The link between phonological patterning and perception of implosive consonants *

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1 Introduction

- **Observation 1:** Implosive segments are conspicuously absent from studies of phonological sound patterning and phonetic sound similarity.
  - Mielke (2012)'s acoustic and articulatory investigation of the level of similarity of 58 segments to understand why certain sounds tend to form 'natural classes'.
  - Parker (2002, 2011)'s 'complete' sonority hierarchy.
- **Observation 2:** Implosives pattern with different groups of consonants in different languages.
  - Ijo: Implosives pattern with oral stops (Williamson 1978).
  - Ikwere: Non-obstruent stops pattern as both [-obstruent] and [-sonorant] (Clements and Osu 2002).
  - Kru: Implosive /ɓ/ patterns with liquids and glides, and never with oral stops (Marchese 1979; Kaye et al. 1981; Sande 2017).
- **Driving questions:**
  - Does a speaker's L1 affect how he/she perceives implosives?
  - What are the articulatory, acoustic, and perceptual features of implosives which allow them to pattern with obstruents in some languages but sonorants in others?
  - Which other sounds are implosives most similar to?
- **Goal:** We begin to answer these questions with a series of perceptual experiments.

Roadmap

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2 Phonological patterning of implosives

2.1 Previous literature

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

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

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

- There has been very little work on the phonological patterning of implosives across languages. Two extant descriptions are presented briefly here.

- **Ijo:**

  - Williamson (1978) describes the patterning of implosives in Ijo, spoken in southern Nigeria.
  - In Ijo, implosives pattern with sonorants in some respects, but with obstruents in others.
  - **Patterning with sonorants:** In some Ijo varieties, sonorants and implosives are nasalized before nasal vowels, while obstruents are not (Williamson 1987).
    - This process also occurs in Ebrié (Bole-Richard 1983), which is not discussed further here.
  - **Patterning with obstruents:** Consonants cannot be 'stronger' than a preceding consonant in the word. The strength divisions are provided below (Williamson 1978).

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

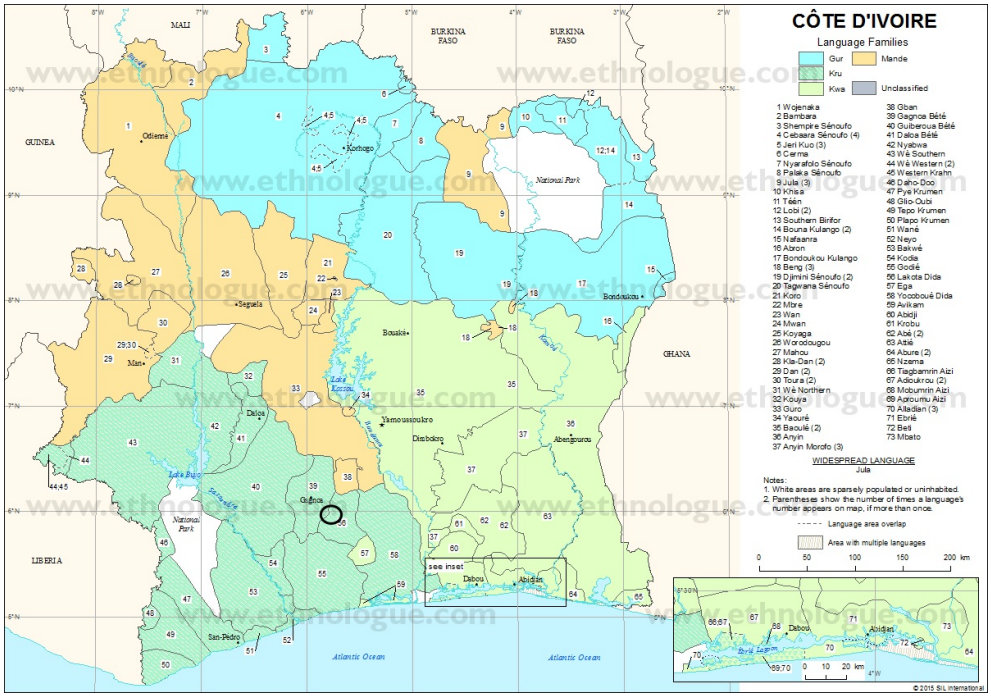
    - Note that the two implosives in the inventory, /ɓ, ɗ/, pattern with voiced plosives.

- **Ikwere:**

  - Clements and Osu (2002) describe a set of non-explosive stops in Ikwere which are articulatorily similar to implosives in that they correlate with negative air pressure and ingressive airflow, but differ in that they do not involve lowering of the larynx.
    - Despite their articulatory differences, I refer to the Ikwere non-explosives as implosives here, for lack of a better term.
  - **Patterning with sonorants:**
    1. Like Ijo, Ikwere implosives and sonorants have nasal realizations before nasals, but obstruents do not.
    2. Implosives and sonorants do not have a depressing (lowering) effect on surrounding tones.
  - **Patterning with obstruents:** Obstruents and implosives are more often present in onset than coda position in Ikwere. They may precede liquids in onset clusters, while other sonorants cannot.
    - Similar distributional restrictions are found in other African languages with implosives: Lendu, Hausa, Fula. See (Clements and Osu 2002, 337) for an overview.

2.2 Implosives in Guébie

- Background on Guébie (Kru, Côte d'Ivoire):
  - ▷ Number of speakers: ∼7,000
  - ▷ One remaining monolingual speaker
  - ▷ Most Guébie speakers speak French, many also speak other neighboring Kru languages.



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

- There is one implosive sound in Guébie: /ɓ/.
  - /ɓ/ patterns with sonorants in three respects, and never patterns with obstruents.
    1. CVCV reduction to CCV is highly likely if the second C is /l/ or /ɓ/, but not otherwise. There are no other instances of CC clusters in the language.

(1) **CVCV → CCV**

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

    2. Vowel hiatus is avoided by inserting /j/, /w/, or /ɓ/.
    3. In certain morphosyntactic environments, when an [l] would otherwise surface before a vowel followed by another [l], the first [l] surfaces as [ɓ].
       - ∗ See Kaye et al. (1981) on a similar historical change in Dida and Bete, two neighboring Kru languages.

(2)

Particle-Verb	**Reciprocal** (reduplicated verb + /-e/)	Gloss
ji-le	ji-ɓe-le-e	'know each other'

3 Experiment 1: ABX

3.1 Methodology

- ABX task
  - Participants hear three "words" and categorize the third as the same as either the first or the second word.

A	B	X
[ala]	[aba]	[ala]

  - Prompted by auditory stimuli in PsychoPy.
- Stimuli
  - A and B stimuli produced by a female speaker, and the X stimuli were produced by a male speaker
  - Stimuli are of the form [aCa] with implosives, oral and nasal plosives, and sonorants in the C position.
- Structure: The X stimuli always contain the same consonant as either A or B stimuli.
- Participants
  - 20 participants: English speakers between ages 18-22

3.2 Results

- Participants were more likely to make errors in categorizing implosives than plosives or approximants.
  - 73.4% of errors involve implosives in either X position or as a distractor.
- A logistic regression, run in Rbrul shows that the significant variables in determining whether a participant will correctly identify whether A or B is the same as sound C are as follows:
  - Sound X = aɓa: likely to be misidentified.
  - Distractor adɗa vs Sound X aɓa: more likely to be correctly identified.

	p-value	intercept
soundX=aɓa	.0445	-1.808
adɗa vs. aɓa	.0248	2.807

- Whenever the implosive ɓ was present as Sound X, participants were more likely to guess incorrectly than correctly about the sound's identity.
- The fact that the interaction between distractor sound adɗa and Sound X being aɓa made it more likely for participants to correctly choose that the Sound X was aɓa suggests that participants did not confuse sounds of distinct places of articulation. This is supported by the results for non-implosive sounds.

4 Experiments 2 & 3

To make the task more difficult, we ran two additional experiments, which we call the ABC and Mixed conditions.

4.1 Methodology

- Experiment 2: ABC Condition
  - Similar to ABX, except C stimulus distinct from A and B
    - *Why?* To make the experiment more difficult for participants than the ABX task.
  - Each trial only compares across plosives that are the same place of articulation and approximants
    - *Why?* To keep the experiment a reasonable length for each participant.

A	B	C
[ala]	[aba]	[aɓa]

- Experiment 3: Mixed Condition
  - Contains trials with ABX and ABC conditions
  - Half the trials have the third sound the same as A or B, half the trials have the third sound different from A and B
- Participants
  - ABC: 17 English speakers between ages 18-22
  - Mixed: 16 speakers between ages 18-22
    - Also: 1 speaker of Guébie, a Kru language with implosive /ɓ/ in the inventory. Results from this speaker are discussed further under Directions for Future Work.

4.2 Results

- For the ABC portion of Experiment 2 and Experiment 3, Observed/Expected values were calculated (Pierrehumbert 1993).
  - Expected: number of times implosives would be categorized as other consonants at chance
  - Observed: number of times implosives were actually categorized as each consonant
  - If O/E value is greater than 1, implosive consonant was categorized for that consonant more often than expected
- Results for the ABC experiment are presented first.

Sound A or B	Expected	Observed	O/E	P-value
aba	85/170	149/170	1.75	$1.5\text{x}10^{-7}$
apa	85/170	118/170	1.39	.002
ama	85/170	90/170	1.06	.59
ala	85/170	60/170	.706	.001
aja	85/170	46/170	.541	$8.9\text{x}10^{-9}$
awa	85/170	47/170	.553	$2.9\text{x}10^{-8}$

Table 1: Experiment 2 ABC O/E Results for Sound X=ɓ

Sound A or B	Expected	Observed	O/E	P-value
ada	85/170	151/170	1.78	$7.8x10^{-8}$
ata	85/170	115/170	1.35	.005
ana	85/170	100/170	1.18	.13
ala	85/170	63/170	.741	.006
aja	85/170	48/170	.565	$9.2x10^{-7}$
awa	85/170	33/170	.388	0

Table 2: Experiment 2 ABC O/E Results for Sound X=ɗ

- Results for the ABC trials of Experiment 3, the Mixed condition, are presented below.

Sound A or B	Expected	Observed	O/E	P-value
aba	85/170	151/170	1.77	$7.8x10^{-8}$
apa	85/170	120/170	1.41	115
ama	85/170	92/170	1.08	.466
ala	85/170	48/170	0.56	$9.2x10^{-8}$
aja	85/170	56/170	0.65	$1.1x10^{-4}$
awa	85/170	43/170	0.5	$1.5x10^{-10}$

Table 3: Experiment 3 O/E Results for Sound X=ɓ

Sound A or B	Expected	Observed	O/E	P-value
ada	85/170	147/170	1.72	$3.1x10^{-7}$
ata	85/170	120/170	1.41	.001
ana	85/170	91/170	1.07	.53
ala	85/170	63/170	0.74	.006
aja	85/170	51/170	0.6	$1.9x10^{-6}$
awa	85/170	38/170	0.44	0

Table 4: Experiment 3 O/E Results for Sound X=ɗ

- Chi-squared test were run in order to determine whether the expected (chance) versus observed number of times that a sound was chosen is significant.
  - All results were significant ($p<.01$) when comparing the number of times each sound was chosen to chance, except for the nasals.
- The results reported above are presented in bar graphs below, where the red line is at 1, and all sounds with bars above that line were chose more often than expected when compared with [aɓa] and [aɗa].
- Results for the ABC portion of Experiment 2 and Experiment 3 follow the same pattern, except that in Experiment 3 only [aɓa] is more often confused with [aja] than [ala].
  - This could be due to the results from a single participant in Experiment 3 whose responses skewed the results.

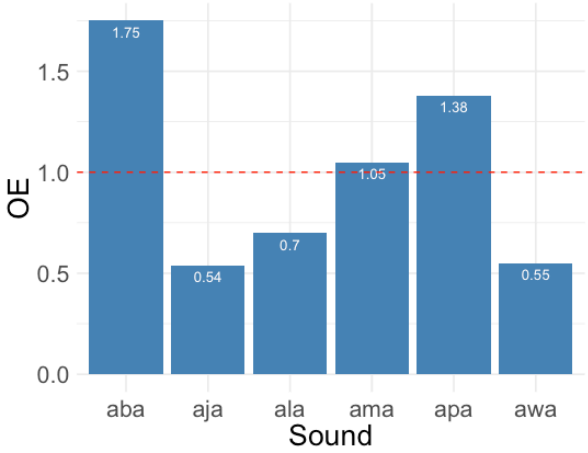


Figure 1: Experiment 2 O/E results for Sound X=aɓa

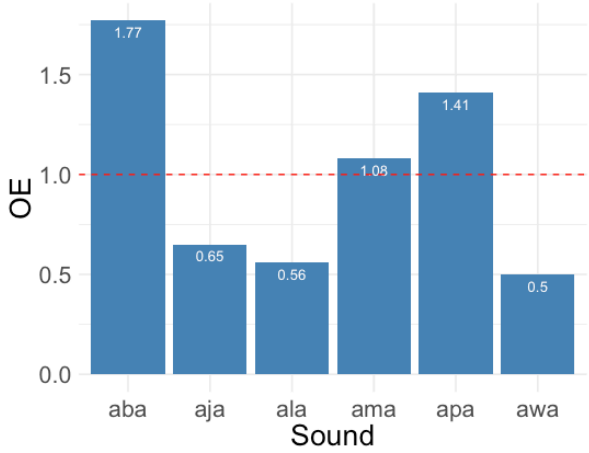


Figure 2: Experiment 3 O/E results for Sound X=aɓa

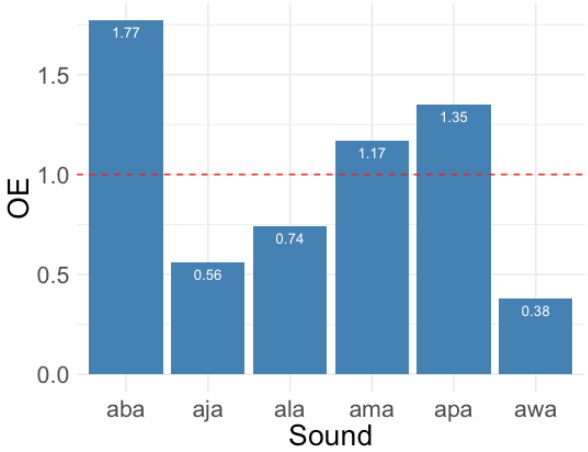


Figure 3: Experiment 2 O/E results for Sound X=aɗa

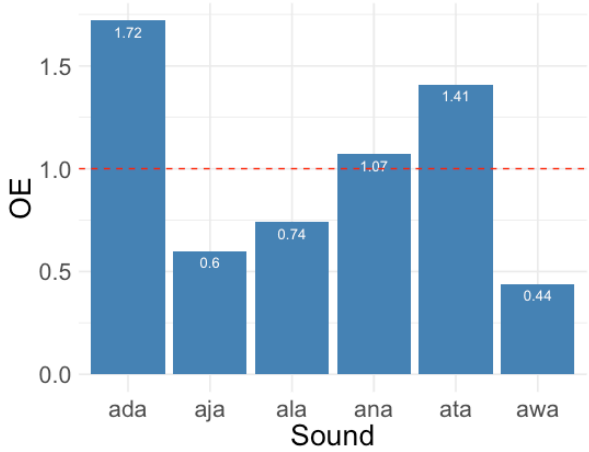


Figure 4: Experiment 3 O/E results for Sound X=aɗa

- English speaking participants were most likely to categorize /ɓ/ as /b/, followed by /p/
- /ɗ/ was most likely to be categorized as /d/, followed by /t/.

5 Discussion and implications

- Native English speakers perceive implosives as most similar to oral plosives, and do not perceive them as similar to sonorants.
  - The result is presented as a similarity hierarchy, below.

(3) **Hierarchy of consonant similarity to implosives**

ɓ: b ≫ p ≫ m ≫ l ≫ j ≫ w
ɗ: d ≫ t ≫ n ≫ l ≫ j ≫ w

- The ABC task used here to discover a hierarchy of perceptual consonant similarity can be used as a tool to examine sound similarity more generally, much like a confusion matrix.

6 Directions for future work

- The data presented here show that speakers without a native implosive/plosive contrast are most likely to categorize implosives as oral plosives at the same place of articulation.
  - However, we expect to see different results from speakers with an L1 implosive/plosive contrast.
  - Initial results from one Guébie speaker suggest that implosives are more likely to be categorized as sonorants than obstruents. This speaker most often categorized [aɗa] and [aɓa] as [awa] and [aja].
    - Recall: implosives pattern with sonorants and never with obstruents in Guébie.
    - These initial results suggest that implosives may be perceived more similarly to sonorants in languages where they pattern phonologically with sonorants, following the literature on perceptual effects of L1 phonological systems (Best et al. 2001; Tyler et al. 2014).
  - Fieldwork in Côte d'Ivoire in July 2018 will determine whether this pattern holds across speakers.
- Future work will determine whether implosives are articulated differently in languages where they pattern with sonorants than in languages where they pattern with obstruents.

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