives), in addition to [+obstruent, -sonorant] sounds (obstruents) and [-obstruent, +sonorant] sounds (sonorants), it also predicts a fourth distinct [+obstruent, +sonorant] class. It is difficult to imagine which sounds might be included in this fourth class. Third, Clements and Osu's proposal requires both [+/- sonorant] and [+/- obstruent] features to be part of the feature system, while most extant feature theories only require one of the two, or privative versions of both [obstruent] and [sonorant], and are thus more restrictive and economical.

Note that Mielke (2013) shows that in a system with the features [-sonorant] and [+sonorant] (sonorant),

[9] See also Williamson (1987:10) who proposes that implosives are [-obstruent] in Kalabari, Nembe, and Biseni (three Ijo languages) in order to account for the fact that implosives become nasal before nasal vowels, as do other [-obstruent] sounds.

the two tend to be targeted for different types of processes. Namely, [-sonorant] sounds tend to be targeted for voicing-related processes, while [+sonorant] sounds are targeted for other processes. Mielke does not specifically discuss the behavior of implosives, though the proposal discussed in this section from Clements & Osu (2002) is that implosives have a [-sonorant, -obstruent] feature. Combining Mielke's observation with this featural representation, we may predict that implosives pattern with [-sonorant] sounds in being targeted for voicing-related processes, but not other processes.[10] While we did find that devoicing processes tend to target obstruents and implosives together, such as the devoicing process discussed for Mambai in §3.2.2, we also found that implosives pattern as obstruents for a number of other processes such as position in a syllable, total assimilation, and harmony.

4.3 Implosives as [-sonorant] and [lenis]

Another option is to search for an additional non-sonorant feature which is specified for implosives and sonorants but not obstruents. Zsiga (2018) proposes that the class of affricates, ejectives, and aspirated stops that can occur post-nasally in Setswana (tsn, Bantu, Botswana and South Africa) share the feature [fortis]. Parallel to Zsiga's proposal, one could consider an analysis where implosives and sonorants in Guébie share a [lenis] feature.[11]

The features [fortis] and [lenis] were proposed features of consonants in Trubetzkoy's (1969 [1939]) original feature set. Jakobson et al. (1951) and Chomsky & Halle (1968) use [tense] and [lax], which are also used to account for vocalic distinctions, rather than [fortis] and [lenis], in hopes of minimizing the number of features in the feature set. In both cases, the [fortis] or [tense] segments are characterized by a strong, effortful production. In the case of the limited and diverse set of Setswana segments that can surface after nasals, they cannot be characterized by either voicing or glottal constriction. Instead, Zsiga proposes that ejectives, affricates, and aspirated stops all share the feature [fortis], and that only [fortis], phonetically strong consonants are possible in post-nasal position.

While [fortis] segments are characterized by a strong production, and distributionally as occurring in strong phonological positions, [lenis] segments show the opposite patterning. Sonorants and, in some languages, implosives, tend to appear in weak phonological positions, such as the second consonant of an onset cluster, and intervocalically. See, for example, the shared behavior of /ɓ/ and sonorants in Guébie, as in Table 10, which, unlike other consonants, can surface as the second consonant in a CCV word. If we say that implosives and sonorants share a [lenis] feature, we can account for their patterning together in languages like Guébie. Implosives may also have, following most extant feature theories, a [-sonorant] feature, accounting for their patterning in languages like Hausa and Fula. On this analysis, the fact that implosive are both [-sonorant] and [lenis] would allow them to show mixed patterning in languages like Ikwere and Ijo, as in Table 21.

The potential downsides of this option are that, like the Clements & Osu (2002) approach, it complicates the feature theory by adding features. Additionally, in languages where implosives pattern only with obstruents (Hausa, Fula), there would be no reason for a speaker to learn that implosives have a [lenis] feature. Similarly, in languages where they pattern only with sonorants (as in Kru languages), there would be no reason for those speakers ever to learn that implosives have a [-sonorant] feature.

[10] We acknowledge here that Mielke (2013) adopted an approach where a single binary feature [+/-sonorant] distinguished obstruents from sonorants, while the Clements & Osu (2002) approach necessarily requires both binary [+/-obstruent] and [+/-sonorant] features, so perhaps the two are not straightforwardly combinable.

[11] See a similar proposal by Stewart (1973) on a fortis/lenis distinction among stops in Volta-Congo languages. However, Stewart was differentiating between what he called fortis and lenis plosives, as well as a separate class of contrastive implosive sounds in Volta-Congo.

Table 21: Proposed features of obstruents, implosives, and sonorants

	Obstruents	*Implosives*	*Sonorants*
[lenis]	–	✓	✓
[-sonorant]	✓	✓	–
[+sonorant]	–	–	✓

The features in Table 21 make an interesting prediction, which is that [+sonorant] sounds should be able to pattern separately from implosives, but that [-sonorant] sounds (obstruents) cannot, unless the feature [lenis] is also a binary feature and all of the [-lenis] sounds are non-implosive obstruents. In the typological sample, we see examples of sonorants undergoing alternations to the exclusion of implosives and obstruents (which could be accounted for with the [+sonorant] feature in Table 21), but we also see examples of obstruents triggering or undergoing some alternation to the exclusion of sonorants and implosives, which is not predicted by the features in Table 21 (e.g., obstruents blocking tone spreading in Vata, to the exclusion of obstruents, as discussed in §2.2.3).

4.4 Exemplars and emergent features

Another alternative option is to adopt the idea that distinctive features may not be universal, but learned based on phonological patterning of sounds in a given language. This idea is compatible with exemplar-based frameworks (Pierrehumbert 2001; Johnson 2007), which assume that instances of production and perception (exemplars) experienced by the speaker/hearer are stored as they occur, and not necessarily categorized as an abstraction. Exemplars that cluster together in the mental space can then be conceptualized as similar in a meaningful way, leading to what we know as phonological generalizations and natural classes[12]. Recent work shows that a computational learning model of grammar is capable of positing phonological features based on the patterning of different natural classes, compatible with an exemplar-based framework (Mayer 2020; Mayer & Daland 2020). On this approach, language-specific phonological patterns lead speakers to posit similarities between segments that pattern together, such that implosives may be associated with a different set of features in different languages.[13]

Mielke (2005) adopts an emergent feature approach, rather than a universal or innate feature-based approach, to the phonologically ambivalent behavior of laterals. He argues against innate feature approaches on the grounds that a single segment would need to have different feature specifications in different languages to account for observable phonological behavior. In an emergent feature approach, phonetic similarity and historical changes, rather than an innate feature set, explain which sounds pattern together in a phonological system, and learners are presumed to posit natural classes based on their linguistic input and observable phonetic properties of sounds they encounter. This approach is able to account for the behavior of implosives in a similar way to Mielke's treatment of laterals. §2.4 discusses the pros and cons of giving up an innate feature account in favor of an emergent feature one.

4.5 A gradient [sonorant] feature

In order to 'save' an innate feature approach, we present here a final alternative, an approach which assumes that innate, universal feature values can be gradient rather than privative or binary. This approach can be mechanized in a modified version of Gradient Symbolic Representations (GSR) (Smolensky & Goldrick

[12] Also see work in contrast-based feature theories (Dresher, Piggott & Rice 1994; Dresher 2003, 2004), Emergent Feature Theory (Mielke 2004, 2008, 2012), and the attractor model (Mohanan 1993).

[13] An intermediate approach between fully specified universal feature values and no universal feature values could be to say that implosives are underspecified for +/- value of the feature [sonorant] in all languages. The + or - value is then learned based on the phonological patterning of implosives in a given language.

2016). GSR typically assumes that input segments can be gradiently activated. This possible analysis follows an emerging line of work proposing that *features* can be gradiently activated (Rosen 2016; McCollum 2019; Walker 2020). On this analysis, implosives would fall between sonorants and obstruents in a universal sonority hierarchy, which would be built into the grammar through gradient values of the feature [sonorant].

Most versions of the sonority hierarchy do not include implosive sounds (Parker 2011) 3.

(3) *Parker's 'complete' sonority hierarchy*
vowels[14] ≫ glides ≫ rhotic approx. ≫ flaps ≫ laterals ≫ trills ≫ nasals ≫ voiced fricatives ≫ voiced affricates ≫ voiced stops ≫ voiceless fricatives ≫ voiced affricates ≫ voiced stops

Implosives can be added to the sonority hierarchy between nasals and voiced fricatives, based on their mixed behavior as either sonorants or obstruents for properties that are typically analyzed as due to sonority (distribution within a syllable, etc.).

A novel aspect of the gradient approach is that each step on the sonority hierarchy would be associated with an activity value for the feature [sonorant], where vowels are fully sonorant, voiceless stops are not at all sonorant, and all other sounds fall somewhere in between 4.

(4) *Proposed gradient sonority hierarchy*
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: $[\text{Son}]_{.15}$ ≫ voiceless affricates: $[\text{Son}]_{.1}$ ≫ voiceless stops: $[\text{Son}]_{.0}$

The proposed gradient sonority feature is related to phonetics in that segments with longer duration, more sustained voicing, and higher intensity (more resonance) are more sonorant, they have a higher activation value of the [sonorant] feature. This is a continuous scale, rather than a binary distinction.

Following previous work in GSR, we could pair these gradient activity values with a MaxEnt-Harmonic Grammar model (Goldwater & Johnson 2003; Hayes & Wilson 2008), where language-specific constraint weights interact with the universal sonority activity scale to result in mixed patterning of implosives within and across languages. Depending on the language-specific weight of a given constraint, for each phonological process a language can draw a line a different place in the sonority hierarchy such that all sounds on one side of the line pattern one way, and all sounds on the other side pattern another way. Thus, implosive behavior in sonorant-patterning, obstruent-patterning, and mixed-patterning languages could be accounted for with a universal set of gradient [sonorant] feature values, plus language-specific constraint weights. Appendix B provides possible constraint weights for multiple languages, and shows how these language-specific weights interact with the universal gradient sonority hierarchy in 4 to result in different surface patterns of implosives across languages.

A benefit of this GSR proposal is that it can account not just for the patterning of implosives, but for other variable sonority-related patterns across languages. Other segments that fall in the middle of the proposed hierarchy are also seen to be phonologically and phonetically mixed across languages, such as voiced fricatives (Bjorndahl 2018), and fricative vowels (Matt Faytak, p.c.), as is predicted based on the gradient feature sonority hierarchy plus language-specific constraint weights. Other segments have been described as ambivalent, showing mixed patterning, with respect other features. For example, nasals and laterals are ambivalent with respect to continuity (Mielke 2005; Krämer & Zec 2020). A similar kind of gradient hierarchy of specifications of [continuant] may be useful in accounting for these kinds of ambivalent behaviors across languages.

[14] Parker breaks down vowel sonority into 5 parts, which we've simplified here for space.

One question for future work is how, in this approach, to capture the fact that for certain types of phonological processes implosives are more likely to pattern with sonorants (such as nasalization), while for others they are more likely to pattern with obstruents (assimilation, position in a syllable). One possibility is that multiple gradient hierarchies are needed, one for syllable position, one for nasalization, etc., where implosives fall in different places with respect to other sounds in different hierarchies. See Walker (2011, 2014) on hierarchies of nasalization targets as distinct from the sonority hierarchy, and see Yin (2021) on the lack of a single universal sonority hierarchy; though note that Walker's nasalization hierarchy does not include implosives as a distinct category, and Yin's work assumes that implosives are obstruents, both of which should be reconsidered in future work given the results of the typological survey presented here. Another possibility is that the constraint weights that govern nasalization are more likely to target implosives along with more sonorant elements due to the specific phonetic properties of implosives, but that this could be built into the constraint weights rather than gradient feature hierarchies. We leave debate about the separation of the sonority hierarchy into multiple process-specific hierarchies for future work.

4.6 Summary

In this section we have ruled out a feature system with a single binary feature that distinguishes sonorants from obstruents. Such a system cannot account for mixed-patterning languages, as discussed in §4.1. Crucially, it cannot be the case that implosives share a feature with obstruents, and do not also share a feature with sonorants.

The three types of workable feature-based approaches are then a. to adopt universal features where implosives share some features with obstruents and others with sonorants (as in Sections 4.2 and 4.3), b. to adopt an approach where the specific features associated with implosives differ across languages, motivated by their language-specific phonological patterning (§4.4), or c. to adopt a gradient-feature approach where implosives fall between obstruents and sonorants on some feature scale (as in §4.5). A number of arguments against the multiple innate feature approaches (a.) are presented in Sections 4.2 and 4.3. These arguments come down to economy and the predictions of specific representational choices. This leaves gradient innate features and emergent features as the best analyses of the mixed phonological patterning of implosives.

The gradient feature approach continues the tradition of adopting universal, innate features to explain sound patterning across languages. It has the added benefit of accounting not just for the mixed behavior of implosives, but also for the mixed behavior of other phonetically ambiguous and phonologically ambivalent sounds such as laterals and voiced fricatives, adopting terminology from Mielke (2005), as discussed in §4.5. For the moment, we see this approach as the most promising for explaining and generating the range of implosive behaviors found across languages.

However, as raised by Mielke (2005), we may ask whether it is desirable to continue in the tradition of assuming universal, innate features, given that so many types of sounds pose challenges to innate feature theories. The alternative is an emergent-feature model, as discussed in §4.4. In such an approach, it may be the case that for cognitive reasons phonetically similar segments tend to pattern together; thus, we would expect to see phonetically similar segments forming natural classes across languages. In an exemplar-based approach, classes of segments that pattern together may not be purely determined by phonetics, though; diachronic facts may also play a roll. Future work on both historical origins and phonetic properties of implosives will shed light on the kinds of information that would need to be built into an emergent feature approach in order to best account for the behavior of implosives. The following section discusses directions for future work on the historical, areal, and phonetic patterning of implosives.

5 Discussion and directions for future work

This section discusses the implications of our typological findings for our areal and historical understanding of implosives, and for phonetics, and suggests directions for future work that will continue to expand our understanding of the behavior of implosive sounds.

5.1 Historical and areal connections

The results of the typological survey in §3 show that implosives in languages with only one implosive sound in their inventory are more likely to pattern with sonorants than obstruents, while implosives in languages with implosive sounds at multiple places of articulation are more likely to pattern with obstruents. One possible reason for this is multiple different origins of implosive sounds.

Implosives are often reconstructed to Proto-languages based on synchronic patterns. However, there is very little work on the historical origin of implosives. If implosives have multiple possible diachronic origins, that may help explain their varying synchronic phonological behavior.

For example, it is likely that the full set of glottalized stops in Hausa (Chadic) has a different origin than the single bilabial implosive in Atchan. If the implosives in systems like Hausa are derived from a series of plosives, that may explain their behavior as patterning with obstruents.[15] While in Atchan (Kwa), perhaps there is an alternative origin of the single bilabial implosive which helps to explain its sonorant-like behavior. While there are no proposals about the historical origin of implosives in Atchan, the synchronic status of [ɗ] as an allophone of /l/ may shed some light on the possible origins of the only phonemic implosive, /ɓ/. [ɗ] appears as an allophone of /l/ when before high vowels, and in onset clusters before /r/. Perhaps the bilabial implosive originated as an allophone of a sonorant, like the relationship between [ɗ] and [l], and eventually underwent a split to become a contrastive sound due to other sound changes. More historical work on Atchan and other languages where implosives pattern with sonorants is needed to fully understand the origin of implosives.[16]

One existing proposal for the origin of implosives comes from the Bantu literature. For Bantu, Meeussen (1969) reconstructs a series of voiced and voiceless plosives, but no implosives. In numerous Bantu languages (especially northwest Bantu), the voiced plosives have become implosives in most phonological environments, though not before super-high vowels or after nasals (Maddieson & Sands 2019). In the Bantu case, implosives are derived from voiced stops. The Bantu languages in our sample show implosives patterning with obstruents or showing mixed patterning, rather than sonorant patterning. If Maddieson & Sands (2019) are right and implosives are historically related to obstruents in Bantu, the synchronic behavior of implosives in Bantu is not surprising.

Whether a difference in historical origin explains the existence of multiple different types of implosive patterning across languages will require a close historical and areal examination of a number of languages with synchronically contrastive implosives. We hypothesize that a more in-depth historical examination will at the very least help to explain the areal patterns we find, discussed in §3.2.3. Though even if we find a consistently different historical origin for implosives in languages where they pattern with obstruents versus languages where they pattern with sonorants, a synchronic explanation of the phonological behavior of implosives is also necessary to explain how learners of a language generalize over natural classes of sounds.[17]

[15] (Newman 2000:229) shows that the origin of the palatal glottalized consonant in Hausa is a **diy* sequence. This glottalized consonant is more recent than the others. The origin of the other implosive and glottalized sounds is not known, or at least not discussed.

[16] Implosives also pattern with sonorants in Kru languages. Zogbo (2012) reconstructs bilabial and alveolar implosives to Proto-Kru. Though see §2.2.3 for a note about a possible historical relationship between /l/ and implosives from Kaye et al. (1981).

[17] For a related areal and typological study, see the forthcoming work of Downing (2020) on laryngeal features in African languages.

5.2 Phonetics

Here we have focused on the phonological rather than phonetic behavior of implosive sounds across languages. However, as discussed in §1.3, we know that implosives show mixed articulatory and acoustic patterns within and across languages.

One hypothesis based on the claim that phonetic ambiguity causes variability or ambivalence in phonological patterning (Mielke 2005) is that in a language where primarily one production strategy is employed in producing ambiguous segments, phonological patterning of those segments is likely to be consistent with that phonetic strategy. For example, in a language where implosives are regularly produced with modal voicing and a lack of negative air pressure, they may be more likely to pattern with explosive obstruents than in a language where implosives are most often produced with no negative air pressure. In other words, can language-specific phonetic strategies influence phonological patterning of sounds? We encourage future work on this question as it relates to implosives, and see it as having significant implications for determining the best phonological analysis of implosive features.

Another specific phonetically driven hypothesis for why implosives sometimes pattern as obstruents and sometimes as sonorants is based on the proposal that obstruents are defined by two properties (Shigeto Kawahara and John Kingston, p.c.): 1. segments must have a narrow enough constriction or closure to give rise to 2. increased oral air pressure. Implosives meet the first criterion, by having a complete closure, but do not always meet the second. As discussed in §1.3, implosives are not always defined by negative intraoral air pressure. One hypothesis proposed by Kawahara (p.c.) is that in languages where implosives pattern with obstruents, implosives have positive air pressure. Thus, implosives in obstruent-patterning languages would meet criteria one and two for the definition of obstruents. On the other hand, in languages where implosives pattern with sonorants, implosives may have negative intraoral air pressure. Implosives in sonorant-patterning languages thus fail to meet the definition of obstruents by criterion 2. This hypothesis requires future empirical investigation, and could provide much needed insight about the relationship between the phonetic and phonological patterning of implosives.

The typological survey presented here provides a foundation for future phonetic work; it categorizes languages with contrastive implosive sounds as obstruent-, sonorant-, or mixed-patterning, pointing out languages that may help test these phonetic questions in future work.

5.3 Conclusion

Here we have presented the first typological study of the phonological behavior of implosive consonants. Despite the phonological predictions of previous phonological feature theories, in which implosives share features with obstruents but not sonorants, implosives often pattern with sonorants across languages. We have shown that there are about equal numbers of languages in our sample with contrastive implosive segments where implosives pattern with sonorants as with obstruents. The fact that implosives ever pattern with sonorants to the exclusion of obstruents has serious implications for distinctive feature theories, as discussed in §4. Additionally, the existence of languages where implosives pattern with sonorants in some phonological processes, but with obstruents in others, also restricts the possible featural analysis of implosives. Namely, in order to correctly predict their cross-linguistic patterning, implosives cannot share features with obstruents (as previously proposed) without also sharing a feature with sonorants in an innate feature theory. A broader methodological point can be learned from this study; namely, basing proposed features off of phonetics makes predictions about phonological behavior that are not always borne out, particularly when there are so few cross-linguistic studies on a class of sounds. We recommend that phonological patterning and natural classes, in addition to articulation and acoustics, be take into account when proposing featural representations of a given sound or class of sounds.

We have also shown that languages with implosives showing obstruent-patterning versus sonorant-patterning are not randomly distributed across the world. Rather, there are some strong areal patterns, such as the fact that in West Africa we see almost exclusively sonorant-patterning languages (§3.2.3). Additionally, the number of implosives in the phonological inventory correlates with overall patterning of implosives as obstruents versus sonorants (§3.2.1), and there are certain phonological processes in which implosives are more likely to pattern with sonorants than with obstruents, and vice versa (§3.2.2). The results presented here suggest a number of directions for future work, including phonetic studies on obstruent-patterning and sonorant-patterning languages to determine whether language-specific phonetics correlate with phonological patterning. Additionally, future historical examinations of the origin of implosives could shed light on the areal distribution of implosives and their mixed behavior. The typological survey presented here only considered languages where implosives contrast with voiced plosives. One might imagine that in languages where implosives do not contrast with voiced plosives, they might be more likely to show obstruent-like properties, since they might pattern as the voiced plosives in the system. Future work examining whether implosives show mixed behavior in languages where they do not contrast with voiced plosives would help to answer this question. We hope that this paper serves as a starting point for further investigation into the areal, historical, phonetic, and phonological patterning of implosive sounds across languages.

Abbreviations

Leipzig Glossing Rules are used throughout this article for language examples. Abbreviations in the body text include C for consonant, N for nasal, and V for vowel.

Appendix A

Table 22: Languages included in the typological sample and their overall patterning

Language	Language family	Overall patterning
Angas	Chadic	Obstruent
Bana	Chadic	Obstruent
Basaa (Cameroon)	Bantu	Obstruent
Chrau	Austroasiatic	Obstruent
Dangaleat	Chadic	Obstruent
Didinga	Surmic	Obstruent
Engenni	Benue-Congo	Obstruent
Epie	Benue-Congo	Obstruent
Gbaya (Sudan)	Kresh-Aja	Obstruent
Hausa	Chadic	Obstruent
Ik	Kuliak	Obstruent
Kada/Gidar	Chadic	Obstruent
Kadugli	Kadugli-Krongo	Obstruent
Karang	North-Volta-Congo	Obstruent
Komo (DRC)	North-Volta-Congo	Obstruent
Koorete	Omotic	Obstruent
Mupun	Chadic	Obstruent
Nyam	Chadic	Obstruent
Pagibete	Bantu	Obstruent
Paumarí	Arawan	Obstruent
Pulaar	North-Central Atlantic	Obstruent
Sre/Koho	Austroasiatic	Obstruent
Swazi (Swati)	Bantu	Obstruent
Syan/Saya	Chadic	Obstruent
Tarok	Benue-Congo	Obstruent
Tirmaga	Surmic	Obstruent
Aari	Omotic	Sonorant
Bade	Chadic	Sonorant
Bagirmi	Central Sudanic	Sonorant
Buwal	Chadic	Sonorant
Daba	Chadic	Sonorant
Daju	Dajuic	Sonorant
Dida	Kru	Sonorant
Ebrié	Kwa	Sonorant
Gavar	Chadic	Sonorant
Gbari	Benue-Congo	Sonorant
Guébie	Kru	Sonorant
Guinean Kpelle	Mande	Sonorant
Gumuz (Northern)	Gumuz	Sonorant
Huehuetla Tepehua	Totonacan	Sonorant
Kpelle (Liberia)	Mande	Sonorant
Laal	isolate	Sonorant

Table 23: Languages included in the typological sample and their overall patterning, continued

Language	Language family	Overall patterning
Lendu/Ngiti	Central Sudanic	Sonorant
Lika/Liko	Bantu	Sonorant
Lua/Niellim	North-Volta-Congo	Sonorant
Madi	Central Sudanic	Sonorant
Mam	Mayan	Sonorant
Mano	Mande	Sonorant
Mbuko	Chadic	Sonorant
Moloko	Chadic	Sonorant
Mumuye	North-Volta-Congo	Sonorant
Mwan/Mona	Mande	Sonorant
Noon	North-Central Atlantic	Sonorant
Nyabwa	Kru	Sonorant
Orma	Cushitic	Sonorant
Pero	Chadic	Sonorant
Sar	Central Sudanic	Sonorant
Shona	Bantu	Sonorant
Toura	Mande	Sonorant
Vai	Mande	Sonorant
Aizi	Kwa	Mixed
Arbore	Cushitic	Mixed
Belanda Viri	North-Volta-Congo	Mixed
Central-Eastern Niger Fulfulde	North-Central Atlantic	Mixed
Dagara	North-Volta-Congo	Mixed
Dan	Mande	Mixed
Degema	Benue-Congo	Mixed
Dime	Omotic	Mixed
Ega	Kwa	Mixed
Gbaya-Mbodomo	North-Volta-Congo	Mixed
Godié	Kru	Mixed
Higi/Kamwe	Chadic	Mixed
Igbo	Benue-Congo	Mixed
Ikwere	Benue-Congo	Mixed
Kalabari	Ijoid	Mixed
Kanakuru	Chadic	Mixed
Kera	Chadic	Mixed
Lagwan	Chadic	Mixed
Mambai	North-Volta-Congo	Mixed
Margi	Chadic	Mixed
Mba-ne	North-Volta-Congo	Mixed
Mbay	Central Sudanic	Mixed
Mbum	North-Volta-Congo	Mixed
Muna	Austronesian	Mixed
Ndogo	North-Volta-Congo	Mixed
Palor	North-Central Atlantic	Mixed
Southeast Ijo/Nembe	Ijoid	Mixed
Wan	Mande	Mixed

Appendix B

In Atchan nasalization processes, implosives and sonorants nasalize when immediately adjacent to another nasal sound. A set of relevant constraints is given below.

(5) IDENT-SONORANT: For each segment, assign violations according to the difference in the value of the feature [sonorant] in the output as compared to the input.

(6) *NASAL-NONNASALSON: For non-nasal each segment adjacent to a nasal segment in the output, assign violations according to the sonority value of the non-nasal segment.

(7) IDENT-FEATURE: For each output segment with at least one feature that differs from the corresponding input segment, assign one violation.

Using the MaxEnt Grammar Tool, the weights in (8-10) were determined to predict the output distribution of candidates that most closely matches the observed facts. The tableaux presented here assume the gradient sonority hierarchy presented in 4.

(8) Atchan nasal harmony: Sonorants

ɛ̃jã	ID-SON 37.6	*NAS-NONNASALSON 33.4	ID-F 7.6	**H**	**Obj**	**Pred**
a. ☞ɛ̃ɲã	.3		1	18.88	1	1
b. ɛ̃jã		.9		30.06	0	0
c. ɛ̃tã	.9		1	41.44	0	0

(9) Atchan nasal harmony: Implosives

ɛ̃ɓã	ID-SON 37.6	*NAS-NONNASALSON 33.4	ID-F 7.6	**H**	**Obj**	**Pred**
a. ☞ɛ̃mã	.1		1	11.36	1	1
b. ɛ̃ɓã		.5		16.7	0	0
c. ɛ̃bã	.25	.25	1	25.35	0	0

(10) Atchan nasal (non-)harmony: Obstruents

ɛ̃zã	ID-SON 37.6	*NAS-NONNASALSON 33.4	ID-F 7.6	**H**	**Obj**	**Pred**
a. ɛ̃nã	.25		1	17	0	0
b. ɛ̃ɓã	.15	.5	1	29.94	0	0
c. ☞ɛ̃zã		.35		11.69	1	1

We can model the behavior of implosives as patterning with obstruents with the same gradient values of the feature [sonorant], but with different language-specific weights of constraints. In Hausa full assimilation, when an obstruent or implosive is followed by another consonant, it assimilates to the features of that following consonant, resulting in gemination. Relevant constraints are given below.

(11) IDENT-SONORANT: For each segment, assign violations according to the difference in the value of the feature [sonorant] in the output as compared to the input.

(12) CODACOND: For every coda consonant segment x in the output, if its features are not licensed by a following consonant y, assign 1-a violations, where a is the sonority value of x.

(13) DEP-FEATURE: Assign one violation for every feature in the output that lacks a corresponding feature in the input.

The MaxEnt Grammar Tool was again used to determine the best weight of each constraint to derive the Hausa pattern of obstruents and implosives, but not sonorants, showing assimilation.

(14) Hausa gemination: Obstruents

zafzaafaa	CODACOND 28	ID-SON 15.2	DEP-F .9	**H**	**Obj**	**Pred**
a. zafzaafaa	.85			23.8	0	0
b. ☞zazzaafaa		.1		1.52	1	1
c. zarzaafaa	.2	.6	1	15.62	0	0

(15) Hausa gemination: Implosives

kaɗkaɗaa	CODACOND 28	ID-SON 15.2	DEP-F .9	**H**	**Obj**	**Pred**
a. kaɗkaɗaa	.5			14	0	0
b.☞kakkaɗaa		.5		7.6	1	1
c. karkaɗaa	.2	.8	1	18.66	0	0

(16) Hausa (non-)gemination: Sonorants

farkaa	CODACOND 28	ID-SON 15.2	DEP-F .9	**H**	**Obj**	**Pred**
a.☞farkaa	.2			5.6	1	1
b. fakkaa		.8		12.16	0	0
c. faɗkaa	.5	.3	1	19.46	0	0

The tableaux in (14-16) show the same set of constraints and constraint weights interacting with the universal sonority hierarchy to determine the correct patterning of obstruents, sonorants, and implosives. Due to differences in constraint weights in Atchan and Hausa, the result is sonorant-patterning in Atchan but obstruent-patterning in Hausa.

While we do not take the space to show it here, mixed behavior within a single language can also be modeled using GSR, with the language-specific weights of some constraints (such as nasalization-related constraints for Ikwere) being high enough to include implosives as targets of certain alternations, while others are low enough to exclude implosives as targets of other alternations (such as phonotactic constraints on syllable position for Ikwere).

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