Final obstruent voicing in Lakota: Phonetic evidence and phonological implications

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ABSTRACT

Final obstruent devoicing is a common sound pattern in the world's languages and constitutes a clear case of parallel or convergent phonological evolution. In contrast, final obstruent voicing is claimed to be rare or non-existent. Two distinct theoretical approaches to sound pattern frequency crystalize around obstruent voicing patterns. Traditional markedness accounts view these sound patterns as consequences of universal markedness constraints prohibiting voicing, or favoring voicelessness, in word- or syllable-final position, and make the explicit prediction that final obstruent voicing does not exist. In contrast, phonetic-historical accounts explain skewed patterns of voicing in terms of common phonetically-based devoicing tendencies, allowing for rare cases of final-obstruent voicing under special conditions. In this paper, phonetic and phonological evidence is offered for final-obstruent voicing in Lakota, an indigenous Siouan language of the Great Plains of North America. In Lakota, oral stops /p/, /t/, and /k/, are regularly pronounced as [b], [l], and [g] in word- and syllable-final position when phrase-final devoicing and pre-obstruent devoicing do not occur.

Keywords: Final voicing, final devoicing, markedness, Lakota, rare sound patterns, laboratory phonology.

1. Final obstruent devoicing and final obstruent voicing in phonological theory.

There is wide agreement among phonologists and phoneticians that many of the world's languages show evidence of final obstruent devoicing (Iverson and Salmons 2011). Like many common sound patterns, final obstruent devoicing has two basic instantiations: an active form, involving alternations, and a passive form, involving static distributional constraints. In languages with active final obstruent devoicing, voiced obstruents like like /b/, /d/, and /g/ are pronounced as voiceless [p], [t], and [k] in word- or syllable-final position. One language with this pattern is Czech (Šimáčková, Podlipský and Chládková 2012) as illustrated in Table 1, where words in italic are orthographic forms, followed by IPA transcriptions in square brackets.

In languages with static final obstruent voicelessness, the contrast between voiced and voiceless obstruents is neutralized in favor of the voiceless series in word- or syllable-final position, though there is no synchronic evidence of productive alternations. This pattern is illustrated by the representative Basque data in Table 2. Though Basque has a contrast between voiced /b/, /d/, /g/ and voiceless /p/, /t/, /k/, the voicing contrast is only possible in word-initial and word-medial position (Egurtzegi 2013).[1] In word-final

[1] Basque dialects differ as to whether /p, t, k/ are voiceless unaspirated or voiceless aspirated in onset position. In aspirating dialects, aspiration is limited to pre-vocalic position.

position, of the oral stops, only /p/, /t/ and /k/ are attested, though /p/ is restricted to sound symbolic words, [t] is rare, and [k] is primarily found in a handful of highly productive suffixes (e.g. *-ak* PLURAL, *-k* ERGATIVE, *-tik* ABLATIVE). Italic forms in (2) are written in the standard Basque orthography, which is phonemic: word-final /p/, /t/ and /k/ represent [p], [t], and [k] respectively.

Table 1. Final obstruent devoicing in Czech

	INITIAL	MEDIAL	FINAL
/b/	*bát se* [ba:tsɛ] 'to fear'	*chleba* [xleba] 'bread.ACC'	*chléb* [xlɛ:p] 'bread'
/p/	*pád* [pa:t] 'a fall'	*čápi* [tʃa:pi] 'stork.PL'	*čáp* [tʃa:p] 'stork'
/d/	*dát* [da:t] 'give'	*ledu* [lɛdu] 'ice.GEN'	*led* [lɛt] 'ice'
/t/	*tát* [ta:t] 'melt'	*letu* [lɛtu] 'flight.GEN'	*let* [lɛt] 'flight'
/g/	*gáza* [ga:za] 'gauze'	*kolega* [kolega] 'colleague'	*gong* [go:ŋk] 'gong'
/k/	*kát se* [ka:tsɛ] 'repent'	*žáky* [ʒa:ki] 'pupil.PL'	*žák* [ʒa:k] 'pupil'

Table 2. Final obstruent voicelessness in Basque

	INITIAL	MEDIAL	FINAL
/b/	*beldar* 'caterpillar'	*zabal* 'wide'	--
/p/	*peldo* 'wild mint'	*zapal* 'crushed'	*zap* [sound of hit, knock]
/d/	*du* 'have.3sg.PRES'	*adar* 'horn, branch'	--
/t/	*tu* 'saliva, spit'	*atal* 'section, piece'	*bat* 'one'
/g/	*gehi* 'more, a lot'	*egarri* 'thirst'	--
/k/	*ke* 'smoke, steam'	*ekarri* 'to bring'	*zutik* 'standing, upright'

Sound patterns similar to Czech and Basque active and static final obstruent devoicing have been described for many other languages. Blevins (2006a) lists over a dozen modern Indo-European languages with final obstruent devoicing, including Bulgarian, Catalan, Dutch, Lithuanian, Polish, Russian, and Zaza. At the same time, she illustrates that the sound pattern has clearly evolved independently in unrelated languages around the world, from Afar, a Cushitic language spoken in the Horn of Africa, to Awara, a Finisterre-Huon language of Morobe Province, Papua New Guinea.[2] Further, as new languages are described, new cases of final obstruent devoicing continue to be discovered: acoustic analysis confirms the sound pattern in Camuno, a Gallo-Romance language of Valcamonica (Cresci 2014) and in Ganza, an Omotic language of Ethiopia and the Sudan (Smolders 2016).[3]

Final obstruent devoicing has received a great deal of attention in the phonological literature since the understanding of this common sound pattern has important implications for phonological theory, as summarized in Iverson and Salmons (2011). One important area of research focuses on explanations for the sound pattern itself, and asks why final obstruent devoicing is a common sound pattern cross-linguistically. Two distinct theoretical approaches offer two very different answers to this question.

Under traditional markedness accounts inspired by Trubetzkoy (1939) (e.g. Wetzels and Mascaró 2001) and modern Optimality treatments (e.g. Kager 1999, Lombardi 1999), final obstruent devoicing is viewed as a direct consequence of universal phonological markedness constraints. Traditionally, voiced obstruents are marked, voiceless obstruents are unmarked, and final devoicing, as neutralization, constitutes a shift to the unmarked. In modern Optimality terms, a markedness constraint prohibiting voicing in obstruents combines with positional markedness or faithfulness constraints. As components of universal grammar, these markedness constraints determine that obstruent voicing will be generally disfavored, and particularly disfavored in final (or non-initial) position.[4] The same kinds of markedness accounts make explicit predictions that final-obstruent voicing should not exist (Kiparsky 2006, 2008): a language with /p/, /t/, /k/ regularly pronounced as [b], [d], and [g] in word- or syllable-final position is ruled out, since, under any analysis, the voiced obstruents are marked in contrast to their voiceless counterparts.

In contrast to markedness theories, phonetic-historical approaches to final obstruent devoicing, like Evolutionary Phonology (Blevins 2004, 2006a, 2006b, 2008, 2015, 2017), attempt to explain the recurrent sound pattern as phonologized instances of natural phonetic processes. Under these accounts, inspired by the Neogrammarian tradition and the early work of John J. Ohala (e.g. Ohala 1981, Ohala 1983), final obstruent devoicing is common cross-linguistically because of the way we speak and the way we perceive speech. More specifically, phrase-final laryngeal gestures, phrase-final

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[2]The description of Ingush, a Nakh-Daghestanian language of the Caucasus, reported to have final obstruent devoicing in Blevins (2006a), should be slightly modified. Following Nichols (2011:80), Ingush has only partial devoicing of voiced obstruents in word-final position. Acoustically, neutralization with the voiceless series is incomplete, though some speakers cannot perceive a contrast (Nichols 2011:8).

[3] Final obstruent devoicing can be viewed as one of five common domain-final laryngeal sound patterns. The other four are: final deaspiration, as in Marathi (Houlihan and Iverson 1979); final aspiration, as in Sierra Popoluca (Elson 1947, de Jong Boudreault 2009); final deglottalization, as in Ganza (Smolders 2016); and final glottalization, as in Standard Thai (Henderson 1964, Harris 2001). In this study, we restrict discussion to final obstruent devoicing in languages with true obstruent voicing contrasts. In true voicing languages, the voiced series show significant voiced closure durations, and the voiceless series have insignificant VOTs. See Jansen (2004) and Ringen, Beckman and Jessen (2013) for further discussion of true voicing languages, and Kakadelis (2018) for analysis of domain-final laryngeal sound patterns in 'no-voicing' languages.

[4]More abstract universalist approaches, like Government Phonology, propose empty nuclei where other frameworks have coda consonants. See, for example, Brockhaus (1995) on German final devoicing.

lengthening, final consonant non-release, along with perception and phonologization of these articulatory routines, can all give rise to voicelessness, or perception of voicelessness, in final obstruents, yielding sound patterns like those illustrated in (1) and (2) above. Within Evolutionary Phonology, nothing prohibits sound patterns of final-obstruent voicing though they are expected to be rare, due to the articulatory and perceptual factors just mentioned that yield devoicing (Blevins 2006a, 2006b).

The debate between markedness and phonetic-historical approaches has led to a special interest in languages that may show evidence of word- or syllable-final voicing. Lezgian, a Nakh-Daghestanian language, is one of these. In Lezgian, there is a contrast between plain voiceless, voiceless aspirated, voiced and glottalized stops, with plain voiceless stops alternating with voiced stops word-finally. Yu (2004) provides acoustic and phonological evidence for a synchronic process of final obstruent voicing and lengthening. In an attempt to maintain predictions of markedness theory, Kiparsky (2006, 2008) offers an alternative analysis of the Lezgian sound pattern: final voiced stops are taken as basic, analyzed as phonologically voiced geminate stops, and degeminated and devoiced in syllable onsets. Another language with possible word-final voicing of obstruents is Somali (Blevins 2006a, 2006b). However, there is a great deal of variation in how final obstruents are pronounced, and Kiparsky (2006, 2008) chooses to analyze Somali final stops as lenis unaspirated, in contrast to aspirated stops that occur syllable-initially. Though Iverson and Salmons (2011:1638) conclude that Kiparsky's proposed markedness universal "does not ultimately hold up empirically", the absence of any constraint against final obstruent voicing within Evolutionary Phonology has led us to search for more convincing examples of this sound pattern. In this context, we offer the present study of Lakota, an indigenous Siouan language of the Great Plains.

Our central argument is that Lakota has a true synchronic process of syllable-final obstruent voicing. This argument is supported by phonological and phonetic evidence that Lakota voiceless oral stops /p/, /t/, and /k/, are regularly pronounced as [b], [l], and [g] respectively in syllable-final position. Section 2 provides an introduction to the Lakota language, its speakers, and the phonology of the language, with a focus on the distribution of obstruent voicing, and a brief summary of earlier analyses. Section 3 presents acoustic analyses of Lakota segments in different positions of the word demonstrating a voicing contrast in pre-vocalic position, and a neutralization of oral stops to the voiced series in syllable-final position. Other patterns of note are optional phrase-initial devoicing, gradient phrase-final devoicing, regressive devoicing of oral stops followed by voiceless segments, categorical syllable-final fricative devoicing, and pre-sonorant oral stop voicing, though our acoustic analysis is focused on showing that /p/ and /k/ undergo final voicing. In section 4 we suggest final obstruent voicing in Lakota is a continuation of an earlier coarticulatory sound change that voiced *p, *t, *k to [b], [d], [g] intervocalically before final unstressed vowels concomitant with devoicing and loss of those vowels. This sound change was followed by a shift of *d > l in Lakota. Under this account, the historical origins for final stop voicing are tied to retiming of the final vowel gesture. Section 5 summarizes the implications of this study for phonological theory.

2. Lakota obstruent voicing patterns

2.1 A brief introduction to the Lakota language. Lakota (aka Lakhota) is an endangered indigenous language of North America. Today, it is mainly spoken on five reservations in North and South Dakota. The number of fluent speakers of Lakota has been declining steadily since the 1950s and intergenerational transmission of the language ended during the 1960s, with a very small and decreasing number of isolated families continuing to speak Lakota to their children up to the 1990s. According to the Lakota Language Consortium, since that time, the number of first language speakers has decreased from approximately 6,000 to about 2,000 speakers today (Ullrich 2018:33).

Lakota is a member of Siouan language family[5], and within Siouan, it is usually classified as a member of the Mississippi Valley subgroup. Siouan languages were spoken primarily in the Great Plains, and in the Ohio and Mississippi valleys. Lakota is a member of a dialect continuum that includes five distinguishable languages, namely: Lakȟóta, the subject of this study; Western Dakhóta (aka Yankton-Yanktonai); Eastern Dakhóta (aka Santee-Sisseton); Assiniboine Nakhóta; and Stoney Nakhóta. Some phonological differences between these languages are illustrated in Table 3.

Table 3. Some phonological differences across the Lakota-Dakota dialect continuum

Lakȟóta	Yanktonai	Yankton	Sisseton	Santee	Assiniboine	gloss
loté	**d**oté	**d**oté	**d**oté	**d**oté	**n**oté	'throat'
-ke**l**	-ke**d**	-ke**d**	-ke**d**	-ke**d**	-ke**n**	'kind of' (ADV SUFF)
blaská	**bd**aská	**bd**aská	**bd**aská	**bd**aská	**mn**aská	'to be flat & solid'
a**gl**éška-**l**a	a**gd**éška-**n**a	a**kd**éška-**n**a	a**hd**éška-**n**a	a**hd**éška-**d**a	a**kn**éška-**n**a	'lizard'

Where Lakota has /l/, it regularly corresponds to /d/ in all languages but Assiniboine, where it corresponds instead to /n/. (In final position /-n/ has diffused to former /-d/ dialects.) However, for some morphemes, like the Lakota suffix /-la/ illustrated in the word for 'lizard', unexpected *n*-forms occur in Yanktonai, Yankton and Sisseton, which are *d*-dialects. (In most instances, these can be attributed to lexical diffusion.) Note also that Lakota /bl-/ corresponds to Assiniboine /mn-/, while Lakota /gl-/ corresponds to Yanktonai /gd-/, Yankton /kd-/, Sisseton-Santee /hd-/ and Assiniboine /kn-/. More will be said about these correspondences in our discussion of the evolution of final obstruent voicing in section 4. In the subsections that follow we focus solely on Lakota.

The Lakota language can be divided into two dialects: Northern Lakota represented by speakers of the Standing Rock reservation and parts of the Cheyenne River Reservation, and Southern Lakota spoken by the Oglála and Sičháŋǧu tribes who reside on the Rosebud and Pine Ridge reservations respectively, and by some speakers from Cheyenne River (Ullrich 2018:38). Since these two dialects show virtually no phonological variation and are characterized by only a small number of lexical variants, they are treated as one for the purposes of this study.

[5] The Siouan language family is also sometimes referred to as Siouan-Catawban to include the more distantly related Catawban languages. See Ullrich (2018:33-35) for a brief summary of language relationships within this family, and Parks and DeMallie (1992) on Lakota-Dakota dialects.

Descriptive and teaching grammars of Lakota include Buechel (1939), Boas & Deloria (1941), Rood and Taylor (1976, 1996), Ingham (2003), the grammar section of Ullrich (2008), and Ullrich and Black Bear Jr. (2016). This study makes extensive use of the *New Lakota Dictionary* (Ullrich 2008, 2011, 2019), a publication of the Lakota Language Consortium. The app version of the dictionary contains over 40,000 entries, and includes not only full forms of words, and thousands of audio files, but also truncated word forms, which are important to this study.

2.2 Segment inventory and orthography. The Lakota vowel system is shown in Table 4, and the consonant inventory is shown in Table 5, following Rood & Taylor (1996) and Ullrich (2011). Here and throughout, we use the orthography of the New Lakota Dictionary (NLD) (Ullrich 2011, 2019), sometimes called the Standard Lakota Orthography. Where orthographic symbols in these tables differ from symbols of the International Phonetic Alphabet (IPA), the IPA symbol is given in square brackets.

Table 4. Lakota vowel contrasts

		Front	Central	Back
High	*oral*	i		u
	nasal	iŋ [ĩ]		uŋ [ũ]
Mid	*oral*	e		o
Low	*oral*		a	
	nasal		aŋ = [ə̃]	

Lakota has a basic five vowel system /i, u, e, o, a/ along with three nasalized vowels, including high /iŋ/, /uŋ/ and non-high /aŋ/. Another vowel symbol in use in the NLD is <A>; this symbol represents a root/stem-final vowel that alternates between /a/, /e/ and /iŋ/, and is often subject to deletion in morphologically complex forms. In addition, the acute accent is used to mark a stressed vowel in this orthography.[6] It should also be noted that in addition to the three contrastively nasalized vowels shown in Table 4, Lakota also has allophonically nasalized vowels that are due to coarticulation with a preceding or following nasal consonant (Scarborough et al. 2015). In our study of properties of oral stop consonant voicing, we do not measure stops in the context of nasalized vowels since these stops are typically nasal and voiced. Given that our study is limited to a discussion of (oral) stops adjacent to oral vowels, it only provides a partial picture of voicing alternations in Lakota.

Table 5 shows the consonant inventory of Lakota, with obstruents at the top of the table and sonorants at the bottom.

[6] For one of the earliest analyses of stress patterns in Dakota-Lakota dialects, see Shaw (1980).

Table 5. Lakota consonantal contrasts

	BILABIAL	DENTAL	ALVEOLAR	POST ALVEOLAR	VELAR	GLOTTAL
OBSTRUENTS						
Stops & affricates						
voiceless unaspirated	p	t		č = [tʃ]	k	
voiceless aspirated (or Th cluster)	ph	th		čh	kh	
voiceless with velar aspiration (or Tȟ cluster)	pȟ	tȟ			kȟ	
voiceless ejective (or T? cluster)	p'	t'		č'	k'	' = [ʔ]
voiced	b				(g)	
Fricatives					(POST)VELAR	
voiceless			s	š = [ʃ]	ȟ = [x], [χ]	h
voiceless glottalized (or S? cluster)			s'	š'	ȟ'= [x'], [χ']	
voiced			z	ž = [ʒ]	ǧ= [ɣ], [ʁ]	
SONORANTS				PALATAL		
Nasals	m		n			
Lateral		l				
Approximant	w			y = [j]		

Several comments are in order regarding the consonant contrasts in Table 5. Note that all Lakota sonorants /m n l w y/ are voiced. In contrast, the non-laryngeal fricatives all have voiced and voiceless counterparts. For the oral stops and affricates, there appear to be at least five contrastive laryngeal series: voiceless unaspirated, voiceless aspirated, voiceless with velar fricative release, voiceless ejective, and voiced. However, the voiceless aspirated, voiceless with velar fricative release, and voiceless ejective series have alternative analyses as clusters of plain voiceless obstruent + /h/, /ȟ/, and /'/ respectively (Boas and Deloria 1941:5). Since the focus of this study is the plain voiceless and voiced series of obstruents, we leave the analysis of these other laryngeal series open, and focus on contrastive (and non-contrastive) obstruent voicing in Lakota.

2.3 The distribution of obstruent voicing. Let us begin by observing a voicing contrast in fricatives. As illustrated in Table 6, the pairs /s/ vs. /z/, /š/ vs. /ž/, and /ȟ/ vs. /ǧ/ contrast in pre-vocalic (onset) position, but not word- or syllable-finally, where, as in Czech, Basque, and many other languages, there is neutralization to the voiceless series, illustrated by the bold characters in the final column. The fricative devoicing pattern exemplified in Table 6 is most obvious in full and contracted (CONT) pairs like *čháǧa* 'ice' vs. *čhá**ȟ*** (CONT). Contracted forms are the primary source of obstruent codas in Lakota, and will be discussed further in 2.4. Of importance now is to observe that the voicing contrast in Lakota fricatives is unremarkable from a typological perspective. There is a voicing contrast that occurs in single member onsets at three distinct points of articulation, and that contrast is neutralized in final position to the voiceless series.

Table 6. Lakota voiced vs. voiceless fricatives, with final devoicing

	INITIAL (ONSET)	INTERVOCALIC (ONSET)	SYLLABLE-FINAL (CODA)
/s/	*só* 'to cut sth into strings'	*pasí* 'research'	*khúskhus*[7] 'couscous'
/z/	*zomí* 'to be a schemer'	*kawázA* 'to throw sth up' *kózA* 'to wave sth'	*kawá**s*** (CONT) 'to throw sth up' *kó**s**kozA* 'to wave sth'
/š/	*šóta* 'smoke'	*itȟášoša* 'to spit sth out'	*itȟášoš* (CONT) 'to spit sth out' *tóš, toštóš* 'yes, surely, of course'
/ž/	*žó* 'to whistle'	*léža* 'to urinate'	*leš* (CONT) 'to urinate' ***leš**léžA* 'to urinate often'
/ȟ/	*ȟolyá* 'being grey'	*iyáyuȟa* 'accompany sb'	*iyáyuȟ* (CONT) 'accompany sb' *iyáyuȟya* 'constantly following sb'
/ǧ/	*ǧópa* 'to snore'	*čháǧa* 'ice'	*čhá**ȟ*** (CONT) 'ice' *čhá**ȟ**nážužu* 'ice breaks up'

Since it is rare to have a voicing contrast in fricatives without having a voicing contrast in oral stops, we expect Lakota to show a series of voiced stops. However, the voiced series of oral stops appears to have only a single member, /b/. Though there are very few contrasts between /b/ and /p/, data like that in (1) argue that voicing is contrastive for pre-vocalic bilabial stops in Lakota.[8] In addition to potentially native roots, like *bá* 'to blame sb', and *bú* 'make a deep noise', there is at least one likely loan, *bébela* 'baby' (<< Fr. *bébé*), which also suggests that Lakota /b/ was contrastive at the time of borrowing. If there was no voicing contrast between /b/ and /p/ in the language, we would expect the word to be borrowed as /pepe.../.

(1) The /b/ vs. /p/ contrast in Lakota

i. /b/	ii. /p/
bá 'to blame sb' (not widely known)	*pa-* 'by pushing'

[7] A loan is used for illustration since all known syllable-final instances of [s] in the native vocabulary derive from /z/, as in the adverb *inák'es* 'to be flush with' from /i-na-k'ezA/, /--k'ezA/ 'to be even with, flush with'.

[8] Though /bu/ and /pu/ contrast in Lakota, there is no /wu/, leading some to suggest that *bu* < *wu historically. However, since *bá* 'to blame sb' and *wa-* contrast (cf. *wa-*[1] indefinite object marker, *wa-*[2] 'with a knife', *wa-*[3] 1psg for class I verbs), the contrastive status of /b/ seems secure in some vocalic contexts. Note that Lakota *wa-*[1] corresponds to *ba-* in Dakota dialects and to *ma-* in the two Nakota languages.

bébela ‘baby’ << Fr. *bébé*	*-pi* PLURAL
bú 'make a deep noise'	*pu-* 'by pressure'
ábela ‘scattered’, *ábeya* 'scattering'	*apé* 'leaf'
kabú ‘to play the drum’ (*ka-* ‘by hitting’; *bu* ‘make a deep noise’)	*kapúza* 'to become dry in the wind' (ka- VBZ, *púzA* 'to be dry')
hibú ‘I am coming’ (archaic form of 1sg of *hiyú* 'to start coming')	*ipáblaye* 'rolling pin'

In other positions within the word, the pronunciation of /p/ as [b] is predictable, as discussed further below. Though the voicing contrast for /p/ vs. /b/ has a low functional load, it is supported by the data in (1).

For the velar stop /k/, the situation is different, and this is why /g/ is in parentheses in Table 5. Though [g] is a common and predictable allophone of /k/, there are no contexts where /k/ and /g/ contrast. In (2), we illustrate two of the three positions where /k/ has predictable allophones: pre-vocalically (2i) where it is voiceless unaspirated; and before sonorant consonants /l, m, n, w/, where it is voiced (2ii). Notice that unlike /b/, in *bébela*, in Lakota *spakéli*, English prevocalic [g] of [spə'gɛɾi] 'spaghetti' is borrowed as /k/ (2i); only when [g] is in pre-sonorant position in source words like *magnet*, or *anglais*, is it borrowed as [g] (2ii).

(2) /k/ with predictable [k] and [g] allophones

i. pre-vocalic [k]	ii. pre-sonorant syllable-initial [g]
akábu 'to drum on sth'	*glalu* 'to fan one's own'
kibá 'to regret'	*gmá* 'walnut'
-lake 'very, really'	*gnúni* 'to lose one's own' < ki-núni
spakéli 'spaghetti' << Eng.	*gwéza* 'rippled, ridged'
	magneta 'magnet' << Eng.
	šagláša 'English' << Fr. *les anglais*

Like /k/, Lakota /t/ also lacks a voiced counterpart. Recall from Table 3 that where other closely related languages show /d/, the corresponding sound in Lakota is /l/. Internal to Lakota, there is also evidence that /l/ is, in some sense, the 'voiced' counterpart of /t/. For example, consider the data in Table 7 where contracted forms of words with medial /p/, /t/, and /k/ show final [b], [l], and [g] respectively. When the preceding vowel is nasalized, the voiced consonants [b] and [g] may be realized as [m] and [ŋ] respectively, or as partially nasalized [m^b]/[m^p] and [ŋ^g]/[ŋ^k] respectively, while [l] is often nasalized and lenited in the same context. For example, compare *núŋpa* ['nõ.pa] 'two, twice' with shortened forms *núŋm* ['nõm], *núŋp* ['nõm^p] and reduplicated *núŋmnuŋpa* ['nõm^ə.'nõ.pa] 'by twos, two each'. We analyze these variants as nasalized instances of [b] and [g], and focus on oral contexts in most of the discussion that follows.

Table 7. A first glance at Lakota final stop voicing

	MEDIAL ONSET	WORD-FINAL (CODA)	MEDIAL CODA
/p/	*tópa* 'four'	***tób*** (CONT) 'four'	*tó**b**topa* 'by fours'
/t/	*napótA* 'to wear sth out with the feet' (of footwear)	*napó**l*** (CONT) 'to wear sth out with the feet' (of footwear)	*napó**l**potA* 'wearing sth out with the feet'
/k/	*šókA* 'to be thick'	*šó**g*** (CONT) 'to be thick'	*šo**g**šókA* 'to be thick'

If the alternations in Table 7 represent a unified process, the expected pronunciation of /t/ is [d], not [l]. A further piece of evidence that Lakota [l] is, in some sense, the voiced counterpart of /t/ comes from place of articulation. As illustrated in Table 5, /t/ (along with /th/, /tȟ/, and /t'/) has a dental place of articulation, while /s/, /z/, and /n/ are alveolar. Since /l/ is a sonorant like /n/, and sometimes considered a continuant like /s/ and /z/, it might be expected to have an alveolar place of articulation. However, like /t/, it is dental. In section 4 we suggest that the voicing alternations in Table 7, and the /d/ correspondent of /l/ in other Siouan languages support a historical sound change of *d > l in Lakota. In other words, the seemingly unnatural synchronic change of /p, t, k/ to [b, l, g] as opposed to [b, d, g] in Lakota is due to telescoping of two sound changes, - obstruent voicing followed by *d > l.[9]

A final context where obstruent voicing is predictable is in word-initial consonant clusters. Given that word-initial position defines the beginning of a syllable at the beginning of an utterance, we take word-initial phonotactics to define (at least partial) syllable-initial phonotactics. Word-initially, any consonant in Table 5 (except [g], which, recall, is not contrastive) can constitute a single-member pre-vocalic syllable onset. Attested word-initial clusters, shown in Table 8, are highly restricted[10]: (i) they are limited to two consonants, $\#C_1C_2$; (ii) C_2 can be either a plain voiceless obstruent, or a sonorant; (iii) if C_2 is a plain voiceless obstruent, C_1 is also a plain voiceless obstruent; (iv) if C_2 is a sonorant, C_1 is either a voiceless fricative, a voiced oral stop [b] or [g], or [m], which we interpret as a nasalized [b] /_n. In other words, singleton onsets show voicing contrasts in Lakota, but within consonant clusters, obstruents may not contrast in voicing. Independent of obstruent voicing, notice that there are no sequences of identical consonants (**), there are no fricative clusters (***), and, though C_2 may be an affricate, there are no clusters with an affricate in C_1 position and a consonant other than the laryngeals /h/, /'/ in C_2 position (*$). Lakota words exemplifying the initial consonant clusters in Table 8 are shown in (3).[11]

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[9] Within Evolutionary Phonology, synchronic patterns of this kind are expected. In other frameworks, the synchronic voicing of /p, t, k/ to [b, l, g] might be viewed as odd, since [b, l, g] do not appear to form a natural class. However, with /l/ specified as [-continuant], one can view the spell-out of a voiced, coronal, non-continuant in Lakota as [l]. For other examples where /l/ shows [-continuant] behavior, or patterns, essentially, as /d/, see Mielke (2008).

[10] For the purposes of this discussion, we follow Table 5 in treating aspirated, velar aspirated and ejective oral stops as either single segments or clusters, indicated here by parentheses in Table 8. Whether these are treated as clusters or not, the same restrictions can be seen to be in effect.

[11] There are a small number of potential initial CCC clusters limited to fast speech forms: *kčhí, kičhí* 'with sb'; *kčhíčho kičhíčho* 'to invite e.o.'; *kčhíčhopi, kičhíčhopi* 'a feast, party'; *kčhíšnala, kičhíšnala* 'with him/her/it alone'; *kčhízA, kičhízA* 'to fight e.o.'; *kčhó, kičhó* 'to invite sb, call to'. However, if /*čh*/ is an

Table 8. Initial consonant clusters in Lakota

C_2	p	t	k	č	s	š	ȟ/h[12]	m	n	l	w	’
C_1												
p	**	pt	--	pč	ps	pš	(pȟ)	**	mn	bl	--	(p’)
t	--	**	tk	--	--	--	(tȟ)	--	**	**	--	(t’)
k	kp	kt	**	kč	ks	kš	(kȟ)	gm	gn	gl	gw	(k’)
č	*$	*$	*$	**	*$	*$	(čh)	*$	*$	*$	*$	(č’)
s	sp	st	sk	sč	**	***	***	sm	sn	sl	sw	(s’)
š	šp	št	šk	šč	***	**	***	šm	šn	šl	šw	(š’)
ȟ	ȟp	ȟt	--	ȟč	***	***	**	ȟm	ȟn	ȟl	ȟw	(ȟ’)

** Absence of cluster may be due to constraint against sequence of identical consonants.
*** Absence of cluster may be due to constraint against sequence of fricative consonants.
*$ Absence of cluster may be due to constraint against /č/ as first member of cluster
Note: Symbols in parentheses may be treated as single segments, or as tautosyllabic onset clusters.

(3) Illustration of word-initial consonant clusters in Table 8

a. /p/-initial: *pté* 'buffalo cow'; *pčéčela* 'to be short'; *psá* 'reed, straw'; *pšíŋ* 'onion'; (*pȟá* 'to be bitter'); *mní* 'water', *blé* 'lake', (*p’é* 'American elm')
b. /t/-initial:
tké 'to be heavy'; (*tȟápa* 'ball'); (*t’éča* 'to be lukewarm')
c. /k/-initial: *kpá* 'to be gouged out'; *kté* 'to kill sb/sth'; *kčeyá* 'to broil sth over coals'; *ksúyeya* 'to hurt or injure sb'; *kšú* 'to bead sth'; (*kȟákA* 'to clack, clatter'); *gmá* 'walnut'; g*nákA* 'to lay sth by'; *glá* 'to loathe sth/sb'; (*k’a* 'to dig sth')
d. /s/-initial: *spáyA* 'to be wet', *stákA* 'tired (of bodypart)'; *sčú* 'be shy'; *ská* 'to be clear white'; *smiyáŋyaŋ* 'bare of any outside layer'; *sní* 'it is cold'; *slá* 'it is greasy'; *swaká* 'to be frayed at the edge'; (*s’a* 'as a habit')
e. /š/-initial: *špáŋ* 'to be burned by heat or cold'; *štákA* 'to be melting'; *ščépȟaŋ* (v. *sčépȟaŋ*) 'sister-in-law'; *škátA* 'to play'; *šmeyá* 'deeply'; *šnížA* 'to shrink, shrivel'; *šlayá* 'being bare'; *šwokÁ* 'it is overflowing'; (*š’ákÁ* 'it is strong/powerful')
f. /ȟ/-initial: *ȟpáyA* 'to lie'; *ȟtálehaŋ* 'yesterday'; *ȟčá* 'to blossom'; *ȟmiyaŋ* 'crookedly'; *ȟná* 'to groan, snort'; *ȟwayÁ* 'to cause sb to be sleepy/bored'; *ȟlí* 'to be muddy or slimy'; (*ȟ’é* 'it is rough')

aspirated affricate, then these can all be analyzed as CC clusters.

[12] Though /h/ and /ȟ/ contrast word-initially (e.g. *há* 'the skin or hide of sb, sth' vs. *ȟÁ* 'to bury sb, sth'; *hé* 'animal horns or antlers' vs. *ȟé* 'mountain, mountain ridge'), they do not contrast after word-initial/syllable-initial stops or affricates before oral vowels. In this position, [h] is found after [tʃ], and before high vowels [i] and [u]; [χ] is found before non-high back/central vowels [a] and [o], and before nasalized /aŋ/ and /uŋ/; [h] and [χ] are in free variation before [e]; and [h] is found before nasalized /iŋ/, unless it is the ablaut vowel, in which case [χ] is found, resulting in a limited case of contrast. Alternations support these phonotactics. For example, we find *phíŋkpa* 'the top of anything' from *pȟá* 'the principal part of sth' + *íŋkpa* 'tip' where *pȟ* → [ph]/_*i*.

While words like those in (3) support the analysis of clusters in Table 8 as syllable-initial clusters, further support for these as true complex onsets comes from distinct phonetic realizations of the same phonological clusters in word-medial position, across a syllable boundary. In Table 9, word-initial and word-medial complex onsets are compared with word-medial heterosyllabic clusters.

Table 9. Tautosyllabic vs. heterosyllabic CC clusters

	INITIAL TAUTOSYLLABIC	MEDIAL TAUTOSYLLABIC	MEDIAL HETEROSYLLABIC
/pt/	*ptá.ya* 'together, collectively'	*ptá.pta.ya* 'in bunches'	*ó**b.t**u* 'to be among, with' *to**b.t**ó.pa* 'by fours, four each'
/kp/	*kpé* 'to make a sharp noise'	*kpé.kpe* 'sharp staccato reports'	*i.wóg.la**g.p**hi.ča* 'it is worth talking about' *o.yá**g.p**hi.ča šni* 'it cannot be told'
/tk/	*tké* 'to be heavy'	*tke.tké* 'they are heavy'	*ȟo**l.k**i.yA* 'to make one's own grey' *kȟa**l.k**ȟá.tA* 'being hot'
/ps/	*psí.čA* 'to jump, leap, hop'	*psí.psi.čA* 'to jump, leap, hop'	*čha**b.s**íŋ.te* 'beaver tail' *sa**b.s**á.pA* 'black' (inan. pl.)
/ks/	*kse.yá* 'abruptly'	*a.pá.ksa* 'to break sth on sth' *čhaŋ.ksá* 'a club, policeman's club'	*šuŋ**g.s**á.pA* 'black horse' *sa**g.s**á.kA* 'to be dried until hard' (inan. pl.)
/pȟ/	*pȟá* 'to be bitter'	*pȟa.pȟá* 'they are bitter' (inan. pl.)	*ȟa**b.ȟ**á.pA* 'rustling sound'
/tȟ/	*tȟá.ȟča* 'deer'	*tȟa.tȟáŋ.ka* 'buffalo bull'	*ȟo**l.ȟ**ó.ta* 'gray'
/kȟ/	*kȟákA* 'to clack, clatter'	*kȟa.kȟá.kA* 'to have the quality of clacking'	*ki.čhí.ya.ȟta**g.ȟ**tag* 'biting each other repeatedly'
/pn/	*mní.žA* 'to be curled, contracted'	*mni.mní.žA* 'to be contracted'	*itȟóka**b.n**i* 'beforehand' *tȟa**b.n**ákȟapapi* 'football, soccer'
/p’/	*p’ó* 'fog, mist, steam'	*ya.p’ó* 'to exhale steam'	*čhe**b.’**í.č’i.yA* 'to gain weight' *tȟa**b.’**á.pȟÁ* 'to play baseball'
/t’/	*t’é.ča* 'to be lukewarm'	*t’a.t’á* 'to be mentally disabled'	*kȟa**l.’**í.slol.ye* 'thermometer' *á**l.’**a.ta.ya* 'whole in each case'
/k’/	*k’á* 'to dig sth'	*k’o.k’ó.ye.la* 'gulping hurriedly & noisily'	*tȟo**g.’**i.ya* 'to speak a strange language' *ka.ȟló**g.’**o.štaŋ.pi* 'vest'

In C_1C_2 onsets where C_2 is non-nasal, C_1 is consistently voiceless, but when heterosyllabic, the same clusters may show voiced codas [b], [l], [g], as in the final column of Table 9. Also, note that the possibility of a medial coda consonant, followed by an onset consonant cluster, predicts $VC_1.C_2C_3V$ sequences in the language, provided that C_1 is [l], [s], [ʃ], [χ], [b], or [g], and C_2C_3 is one of the clusters shown in Table 8. Some examples of triconsonantal clusters are: *pȟelmná* 'to smell of fire', *lešmná* 'to smell of urine' (cf. *pȟéta* 'fire', *léžA* 'to urinate', *mná* 'to have a particular smell'), *škalškátA* 'to play frolicking' (cf. *škátA* 'to play'), and *wetȟábskala* 'white blood cells' (cf. *tȟápa* 'ball', *ská* 'white').

Note that the syllable structure described for Lakota is not typologically unusual. The majority of Lakota syllables are open, ending in a vowel. Assuming two major classes of consonants, obstruents with low sonority, and sonorants with high sonority, one can view Lakota as a language that weakly adheres to a general sonority sequencing principle: within the syllable, there is a sonority plateau or rise to the nucleus, and an optional sonority fall after the nucleus (i.e. an optional coda). Under this analysis, Lakota single-member onsets are unrestricted, onset clusters are those shown in Table 8, and coda consonants are restricted to [l], [s], [ʃ], [χ], [b], and [g]. However, what has yet to be detailed is the origin of these coda consonants. With only a few exceptions, all Lakota roots, stems, and words end in vowels. As a consequence, the majority of coda consonants are found only in derived forms, where truncation or final vowel loss may occur under compounding, derivation, or inflection. A discussion of truncation is offered in section 2.4.

Before examining the status of derived coda consonants, let us summarize the distribution of voicing for obstruents that we have seen thus far. Voicing is contrastive for all fricatives in Lakota, with evidence of syllable-final fricative devoicing in Table 6. For oral stops, the situation is different. Of the oral stops, /p/, /t/, and /k/, only /p/ has a voiced obstruent counterpart, /b/. In contrast to fricative devoicing, oral stops appear to be voiced in the same contexts, independent of whether voicing is contrastive or not. In syllable-final position, /p/, /t/, and /k/ are realized as [b], [l], and [g] respectively (Table 7). Syllabification of tautosyllabic vs. heterosyllabic consonant clusters may be signaled by differences in obstruent voicing (and manner), as shown in Table 8 and Table 9, where, for example, tautosyllabic /pt/, /ps/, and /pn/ are realized as [pt], [ps] and [mn], but the same heterosyllabic sequences can be realized as [b.t], [b.s] and [b.n]. Section 3 of this paper supports these observations regarding obstruent voicing with acoustic measurements. In 2.4 we describe the truncation process which gives rise to the majority of syllable codas. Since our argument is that oral stops undergo voicing in syllable-final position, it is important to understand how truncation gives rise to syllable codas in the language. In 2.5, we briefly review other analyses of the voicing pattern in Lakota obstruents and highlight differences between our proposal and those of earlier scholars.

2.4 Truncation and syllable codas. Lakota syllables may be of the form CV, CCV, CVC, or CCVC, with representative examples in Table 10. Note that onsets appear to be obligatory, at least in careful speech: syllables that are vowel-initial phonologically are pronounced with an initial glottal stop in careful speech: *á* ['ʔa] 'armpit'; *alí* [ʔa'li] 'to climb up'; *aá* [ʔa'ʔa] 'to be moldy'. Notice also that three of the four examples of word-final consonants in Table 10 are marked (CONT), indicating that they are "contracted" forms.

Table 10. Lakota Syllable Types

	MONO- σ	INITIAL	MEDIAL	FINAL
OPEN				
CV	*šá* 'red'	*sá.pA* 'black'	*tȟó.sa.pA* 'dark blue'	*ša.šá* 'red' (INAN.PL)
CCV	*tké* 'heavy'	*tke.yá* 'heavily'	*wó.tke.ya* 'to hang things	*tke.tké* 'heavy' (INAN.PL)
CLOSED				
CVC	*sáb* 'black' (CONT)	*sab.sá.pA* 'black' (INAN.PL)	*ǧí.sab.ye.la* 'very dark brown'	*yu.šáb* 'making smth/sb dirty' (cf. *šápA*, *šáb* 'dirty')
CCVC	*gléb* 'vomiting' (CONT)	*gleb.khí.yA* 'to make sb vomit'	*í.ksab.ya* ['ʔiksabja] 'to be a burden for sb'	*a.gléb* 'vomiting on sth' (CONT)

Indeed, the majority of syllable codas in Lakota are the result of contraction or truncation, as described below.[13]

Recall from Table 6 and Table 7 data suggesting that the set of syllable codas is limited to voiceless fricatives [s], [ʃ], [χ] and to the voiced consonants [b], [l] and [g]. However, of all of the morphemes described in the *New Lakota Dictionary*, only a few appear to be truly consonant final. Two productive suffixes that appear to be consonant-final are -*kel* a derivational affix meaning 'somewhat, rather, fairly, kind of, sort of' and -*š* a suffix used with a number of word categories to express adversative (opposition or contrast) or emphasis. Some examples of words with these suffixes are given in (4). Since the suffixes occur word-finally, and both /l/ and /š/ are possible word-final codas, these suffixes show no evidence of alternations in voicing or manner, and simply support the observations we have made regarding syllable structure up to this point.

(4) Codas in the lexicon: adverbial suffixes -*kel* and -*š*

i. -*kel* 'somewhat, rather'

apȟé/apȟékel	'to wait/kind of waiting'
ečhá/ečhákel	'naturally of such quality/by nature, naturally'
naȟmá/naȟmákel	'to hide sth, sb/hiding in a way'
pasí/pasíkel	'to research/kind of researching'
yasú/yasúkel	'to judge/passing judgment hastily'

ii. -*š* 'adversative; emphatic'

iyé/ iyéš	'he/she/it'/'at least him/her/it'
naké/ nakéš	'finally now'/'now at last'
miyé/ miyéš	'I, me, it is me' /'at least I'
waná/ wanáš	'now, already'/'now indeed, at last'

[13] Another source of coda consonants is glottal stop insertion at the end of statements after vowel-final words: *alí* [ʔa'liʔ], [ʔa'li] 'he climbed up on it'.

Another set of free morphemes that appear to be consonant-final are a small class of adverbs ending in *-b*, including: *itkób* 'in the direction towards sb who is approaching', *óčib* 'by degrees, slowly, step by step, little by little' (red. *óčibčib)*, and *sakhíb* 'together'. Other *b*-final adverbs appear to be contracted forms of words ending in *-pȟa*: *akáb* 'extra, overflowing, on top of' from *akápȟa* 'on the outside of, on top'; *hakáb* 'afterwards' from *hakápȟa* 'to be the following'; *hútawab, hútab* 'downstream' from *hútawapȟa* 'somewhat farther downstream'; *ȟeyáb* from *ȟeyápȟa* 'out of the way, removed'; *isáŋm* from *isáŋpȟa* 'further than'; *ób* 'with them (more than one), together with them' from *ópȟa* 'to join in something, to be a member of something'; and *watób* 'by boat' from *watópȟa* 'to travel by boat' (< *wáta* 'boat' + *opȟÁ* 'to go by way of sth'). On this basis, we hypothesize that adverbs like *itkob* historically derive from words ending *-pȟa*, though synchronically, there is not always evidence of a longer form.[14]

In contrast to the coda consonants just mentioned, the majority of closed syllables in Lakota are the result of a process generally referred to as "truncation". Under truncation, a word (or stem) of a specific phonological shape undergoes final vowel loss, and the consonant which is rendered in final position may alternate predictably, depending on its quality and position. For example, the word *tópa* 'four' has a truncated form *tób* which can occur as an independent word, or as the first member of a derived word, as in *tóbkiya* 'in four ways, four places' and *tóbtopa* 'by fours' (RED). Truncation regularly occurs in two kinds of word-formation processes: prefixal reduplication, where the prefixed element can be viewed as a truncated base; and compounding, where the first element in the compound is a truncated base. With other word-formation processes, as detailed in Ullrich (2018), morphosyntactic properties may determine whether truncation takes place or not. Another important finding of Ullrich (2018) is that truncated forms can function as independent phonological words in various syntactic constructions. As a consequence, truncation may give rise to word-medial or word-final coda consonants. In the remainder of this section, we focus on the phonology associated with regular truncation, since truncation is the primary source of coda consonants in Lakota. We will refer to morphological environments for truncation simply as "complex words", including in this category nominal compounds and prefixal reduplication, as well as a host of derived verb forms.

Our understanding of truncation has four phonological components. First, the phonological conditioning of vowel loss (5i); second, the alternations in voicing, discussed earlier, that result when a consonant is in coda position (5ii)[15]; third, a dissimilatory process that applies to sequences of coronal consonants derived by reduplication (5iii); and finally, an optional resyllabification of consonants into complex onsets that can result in derived ejectives, aspirates, or onset clusters (5iv). This last

[14] Further work is needed to determine whether truncation of forms ending in *...pȟV, ...kȟV, ...tȟa* is generally possible, limited to adverbs, or lexically determined. At present, examples with *...kȟV* and *...tȟa* are limited to adverbs *anúŋkȟa/anúŋg* 'on both sides' and *tókȟa/tog* 'how, how is it?', while examples with *...pȟV* include the adverbs mentioned in the text, as well as verbs *ičȟápȟA/ičȟáb* 'to get accidentally stabbed', *mničȟópȟA/mničȟób* 'to wade in water'.

[15]Truncation, voicing, and regressive- and phrase-final devoicing (see 3.1) results in voiceless oral stop/nasal stop variants when the nuclear vowel is nasalized, since a voiced stop after a nasalized vowel is realized as a (voiced) nasal stop. For example, truncated variants of *núŋpa* 'two' are *núŋp* [nõp] and *núŋm* [nõm] < [nõb].

process is supported by two facts: (i) the only consonant clusters that appear to show optional resyllabification are clusters that are allowed word-initially; (ii) the devoicing patterns can only be explained by resyllabification since a medial stop coda in V**C**.CV is typically voiced, as we show in section 3.

(5) Understanding truncation as prosodic morphology

i. Truncation.

If a Lakota form ends in /...VC_fV_f/, where C_f is a possible coda consonant, then:

a. ...$VC_fV_f \rightarrow$ ...VC_f when it is the first member of a complex word

a'. $VC_fV_f \rightarrow$ ...VC_f in isolation, provided that V_f is unstressed (optional)

ii. Coda voicing constraints.

In syllable coda position:

b. Fricatives devoice:

ǧ → ȟ   ž → š   z → s

b'. Oral stops and affricates voice:

p → b   t → l

k → g   č → l

iii. Dissimilation (in reduplication only/morphophonemic).

c. Heterosyllabic lateral + coronal consonant clusters dissimilate:

l.T → g.T, where T is a coronal consonant

(See Section 4 for further discussion)

iv. Optional resyllabification (fast speech, variable).

d. In $VC_1.C_2V$ where C_1C_2 is a possible syllable onset:

$VC_1.C_2V \rightarrow V.C_1C_2V$ (with regressive devoicing as per Tables 8, 9)

The patterns described in (5i-iii) are illustrated in Table 11 with relevant reduplicated and compound forms. In this Table 'n.a.' means 'not applicable'; -- indicates a predicted but unattested form, and (?) indicates a resyllabified form that may be indistinguishable from the original complex word, since no regressive voicing assimilation distinguishes the complex onset from the coda-onset CC cluster. Notice that, in word-medial position, triconsonantal clusters like /šmn/ and /ȟsn/ are found. Since only a single consonant is allowed in the coda, all medial CCC clusters must be syllabified as C.CC, with a simple coda followed by a complex onset.

Table 11. Illustrating the phonology of truncation

	5ia'	5ia	5ii	5iii	5iv	
BASE	simple wd truncation	complex wd truncation	coda voicing	cluster diss.	resyllab. (optional)	2nd base of complex wd
okáspA 'to sink'	n.a. (...CCV#)	n.a. (...CCV#)	n.a.	n.a.	n.a.	n.a.
tȟaǧé 'saliva'	n.a. (...´V#)	*tȟaȟ.glá.tȟA* 'to chew cud'	ǧ → ȟ	n.a.	n.a.	*gla.tȟÁ* 'to chew one's own'
šaké 'nail,claw'	n.a. (...´V#)	*šag.tȟúŋ* 'to have claws'	k → g	n.a.	*ša.ktȟúŋ*	*tȟúŋ* 'to have sth'
sápA 'black'	*sáb*	*sab.sá.pA* 'black' (IN.PL)	p → b	n.a.	*sa.psá.pA*	RED
čhápa 'beaver'	*čháb*	*čhab.síŋ.te* 'beaver tail'	p → b	n.a.	*čha.psíŋ.te*	*síŋte* 'tail'
ȟótA 'gray'	*ȟól*	*ȟol.ȟó.tA* 'gray' (IN.PL)	t → l	n.a.	n.a.	RED
šókA 'thick'	*šóg*	*šog.šó.kA* 'thick' (IN.PL)	k → g	n.a.	*šo.kšó.kA*	RED
tȟóka 'enemy, alien'	*tȟog* 'different, foreign'	*tȟog.'í.yA* 'to speak a foreign language'	k → g	n.a.	*tȟo.k'í.yA*	*íyÁ* 'to speak'
lúta 'red, scarlet'	--	*lul.yÁ* 'to dye sth red' *lug.lú.ta* 'red' (INAN.PL)	t → l t → l	n.a. ll → gl	n.a. *lu.glú.ta* (?)	*-ya* CAUS RED
šéča 'dry'	*šél*	*šeg.šé.ča* 'dry' (INAN.PL)	č → l	lš → gš	*še.kšé.ča*	RED
pȟéta 'fire'	*pȟél*	*pȟel.čhó.la* 'without a fire'	t → l	n.a.	n.a.	*čhóla* 'without'
wáŋčala 'only once'	--	*wáŋčagčana* 'only once each time'	n.a.	lč → gč	*wáŋ.ča.kčana*	RED
léžA 'to urinate'	*léš*	*leš.lé.žA* 'to urinate often' *leš.mná* 'smell of urine'	ž → š ž → š	n.a. n.a.	*le.šlé.žA* (?) n.a.	RED *mná* 'to smell'
máza 'metal'	--	*mas.kȟó.ka* 'can'	z → s	n.a.	n.a.	*kȟoká* 'keg'
čháǧa 'ice'	*čhaȟ*	*čhaȟ.sní.yaŋ* 'ice cream'	ǧ → ȟ	n.a.	n.a.	*sniyÁŋ* 'to cool sth off'
tȟaló 'meat'	n.a.	*tȟal.'á.gna.ke* 'rigid goldenrod'	n.a.	n.a.	n.a.	*agnákA* 'to lay sth on'

Due to truncation in reduplication and compounding, triconsonantal sequences are not uncommon, and support our view that voiced [b], [l] and [g] are codas, since word-initial clusters are limited to two consonants (see Table 8 and footnote 11): *aǧúya***bsk***uyela* 'Danish, cake' from *aǧúyapi* 'bread' + *skúyela* 'sweet'; *wetȟá***bsk***ala* 'white blood cells' from *wé* 'blood' + *tȟápa* 'ball' + *ská-la* 'white'; *tȟa***bšk***átA, tȟa***bšk***ál* 'playing basketball' from *tȟápa* 'ball' + *škátA* 'to play'; *pȟe****lmn****á* 'to smell of fire' from < *pȟéta* 'fire' + *mná* 'to smell of sth'; *wašíl****ȟp****aya* 'garbage, trash' from *wa-* indef.obj + *šíčA* 'bad' + *ȟpáyA* 'to lie, be lying'.

It is worth stressing here that the phonological properties detailed in (5) for truncation are regular and, as far as we can tell, productive. New compounds like those in Table 11 for *čhaȟ.sní.yaŋ* 'ice cream', *ağúyabskuyela* 'Danish (pastry)', and *wethȟábskala* 'white blood cells' follow the same patterns as arguably older compounds that refer to indigenous culture items like *tȟal'ágnake* 'rigid goldenrod' (a plant used to lay meat on), and *čhábsiŋté* 'beaver tail' (used to comb hair). A further argument for the productivity of final obstruent voicing is that it occurs, not only in the lexical truncation processes described here, but also in post-lexical vowel-dropping described as a feature of rapid speech by Rood and Taylor (1996:447): "Also characteristic of rapid speech is the dropping of unstressed word-final vowels... In these examples, note that *p* and *k* are voiced to *b* and *g* when they come to stand before a consonant."

Clearly Lakota is not a language like Czech or Basque in which all obstruents are devoiced in the coda. Devoicing is found for the fricatives /z/, /ž/ and /ğ/ (5b), but the oral stops /p/ and /k/ become voiced [b] and [g] respectively, while /t/ and the affricate /č/ are both pronounced as [l]. Since the existence of phonological coda obstruent voicing is debated, section 3 of this paper provides acoustic evidence for the patterns we have just described. More specifically, we demonstrate that the sounds transcribed as [b] and [g] are often voiced, that they have the closure duration, burst properties and low energy values of oral stops, and that where they are voiced, their voicing is best viewed as a consequence of voicing of coda stops. Before turning to this evidence, we briefly review previous analyses of Lakota voicing patterns, and highlight details that distinguish our approach from previous ones.

2.5 Previous analyses of Lakota voicing patterns.

The analysis presented above agrees in most respects with that presented in Rood and Taylor (1985) and Rood and Taylor (1996). They describe /b/ as a marginal phoneme, and discuss the [b] and [g] as positional variants of /p/ and /k/ respectively when final vowels are dropped or words are reduplicated. In particular, they say that "When vowel dropping (of any origin except possibly the fast speech phenomena illustrated in section 4.3.1.2.) places /p t č k/ in word-final position or at an internal boundary between linguistic elements, these become [b], [l], [l], [g], respectively" (Rood and Taylor 1996:449).[16]

In contrast, Rankin (2001) and Rood (2016) take a very different view of the oral stop voicing process from historical and theoretical perspectives respectively. Under both accounts, oral stops are lenited to sonorants in syllable-final position. Rankin (2001:5) suggests a sound law whereby syllable-final stops become sonorants by first becoming nasals, and then, shifting to oral stops after oral vowels. Rood (2016) instead uses a

[16] Rood & Taylor (1996:449) continue: "When a nasalized vowel precedes these sounds, they may further shift to a nasal consonant...." Recall that we are restricting our attention to oral syllables in this study, partly for reasons of time, but also because our preliminary findings are that stops are sometimes only partially nasalized in this context, and measuring acoustic properties is more complex than examining those following oral vowels.

theoretical device, the feature [SONORANT VOICE] (Rice 1993), which is assigned to oral stops in coda position. Rood's argument that voiced stops [b] and [g] are sonorants seems to have four parts. First, since /t/ and /č/ are realized as [l], a sonorant, in the coda, [b] and [g] should be sonorants too. Second, since [b] alternates with [m] in Lakota in nasal contexts, it should be a sonorant. Third, consonant lenition is common in coda position cross-linguistically, so "Since our target sounds are in coda position, we should therefore look for a way to declare their voicing to be lenition." (Rood 2016:246). Finally, Rood claims that, like sonorants in many of the world's languages, voicing of [b] and [g] (but not [l]) is variable. Evidence for this variability "comes from the informal observation that [b] and [g] in coda position often seem to match the voice phonetics of the following consonant." (Rood 2016:249). Since Rood (2016) treats [b] and [g] as sonorants, not obstruents, Lakota does not violate the universal markedness constraints discussed in section 1 which give rise to common obstruent devoicing, and prohibit obstruent voicing in the coda.

The most important difference between our account and all of the previous studies of Lakota voicing we are aware of, including those just mentioned, is that we provide acoustic evidence in section 3 for the impressionistic descriptions of a range of voicing patterns in the language, including voicing of oral stops in coda position.

3. Phonetic analysis of Lakota stop voicing patterns

Despite its endangered status, Lakota is well documented in comparison to most indigenous languages of North America. This is especially true where audio recordings are concerned. The third author of this paper has made recordings of over 400 native speakers between 1992-2018, including hundreds of hours of narratives and dialogues, and has also collected recordings of several dozen speakers from other sources. Given that there are only about 2,000 speakers today, this corpus may represent the speech of 10-20% of the Lakota speech community. While we have listened to some of these recordings, and analyzed voicing patterns in running speech from a handful of them, the central study of voicing in this paper is based not on recordings of natural running speech, but on studio recordings of native speakers that form part of the database of *The New Lakota Dictionary*, published by the Lakota Language Consortium (Ullrich 2011). Before saying more about this dictionary, a general comment is in order. Language documentation can take many forms, but a general piece of advice to those working on endangered languages is to create documentation that can be used for multiple purposes. Even if one has no interest in phonetics or phonology, creating high-quality audio recordings allows future scholars to do research in these areas. In this context, *The New Lakota Dictionary*, a descriptive lexicographic work with multiple purposes, including language documentation, language pedagogy and language revitalization, is exemplary. The high-quality recordings of *The New Lakota Dictionary* are of great value to the scientific community, and without them, the current research would not be possible.

The New Lakota Dictionary (NLD) currently offers approximately 52,000 sound files from eight native speakers on its smartphone app representing 28,000 dictionary headwords, with about 95% of the audio files found in pairs, spoken by the same male and female native speakers. Though the audio files in the dictionary application are compressed OGG files, not ideal for acoustic analysis, the Lakota Language Consortium was extremely kind to offer us access to a subset of the original uncompressed audio WAV files. These recordings made in a professional sound studio with control room constructed specifically for the Lakota Dictionary project are of very high quality. The detailed phonetic analysis of Lakota stop voicing presented in this section is based entirely on these recordings. For almost every word examined, there are two tokens: one spoken by Ben Black Bear, Jr. from the Rosebud Reservation, indicated by (M) after the token; and one spoken by Iris Eagle Chasing from the Cheyenne River Reservation, indicated by (F) after the token. Many people consider these two speakers to be the most competent and literate native speakers of Lakota.

The New Lakota Dictionary recordings were made by prompting speakers with words as they are written in the dictionary. A possible complication for this study is that pronunciation of voiced vs. voiceless stops in the coda could have been influenced by spelling. While this possibility cannot be ruled out, two observations suggest that pronunciations of the two speakers are natural and not influenced by spelling. First, the patterns we discuss below do not always follow spelling conventions: for example, in *sabsápa* <b> is typically pronounced as voiceless though it is spelled with the symbol for a voiced stop (an alternative spelling is *sapsápa*). Second, both speakers have high levels of phonological awareness, and commented when spellings did not fit their phonological intuitions. Both speakers were encouraged to say words in the way that was most natural to them. After recording sessions, if a speaker was uncomfortable with an audio file because it did not sound natural or did not feel right to them, that audio file was deleted.

Another issue that could influence pronunciation is that words recorded for the dictionary were spoken at a relatively slow rate, clearly and in isolation or as part of two-word phrases. Our results must be interpreted, then, as results relating to the phonology of clear speech.

The corpus compiled specifically for this study has a total of 611 words: 304 distinct words with two tokens each, spoken by male and female speakers + 2 distinct words spoken only by the male speaker, + 1 distinct word spoken only by the female speaker. From these 611 words, a database of oral stops was created including: 631 voiceless stops (<p> = 150, <t> = 196, <k> = 285); 584 voiced stops (<b> = 285, <g> = 299); and 14 ejectives (<p’> = 6, <t’> = 4, <k’> = 4). In addition, we included 111 instances of glottal stop, as we were particularly interested in the realization of coda stops before a glottal stop (see below). Of the 1215 oral voiceless and voiced stops (excluding ejectives and glottal stops), 225 intervocalic tokens (between oral vowels) were used to establish voicing categories (see below). The remaining 841 oral stops that were not intervocalic were subject to analysis based on the established voicing categories. Given our initial hypotheses that final coda voicing might be masked by phrase-final devoicing and possible assimilation to following voiceless obstruents, an attempt was made to include tokens where this masking effect might be absent, including word-final stops that were not phrase-final and syllable-final stops followed by glottal stop. All words were orthographically transcribed following the NLD spelling conventions. The transcriptions were then converted to SAMPA for automatic segmentation of the audio files using the *WebMAUS* application (Kisler et al. 2017) set for “Language independent (SAMPA)”, and subsequently hand-corrected as needed.

Given our central interest in determining whether Lakota shows final obstruent voicing of /p/ and /k/, the first part of the phonetic study, summarized in 3.1, was focused on the question of whether /p/ and /k/ show phonetic voicing word-finally and more generally, in syllable-final position. With positive evidence of syllable-final voicing, we turned our attention to the question of whether these voiced segments still had properties of oral stops. This was necessary in order to rule out interpretations of voicing as a secondary feature of lenition, where voiced codas might be interpreted as fricatives or glides. In 3.2 we present evidence that coda [b] and [g] have acoustic properties of oral stops, including significant closure durations, absence of fricative noise, release bursts, and low energy levels typical of oral stops. Together, acoustic evidence for voiced [b] and [g] in the coda and acoustic evidence for oral stop production of these segments support the view that Lakota has a sound pattern of oral stop coda voicing for /p/ and /k/.

3.1 Evidence for voicing in oral stops: An analysis of auto-correlation coefficients

The corpus for this study were 876 oral stops extracted from the 611 word files from the original NLD audio WAV recordings. The central goal was to determine if there is a bimodal distribution of voicing in the data (voiceless vs. voiced), as described in phonological analyses, and, if so, to determine the distribution of each category.

For each segment in the corpus, the auto-correlation (AC) peaks were calculated with the program EMU (Harrington 2010 for the legacy version, Winkelmann 2017 for the R package *emuR*), using the ESPS method with a frame spacing of 10 ms., a window length of 7.5 ms. and pitch ranges between 60-400 Hz for the male speaker and 90-600 Hz for the female speaker. This yielded a total of 6921 measurements with a voicing coefficient between 0 and 1 at each time point, 0 standing for no correlation (voiceless) and 1 for perfect correlation (voiced). Then, the median value of the AC coefficients of all measured time points within a given stop was calculated for all the stops in the corpus.[17]

The statistical analysis was carried out in R (R Core Team 2019). We ran a binomial linear mixed effects model that used the AC coefficients (continuous variable: probability of voicing) to predict the voicing label (binary categorical variable: voiceless or voiced) with the R function glmer() (from the R package "lme4", Bates et al 2015). As random effects, we had inteceps for speakers. The intervocalic context was the only clear phonological context where the voiced vs. voiceless opposition appeared to be secure. Given this, we trained the binomial linear mixed effects model on intervocalic stops (225

[17] Regarding the preference for the metrics we selected (AC coefficients) over others (percent of voicing into closure or absolute voicing duration), we chose to perform measurements of AC coefficients during the whole stop closure with the understanding that they provide information that is comparable to that provided by percent of voicing into closure, with the additional benefit of the reduction of the degrees of freedom of the researcher, thus reducing the risk of a false positive. We selected the median over the mean, in part, to avoid skewed results due to potential artifacts or sub-par segment alignments. The results of this method should not differ greatly from those of methodologies in other works on voicing in endangered languages (e.g. Coetzee & Pretorius 2010), where closure duration and voicing into closure are measured (often by hand, which might yield complications regarding the marking of boundaries), and then, the percentage of voicing into closure is calculated. Segments with a voicing over closure percentage of over 50% are considered voiced, and those below 50%, voiceless. In our study, the median of all measurements of a given stop (performed at each 10 ms.) would mark 50% of the distribution: if that point is over .5, then the segment is considered voiced, while segments below .5 are considered voiceless.

tokens). **Figure 1a,b** provide waveforms and spectrograms illustrating the intervocalic voiced versus voiceless contrast for /b/ vs. /p/ (here and throughout, <p:> in the transcription line indicates pause). An AUROC test (Area Under the Receiver Operating Characteristic curve, see Fawcett 2006) of the model predictions performed with the function auc() (R package "pROC", Robin et al 2011) resulted in 0.8871 (0.5 being the chance threshold and 1 being the point of perfect prediction). A model with random intercepts for speakers and words showed a lower AUROC coefficient (0.8655) than the model with random effects only for "speaker", and it was thus disregarded. The model showed no singularities or any other obvious deviations from the model assumptions. Based on the voicing values of intervocalic stops, we predicted response values between 0 and 1 (0 being fully voiceless and 1 fully voiced, with the categories been divided by 0.5) for the full data set grouped by the phonological context of each of the analyzed stops.

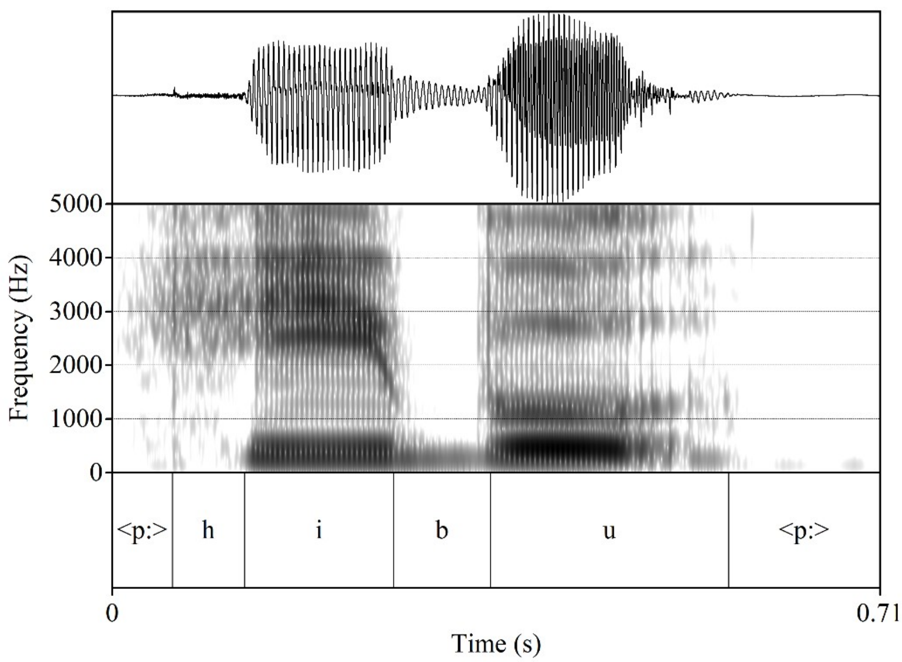


Figure 1a - Lakota contrast between /p/ and /b/ in intervocalic position: hibú (F) 'I am coming'.

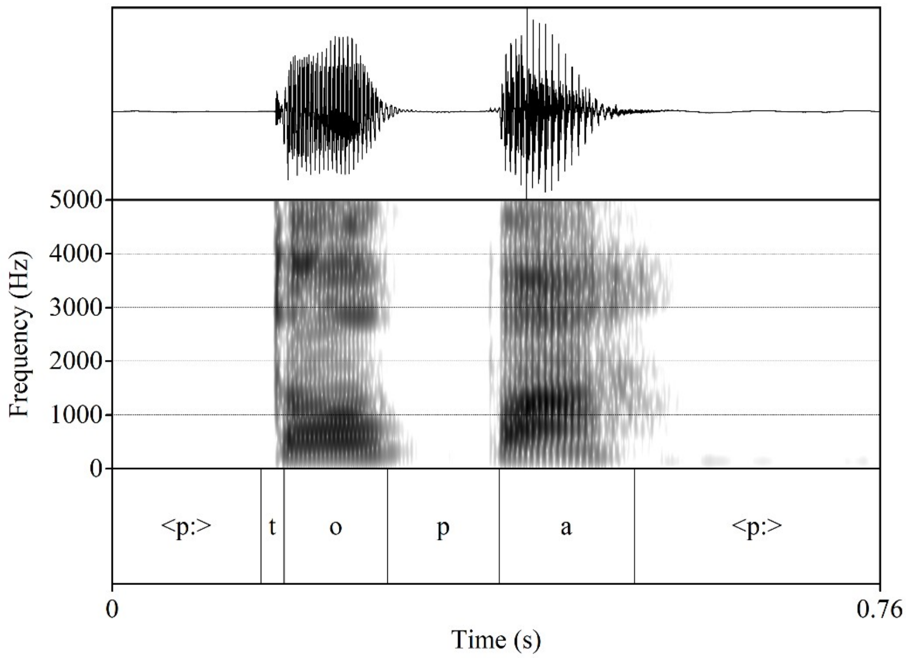


Figure 1b - Lakota contrast between /p/ and /b/ in intervocalic position: topa (F) 'four'.

In addition to the intervocalic stops used to train the model, the analysis of phonetic voicing of Lakota stops was applied to three different general phonological contexts: word-initial stops, word-internal stops at the end of a morpheme which constitute word-internal codas, and word-final stops.

Lakota word-initial stops /p/ vs. /b/ are considered to have a voicing contrast in the literature, and thus we analyzed word-initial voiced and voiceless stops separately by using annotation labels that follow the NLD transcription of each word. A Hartigans' dip test (Hartigan & Hartigan 1985) performed on word-initial stops transcribed as voiceless (102 tokens in our dataset) suggested a unimodal distribution (p-value = 0.8041), with results summarized in **Figure 2a**. However, applying the same test to word-initial stops that are written as <b> or <g> in the dictionary strongly suggested a bimodal distribution (p-value $< 2.2 \times 10^{-16}$).[18] **Figure 2b** shows word-initial stops that are written as voiced <b> or <g> in the dictionary: while some of these are clearly voiced, most were produced without voicing according to our model. Since all word-initial stops in this corpus were taken from words spoken in isolation, we interpret this result as evidence for optional devoicing of phrase-initial stops.

In contrast to word-initial stops, word-medial morpheme-final stops in Lakota function as codas, and are thought to have predictable voicing, though there is debate as to if and where final obstruent voicing occurs (see section 2). For the word-medial, morpheme-final stops in our corpus which are analyzed as codas (361 tokens), Hartigans' dip test suggests a bimodal distribution (p-value $< 2.2 \times 10^{-16}$), as shown by the histogram

[18] Initial [b] and [g] are rare in Lakota. There were only 38 tokens in our data-base, including words with initial <gl> clusters, where voicing of [g] is predictable and allophonic, as described in section 2.

in **Figure 2c**. However, dividing this single context into three sub-contexts based on the nature of the following segment yields different distributions.

Recall from section 2 that morpheme-final stops preceding /p, t, k, tʃ, s, ʃ, χ, h/ can be resyllabified as complex onsets, in which case, the entire cluster is expected to be voiceless (5.iv). **Figure 2d** shows hypothesized resyllabified morpheme-final stops (203 tokens, p-value = 0.3001) with values close to 0, supporting the analysis of morpheme-final coda stops as typically voiceless in this context. At the same time, over 40 tokens maintain voicing, suggesting that, although regressive devoicing (with resyllabification) is the norm in this context, it is not obligatory. (An alternative analysis without resyllabification is also possible: regressive devoicing optionally yields voiceless clusters in these contexts.) To highlight the possibility of a voiced coda preceding a voiceless consonant /p, t, k, tʃ, s, ʃ, χ, h/, we offer the spectrograms in **Figure 3a,b**.

Complementary contexts are those where morpheme-final stops in coda position precede /l, m, n, j, w/ or glottal stop. Let us first consider codas followed by one of the voiced sonorants /l, m, n, j, w/. Under our analysis, these codas undergo coda stop voicing (5.ii.b'), and are expected to be voiced, since there is no contextual devoicing that occurs in this context. **Figure 2e** shows morpheme-final coda stops before sonorants (123 tokens, p-value = 0.9697), with values close to 1 and unimodal distribution, supporting an analysis of final stops as voiced in this context. Spectrograms in **Figure 3c,d** offer examples of this sound pattern. Though regressive voicing from following /l, m, n, j, w/ might be suggested, the results summarized in **Figure 2f** and **Figure 2g** provide further support for a general process of coda stop voicing.

Figure 2f shows morpheme-final coda stops before glottal stop (35 tokens, p-value = 8.266×10^{-5}) suggesting bimodal distribution. While the majority of tokens are fully voiced, there are 10 fully voiceless tokens, which we interpret as instances of the optional fusion/resyllabification of [b.ʔ], [g.ʔ] to onset [p'], [k'] respectively included under (5.iv), and illustrated in Table 11 by variants *tȟog.'í.yA*, *tȟo.k'í.yA* 'to speak a foreign language'. To illustrate the sequence of voiced stop in the coda followed by glottal stop, we offer the spectrograms in **Figure 3e,f.** Since glottal stop is voiceless, the voicing of oral stops in the coda preceding glottal stop must have another source. We argue that the source is coda stop voicing (5.ii.b').

The results tabulated in **Figures 2c-f** support our analysis in section 2. Oral stops /p/ and /k/ are voiced in the syllable coda: when followed by a voiceless obstruent or /h/, they are usually devoiced and resyllabified, forming complex onsets; when followed by glottal stop, optional fusion may give rise to voiceless ejectives.

Further support for the process of obstruent voicing in the coda is found in the last distributional category of word-final (and phrase-final) oral stops. The dip test performed on word-final stops (150 tokens) suggested a bimodal distribution (p-value < 2.2×10^{-16}). Further, **Figure 2g** shows that, among these, there are more stops categorized as voiced than as voiceless. Since all stops in word-final position are analyzed as phonological instances of /p/ or /k/, voicing in this context can be interpreted as a consequence of coda-voicing (5.ii.b'). Another interesting aspect of word-final stops visible in **Figure 2g** is that there is a greater proportion of tokens in the intermediate prediction values. Given that all of our word-final tokens were also phrase-final, we interpret this as evidence of a gradient phrase-final devoicing process. In phrase-medial position, where a word-final stop is followed by something other than a voiceless obstruent, it is voiced, as predicted by (5.ii.b'). To highlight the common occurrence of voiced oral stops word-finally, we offer the spectrograms in **Figure 4.** Further discussion of acoustic properties of coda [b] and [g] is offered in section 3.2.

Overall, our acoustic analysis of voicing in Lakota stops suggests that stop voicing is contrastive intervocalically and word-initially, but is non-contrastive elsewhere. The distribution of phonetic voicing in Lakota oral stops supports an analysis of phonological syllable-final voicing of /p/ and /k/ to [b] and [g] respectively (5.ii.b'). In addition to coda-voicing, four distinct devoicing processes are observable in the data. First, in phrase-initial position, there is often devoicing of (underlying) voiced stops (Figure 2b). Second, in phrase-final position, coda-voicing can be obscured by gradient phrase-final devoicing (Figure 2g). Third, in phrase-medial position, a regular process of regressive obstruent devoicing is triggered by the class of voiceless sounds /p, t, k, tʃ, s, ʃ, χ, h/, which, under our analysis, can be related to resyllabification (5.iv). A final optional process that can yield voicelessness is fusion/resyllabification of [b.ʔ], [g.ʔ] to onset ejectives [p'], [k'] respectively (5.iv). While all of these processes (with the possible exception of phrase-initial devoicing) have been described in the literature, this is the first study presenting acoustic evidence in support of syllable-final oral stop voicing together with these devoicing processes.

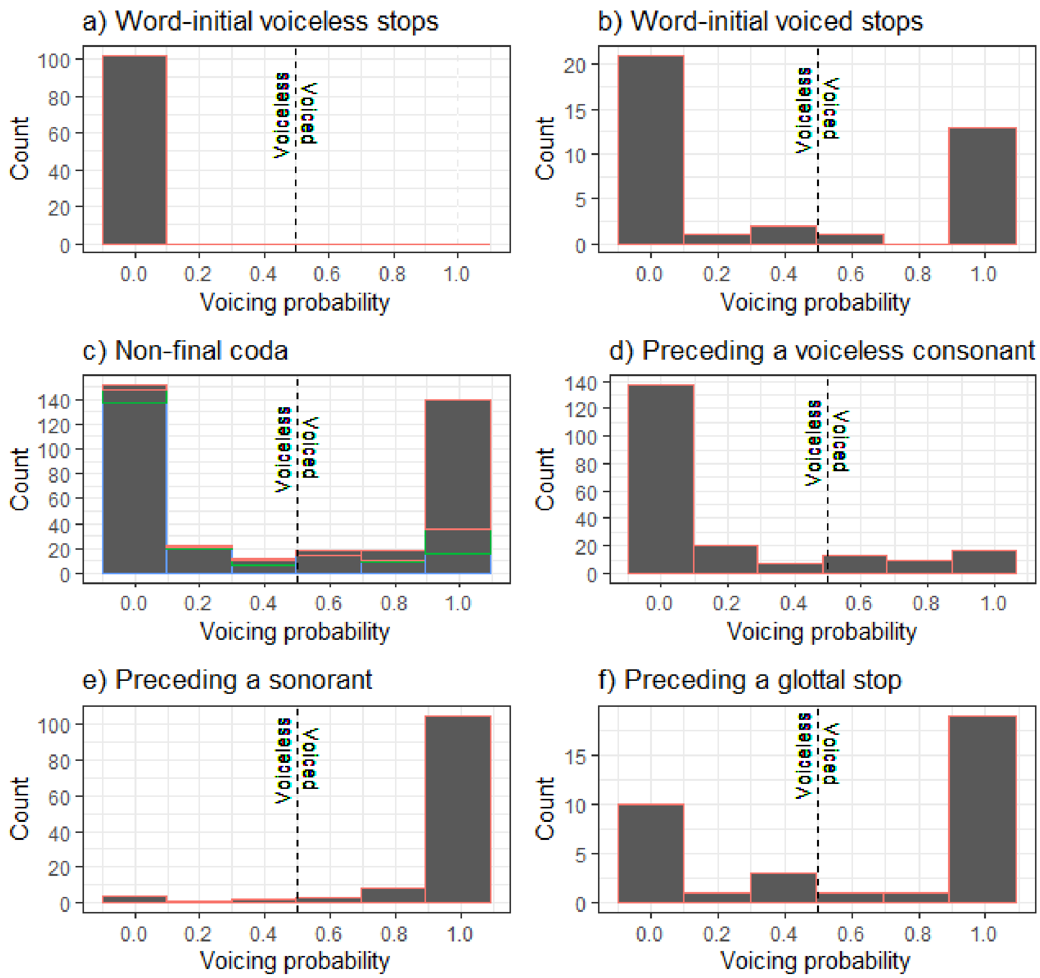


Figure 2a-f - Probability of stop voicing in different phonological contexts

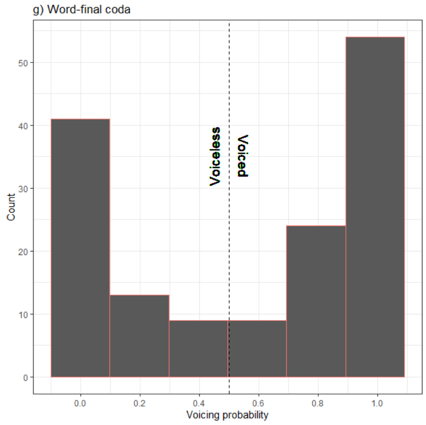


Figure 2g - Probability of stop voicing in word-final coda.

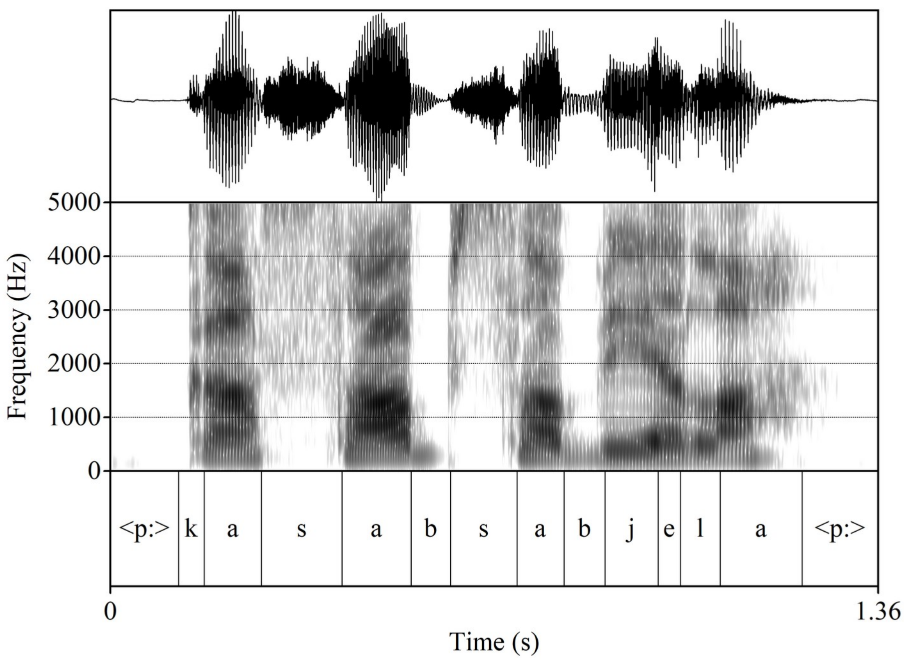


Figure 3a - Voiced coda stop preceding voiceless obstruent: [b.s] *in kasábsabyela (F) '(repeatedly falling) heavily or flat'*

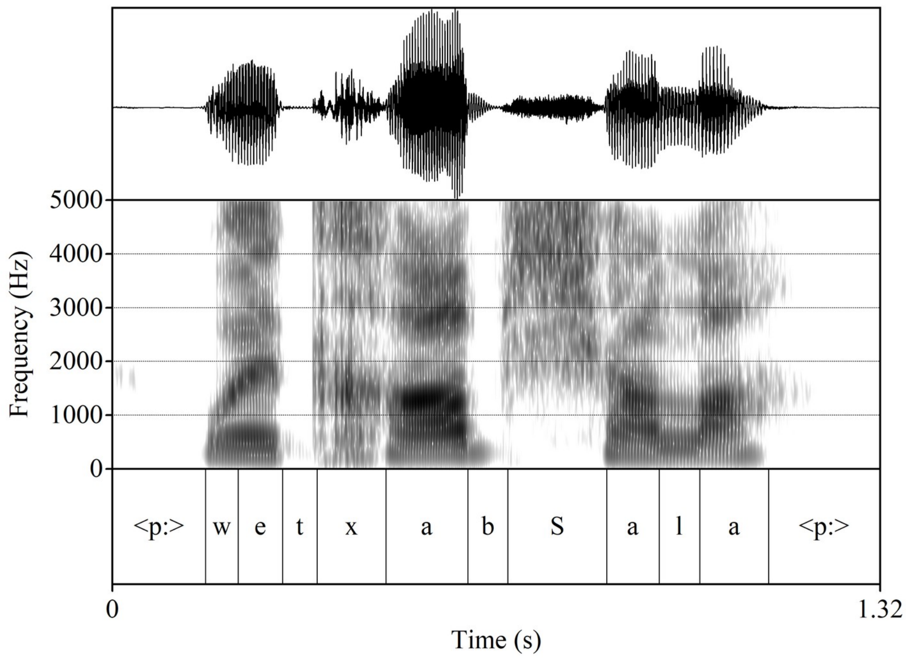


Figure 3b - Voiced coda stop preceding voiceless obstruent: [b.ʃ] *in wetȟábšala (F) 'red blood cells'.*

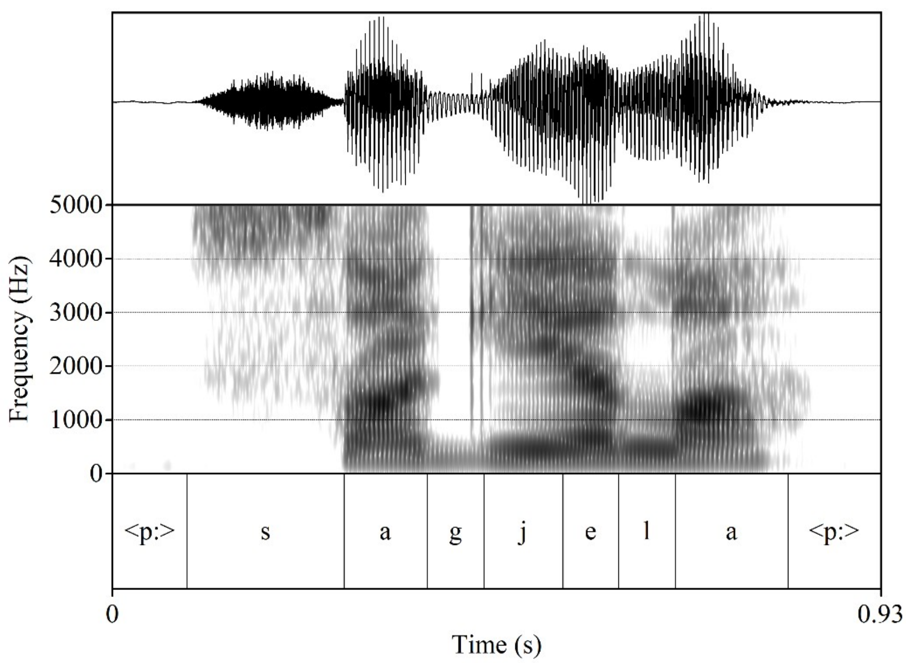


Figure 3c - Voiced coda stop preceding sonorant: [g.j] *in sagyéla (F) 'in a dried, hard or stiff condition'.*

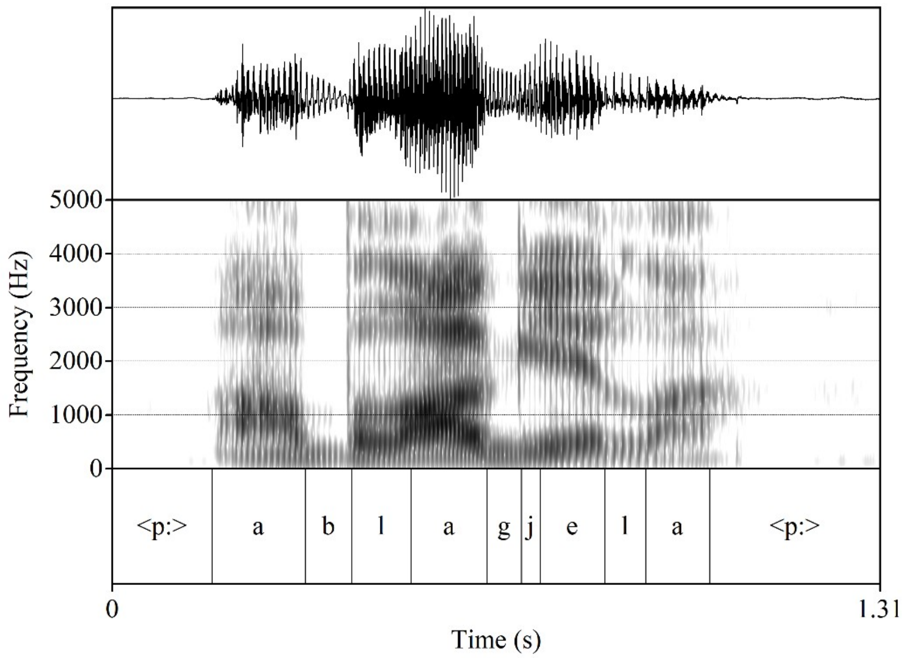


Figure 3d - Voiced coda stop preceding sonorant: [b.l] *and* [ɡ.j] *in ablágyela (M) 'quietly, peacefully'.*

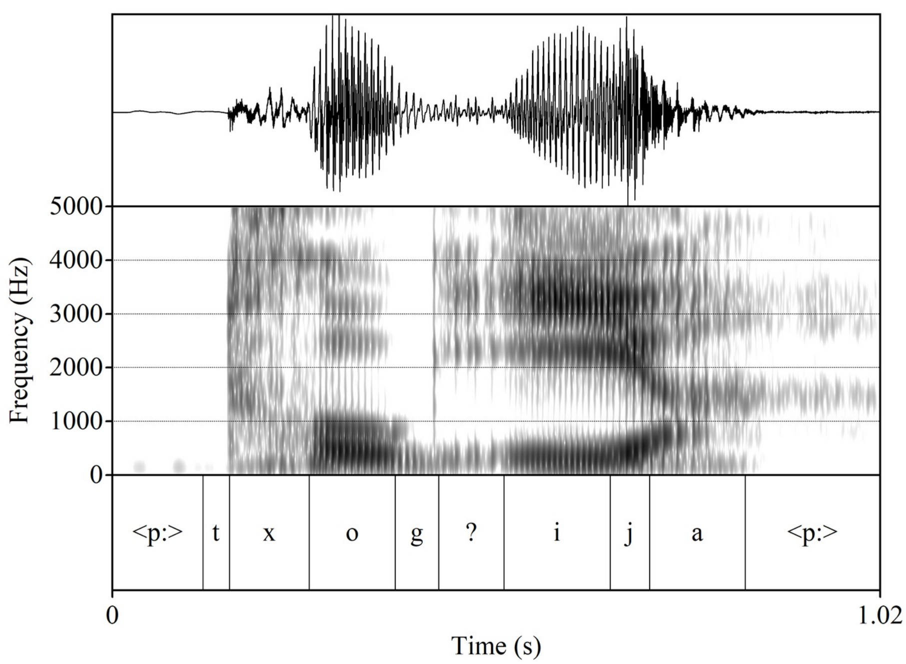


Figure 3e - Voiced coda stop preceding (voiceless) glottal stop: [ɡ.ʔ] *in tȟog'íyA (M) 'to speak a foreign language'.*

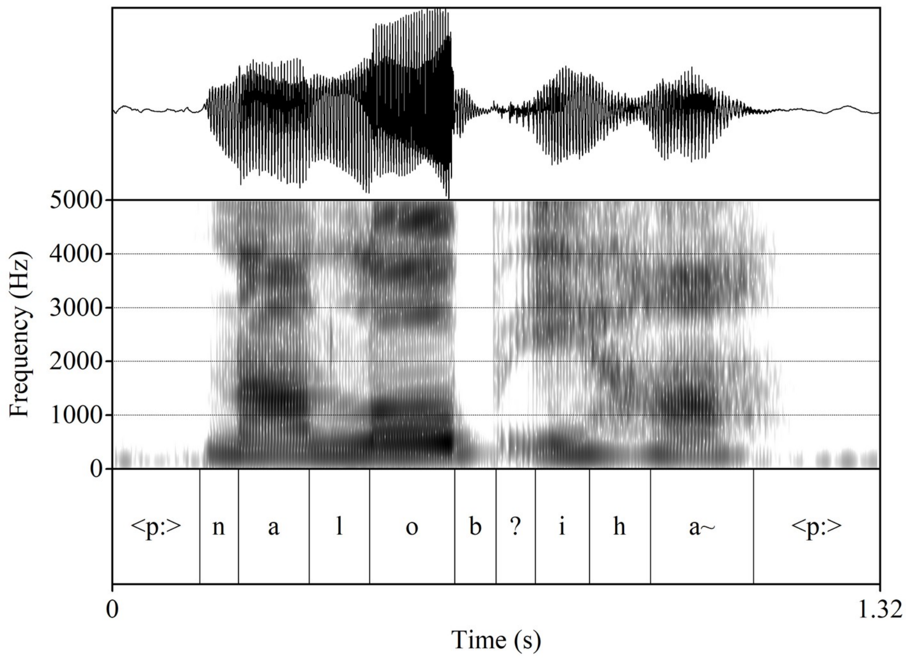


Figure 3f - Voiced coda stop preceding (voiceless) glottal stop: [b.ʔ] *in nalób ihÁŋ (F) 'to step into smth muddy or miry'.*

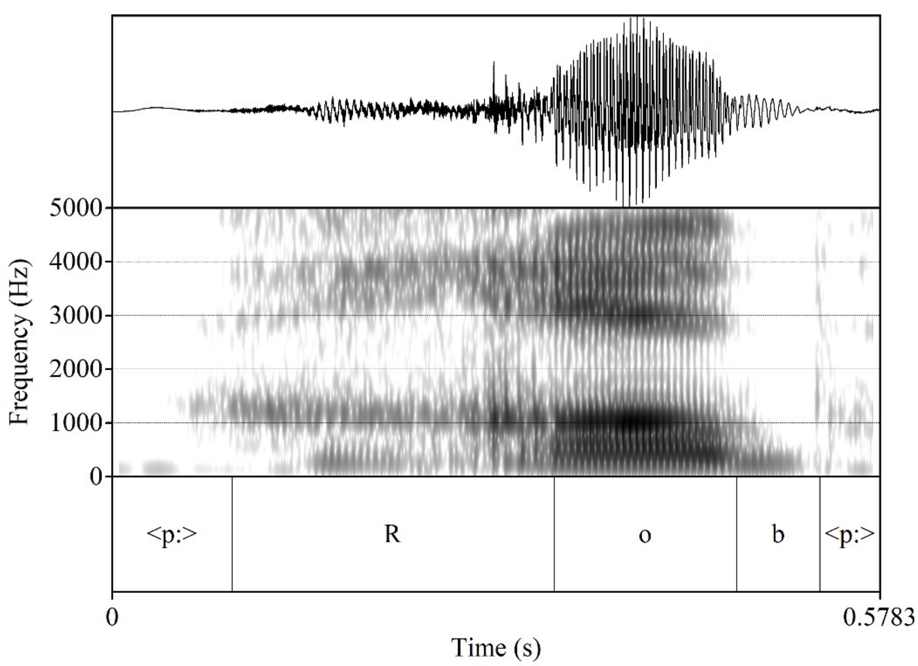


Figure 4a - Word-final voiced stop: [b] *in ǧób (F) 'snoring'.*

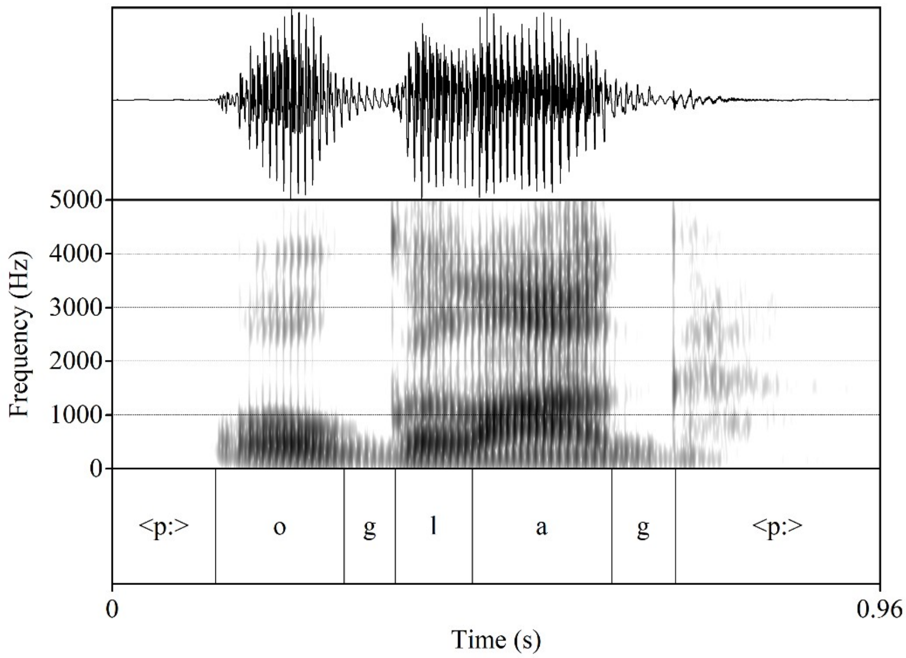


Figure 4b: Word-final voiced stop: [g] *in oglág (M) 'telling one's own, relating'.*

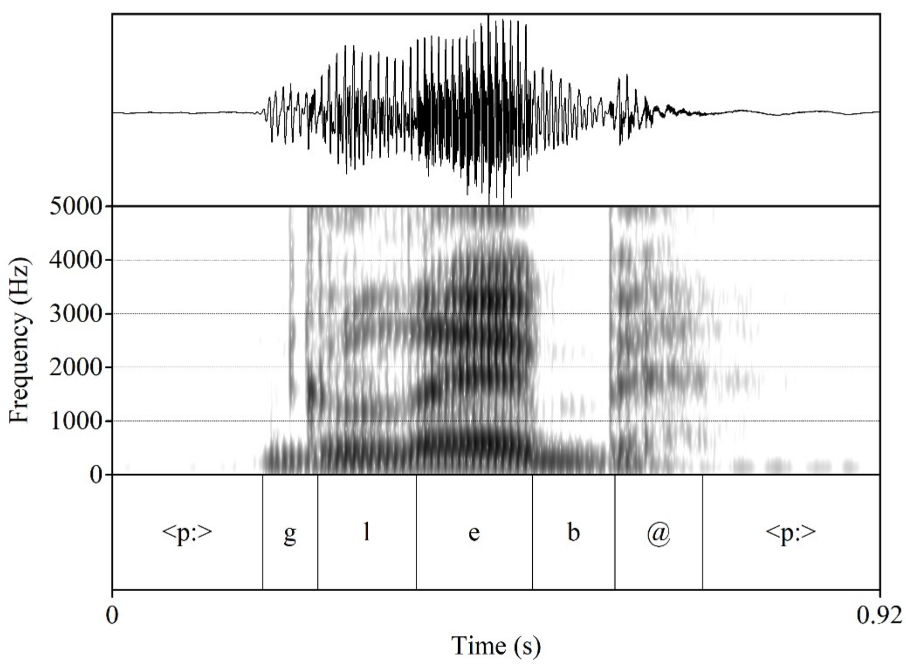


Figure 4c - Word-final voiced stop: [b] *in gléb (M) 'vomiting'.*

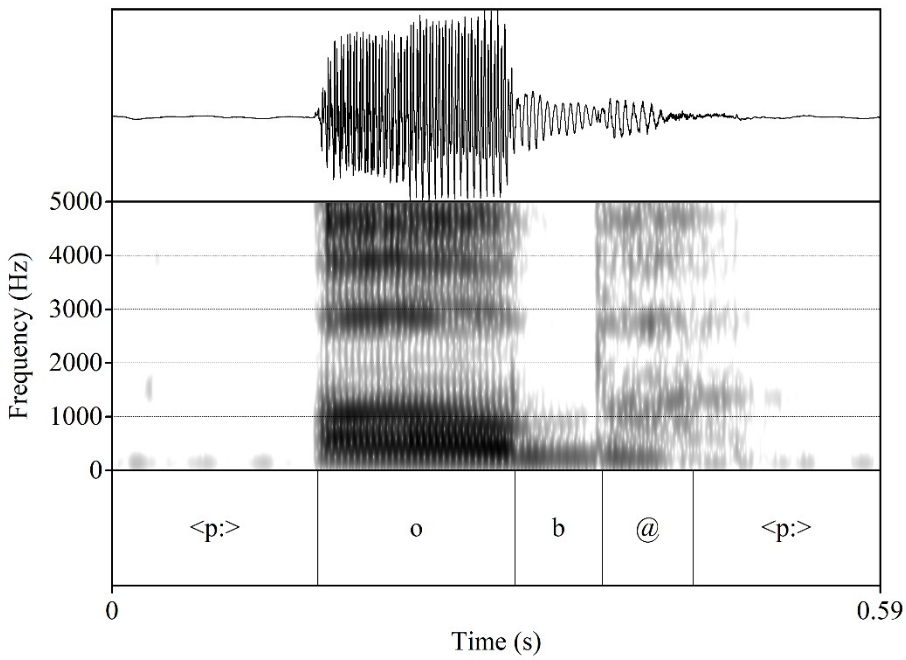


Figure 4d - Word-final voiced stop: [b] *in ób (F) 'with them, together with them'.*

3.2 Evidence that [b] and [g] are oral stops, not fricatives or glides.

The general question of whether final obstruent voicing processes exist is complicated by the existence of many final lenition or weakening sound patterns where voicing is coupled with reduced stricture. For example, though Blevins (2006a) suggests that Tundra Nenets may show a final obstruent voicing pattern, Kiparsky (2006:228-29) argues that Tundra Nenets /p t k/ vs. /b d/ should be treated as a "contrast of tenseness, not of voicing", noting that "/b/ and /d/ are lax, and articulated with various kinds of lenition." In order to determine whether Lakota has a sound pattern of coda voicing for /p/ and /k/ then, it is necessary to show, not only that these sounds are voiced, as we have in 3.1, but that the voiced segments are oral stops. Here we present acoustic evidence of significant closure durations, absence of fricative noise, release bursts, and low energy levels that are all characteristic of oral stops in contrast to fricatives, taps/flaps and glides.

Where hand-eye inspection of waveforms and spectrograms is mentioned, these waveforms and spectrograms are extracted from the NLD data. All waveforms, spectrograms and annotations were plotted with the computer program Praat (Boersma & Weenik 2019) and were exported as 600 dpi PNG files.

3.2.1 Closure duration. As detailed in section 2, oral stops and oral fricatives contrast in Lakota, but due to coda stop voicing and coda fricative devoicing, the only environment where voiced and voiceless stops and fricatives contrast, and where accurate measures of duration can be made is intervocalic position. **Figure 5** shows durational measurements for all of the obstruents in our database in intervocalic position. Note that the horizontal line within each box marks the median while the circle marks the mean. The durational measurements have been speaker-normalized by converting them to z-scores and back to milliseconds for easier comparison. Three outliers (>3 SDs) have been removed under the assumption that they originated from hesitation or similar effects, resulting in a total of 348 intervocalic obstruents analyzed. Voiced stops have the shortest closure durations of all obstruents, with averages ranging from 62 ms. for [g] to 77 ms. for [b]. Plain voiceless stops show longer closure durations, averaging 110-113 ms., with voiced fricatives slightly longer (99-120 ms.), and voiceless fricatives (excluding /h/) the longest of all (148-163 ms.). These durational measurements are unremarkable, and are consistent with interpreting sounds transcribed as [b] and [g] as voiced oral stops, since flaps or taps would be expected to show shorter closure durations averaging around 20ms. We performed a linear mixed effects analysis of the duration measurements of intervocalic consonants, with random intercepts by Speaker and Word, using the non-normalized values to avoid singularity. A Tukey post-hoc comparison with Benjamini-Hochberg adjustment for multiple testing showed significant differences between [b] and [g] and any other given consonant at the 0.001 level, as shown by Table 12.

Table 12. Comparison of the duration of different obstruents against [b] and [g]

Linear Hypothesis	Estimate	Std. Error	*z* value	*Pr*(> |*z*|)
g - b == 0	-13.6356	3.9749	-3.430	< 0.001
k - b == 0	35.0904	3.0892	11.359	< 0.001
p - b == 0	32.5055	3.3951	9.574	< 0.001
R - b == 0	40.5085	9.1923	4.407	< 0.001
s - b == 0	72.6519	4.2175	17.226	< 0.001
S - b == 0	87.2562	10.5256	8.290	< 0.001
t - b == 0	35.7116	4.2953	8.314	< 0.001
x - b == 0	83.1465	5.7934	14.352	< 0.001
z - b == 0	24.7052	4.6610	5.300	< 0.001
Z - b == 0	31.0778	5.2792	5.887	< 0.001
k - g == 0	48.7260	3.6550	13.331	< 0.001
p - g == 0	46.1411	3.8593	11.956	< 0.001
R - g == 0	54.1441	9.3850	5.769	< 0.001
s - g == 0	86.2875	4.6902	18.398	< 0.001
S - g == 0	100.8918	10.6962	9.432	< 0.001
t - g == 0	49.3471	4.6953	10.510	< 0.001
x - g == 0	96.7821	6.0956	15.877	< 0.001
z - g == 0	38.3407	5.0317	7.620	< 0.001
Z - g == 0	44.7133	5.6074	7.974	< 0.001

However, since the measurements in **Figure 5** are taken only from intervocalic [b] and [g], checks are necessary to ensure that the same segments in syllable coda show similar closure durations. Since we could not automate this process due to the phonotactics, we resorted to hand-eye-checking spectrograms of fully voiced tokens from data like that presented in Figure 2e, Figure 2f, and Figure 2g. Waveforms and spectrograms in Figures 3 and Figure 4 exemplify our findings: voiced coda consonants transcribed as [b] and [g] in the NLD orthography which were measured as fully voiced by the acoustic analysis in section 3.1 show closure durations falling within the central range of the distribution bars for voiced stops in Figure 5. There is no evidence of significant temporal reduction of articulatory undershoot that might be associated with flapping/tapping or general lenition.

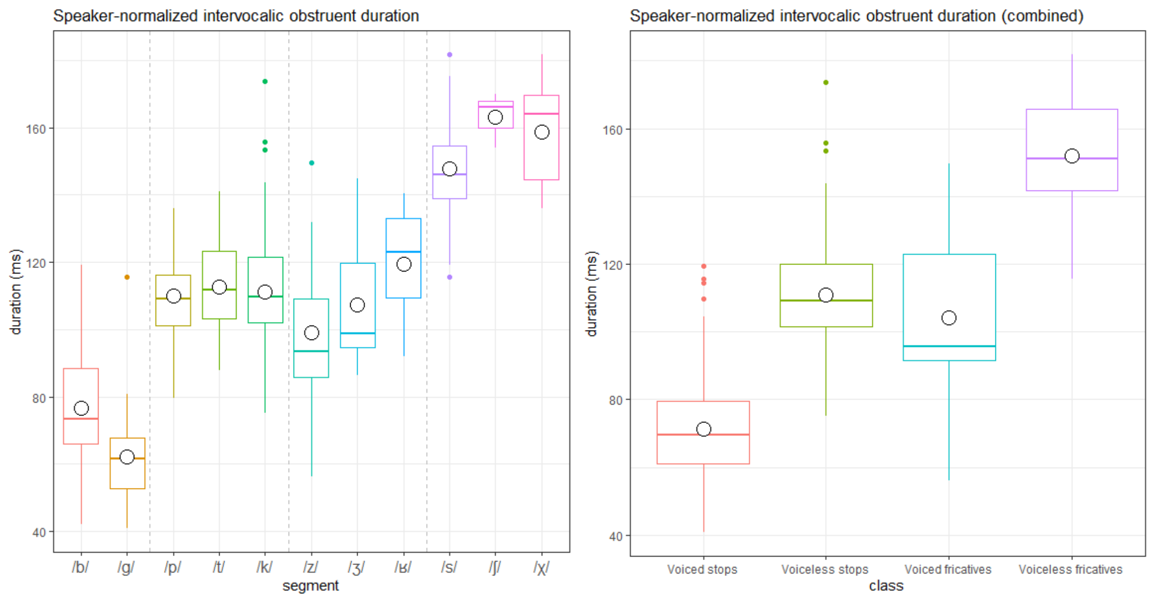


Figure 5 - Speaker-normalized duration of intervocalic obstruents.

3.2.2 Absence of fricative noise during closure phase of voiced oral stops. To determine whether voiced codas were produced as stops vs. fricatives or glides, we performed two tasks. One was an automated measure of spectral energy, described in 3.2.4. The other was hand-eye-checking of spectrograms of fully voiced tokens from data presented in Figure 2e, 2f, 2g, looking for noise above the voicing bar that would indicate incomplete stop closure. Spectrograms in Figures 3 and 4 exemplify our findings: voiced coda consonants transcribed as [b] and [g] in the NLD orthography which were measured as fully voiced by the acoustic analysis in section 3.1 show silent closure durations consistent with oral stop production. These stops do not show aperiodic components in the spectrum during the closure phase that would indicate frication, nor do they show formant structure indicative of vowel-like productions. There is no evidence of significant noise at frequencies above the fundamental that might be associated with incomplete oral closure, frication, or general lenition.

3.2.3 Presence of release bursts for voiced oral stops. A salient characteristic of (released) oral stops is their release bursts. Release bursts are not generally found in flaps/taps, and are absent in fricatives and glides. To check for release bursts, we resorted to hand-eye-checking of spectrograms of fully voiced tokens from data presented in Figure 2e,f,g looking for a spike of noise at the end of the closure that would indicate release of intra-oral air pressure. Spectrograms in Figure 3c,d & Figure 4 exemplify positive findings: voiced coda consonants transcribed as [b] and [g] in the NLD orthography which were measured as fully voiced by the acoustic analysis in section 3.1 sometimes show visible release bursts before sonorants and in word-final position before pause. Note that in Figure 3c, the [g] of *sagyéla* (F) 'in a dried, hard or stiff condition' shows a double burst: this is not uncommon before sonorants, where preceding voiced stops are often described as being followed by a short open transition. Presence of release bursts in medial and final codas were taken as positive evidence that the sounds measured as fully voiced instances of [b] and [g] were indeed oral stops, and not fricatives or glides.

The finding of release bursts in phrase-final position, as illustrated in Figure 4 for [b] in *ǧób* 'snoring', [g] in *oglág* 'telling one's own, relating', [b] in *gléb* 'vomiting', and [b] in *ób* 'with them' was interesting for two reasons. First, as just mentioned, it supported the analysis of these sounds as voiced oral stops. Second, it focused our attention more on properties of the release. As detailed in section 2, like the majority of Lakota words with final consonants, these words are contracted forms which have undergone final vowel loss: *ǧób* from *ǧópA* 'to snore', *oglág* from *oglákA* 'to tell one's own (as a story, decision, name)', *gléb* from *glépA* 'to vomit', and *ób* from *ópȟa* 'to take part'. Though our findings remain preliminary, formant structure in the final release burst of these tokens is consistent with production of a final voiceless or partially devoiced vowel. In section 4, we discuss aspects of the diachrony of final stop voicing in Lakota, and suggest an earlier stage (attested in Assiniboine) of intervocalic voicing concomitant with final vowel devoicing. Voiceless release of Lakota final voiced stops could continue this earlier hypothesized sound pattern.

3.2.4 Overall low spectral energy of voiced oral stops. If the coda consonants measured as fully voiced in section 3.1 (Figures 2e-g) are oral stops, as opposed to flaps/taps, fricatives, glides or other sonorant sounds, then they will be expected to have lower overall energy envelopes than these other sound types. In order to assess this factor, we used quantitative measures across the entire dataset. First, we applied a high-pass filter (350 Hz) to the audio data with the R package *wrassp* (Winkelmann et al. 2017) to remove the lower frequencies, where most of the energy of voiced stops is expected to be concentrated. Then, we performed a root mean square analysis (rms), also with the R package *wrassp*, to the resulting filtered data. The rms values were speaker-normalized (z-normalization), and converted back to decibel. We excluded intervocalic voiced stops from the analysis, because there seems to be consensus on their status as stops, and because our focus was whether voiced consonants that result from the proposed stop coda voicing process (5.ii.b') were produced as oral stops, or with some other manner of articulation. Our corpus of purported voiced coda stops included 299 tokens. These were compared with the entire set of approximants and voiced fricatives in our database, which included 219 tokens. Relevant results of our measurements are plotted in **Figure 6**.

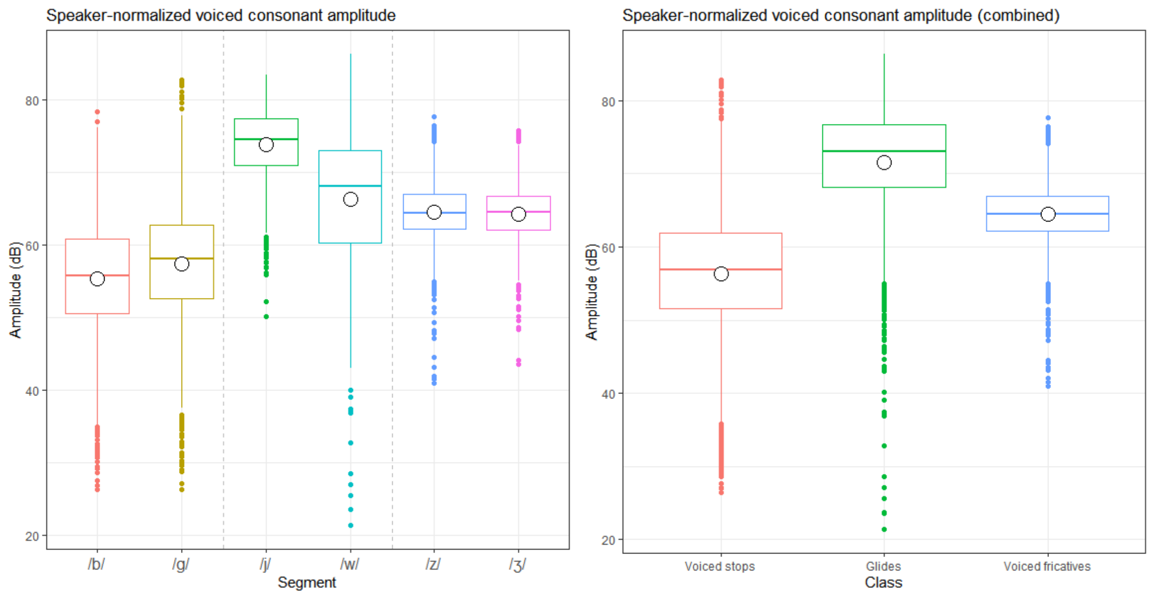


Figure 6 - Comparison of the speaker-normalized spectral amplitude of some voiced segments

Table 13 shows the results for the linear mixed effects model constructed to test the intensity (dB) differences between coda voiced stops and the approximants and voiced sibilants in the language. We added random slopes and random intercepts by *Speaker* and *Word*. Non-normalized values were used in order to avoid singularity due to the incorporation of random effects by *Speaker* to the model. Results shown are for Tukey post-hoc comparisons with α level compensation for multiple comparisons using Benjamini-Hochberg adjustment.

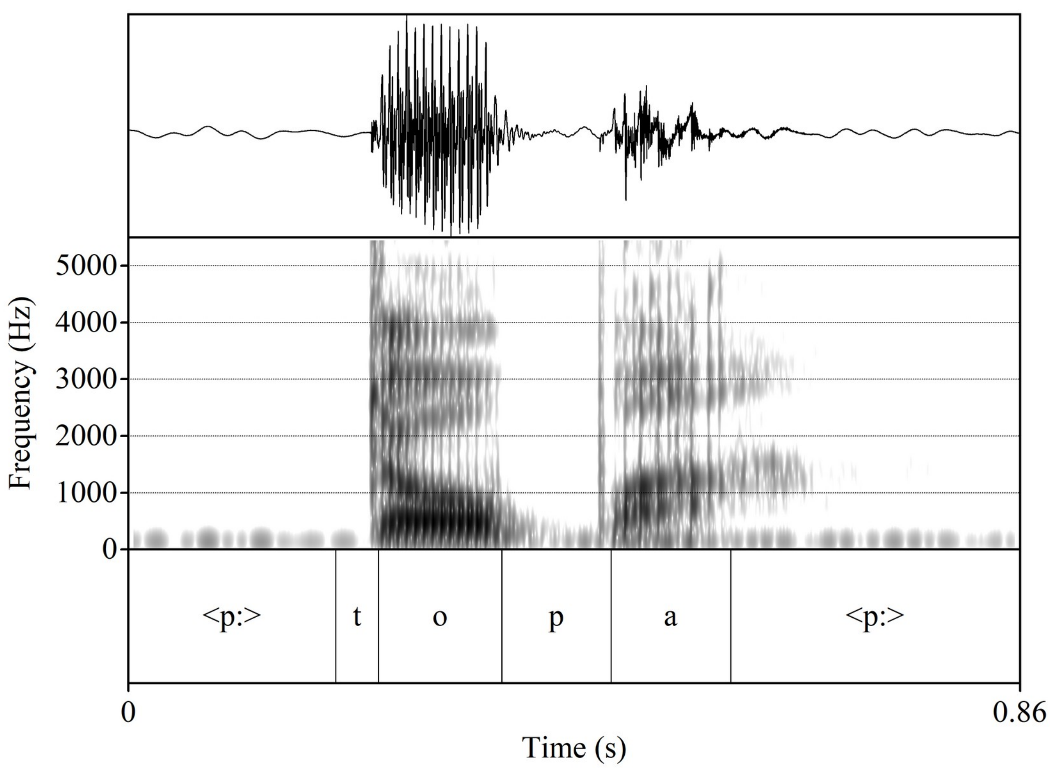
Table 13. Comparison of the intensity of voiced consonants against [b] and [g]

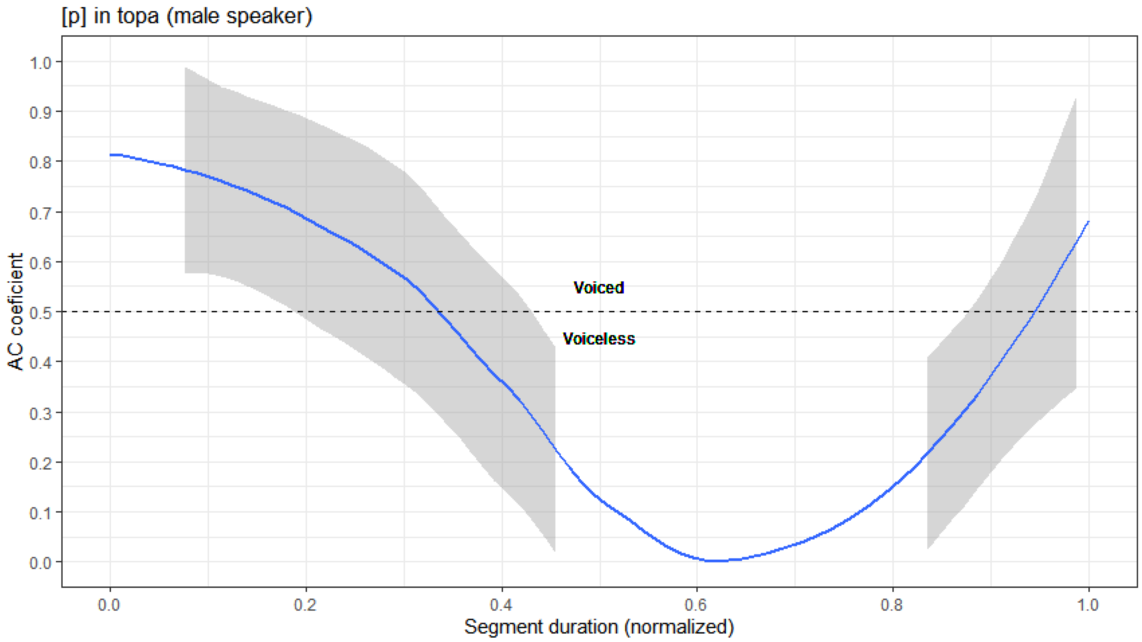
Linear Hypothesis	Estimate	Std. Error	*z* value	*Pr*(> |*z*|)
g - b == 0	2.1099	1.1627	1.815	0.074548
j - b == 0	18.1264	1.6735	10.832	< 0.001
w - b == 0	12.0250	1.4124	8.514	< 0.001
z - b == 0	8.2392	0.8380	9.832	< 0.001
Z - b == 0	9.0625	1.1301	8.019	< 0.001
j - g == 0	16.0165	2.5464	6.290	< 0.001
w - g == 0	9.9151	2.0854	4.755	< 0.001
z - g == 0	6.1294	1.5069	4.067	< 0.001
Z - g == 0	6.9526	1.7378	4.001	< 0.001

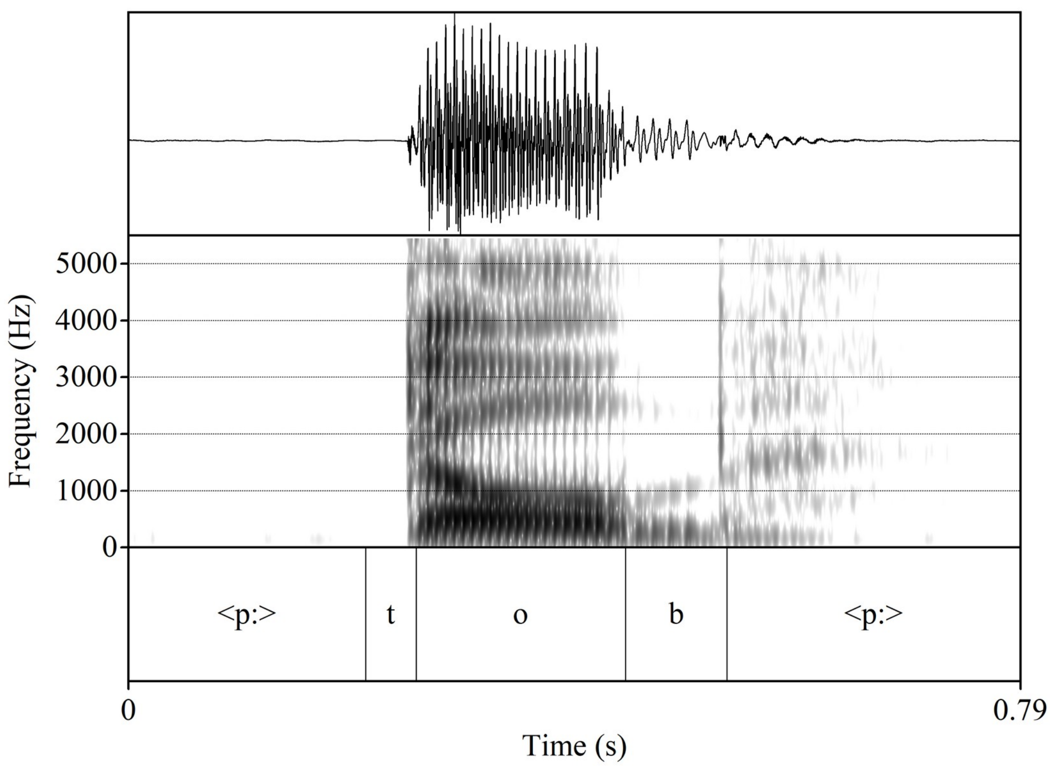
The comparison shows a categorical difference in amplitude between voiced stops in the coda and all voiced fricatives and approximants, and no statistically significant difference between [b] and [g]. Average spectral amplitude of voiced stops is below 60 decibel (55 and 57 dB), while voiced fricatives have averages of 64 dB, and the averages for glides are 66 and 74 dB. These results suggest that [b] and [g] form a category of low energy sounds, consistent with their production as oral (voiced) stops, distinct from the category of voiced fricatives and voiced approximants.

3.3 Final voicing as alternation

As reviewed in section 2, many researchers describe voicing alternations for Lakota when a stem ending in ...VTV- , T a voiceless oral stop or affricate, is produced as consonant-final. For example, *sákA* ‘to be dry, to be dried until hard or stiff’, with medial [k], but reduplicated *sagsákA*, where truncation (5.i) results in /k/ pronounced as [g] in coda position (5.ii.b). In this section, acoustic analysis of alternating consonants in morpheme-alternant pairs support these descriptions: intervocalic instances of /k/ and /p/ are typically voiceless, while phrase-final and pre-consonantal instances of the same consonants in the same morphemes are often voiced *in non-voicing contexts*, namely, word-finally and before voiceless consonants and glottal stop. Since our tokens are taken from recordings made for dictionary purposes, we have limited numbers of these pairs, making a statistical analysis unsuitable. However, the acoustic measurements presented below demonstrate that the voicing alternations described for Lakota are attested. Spectrograms and waveforms of each word in **Figure 7** are accompanied by a plot showing the details of the voicing of each relevant segment by means of AC coefficients as a function of time. As discussed in 3.1, AC coefficients go from 0 (completely voiceless) to 1 (completely voiced) with .5 as the voicing threshold. Time in the x-axis has been normalized to the duration of each segment to facilitate the visualization of the proportion of voicing. Note that the last time point in the plot might be affected by the voicing of the following segment.




[p] in topa (male speaker)
AC coeficient
Voiced
Voiceless
Segment duration (normalized)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.2
0.4
0.6
0.8
1.0


Frequency (Hz)
5000
4000
3000
2000
1000
0
<p:>
t
o
b
<p:>
0
0.79
Time (s)

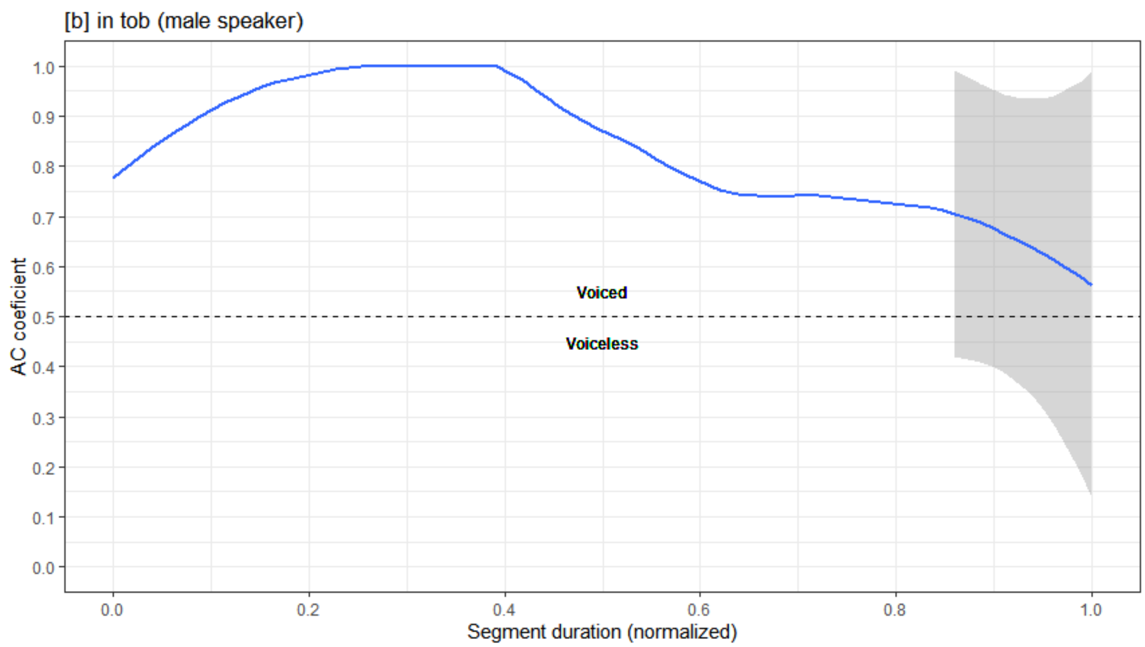
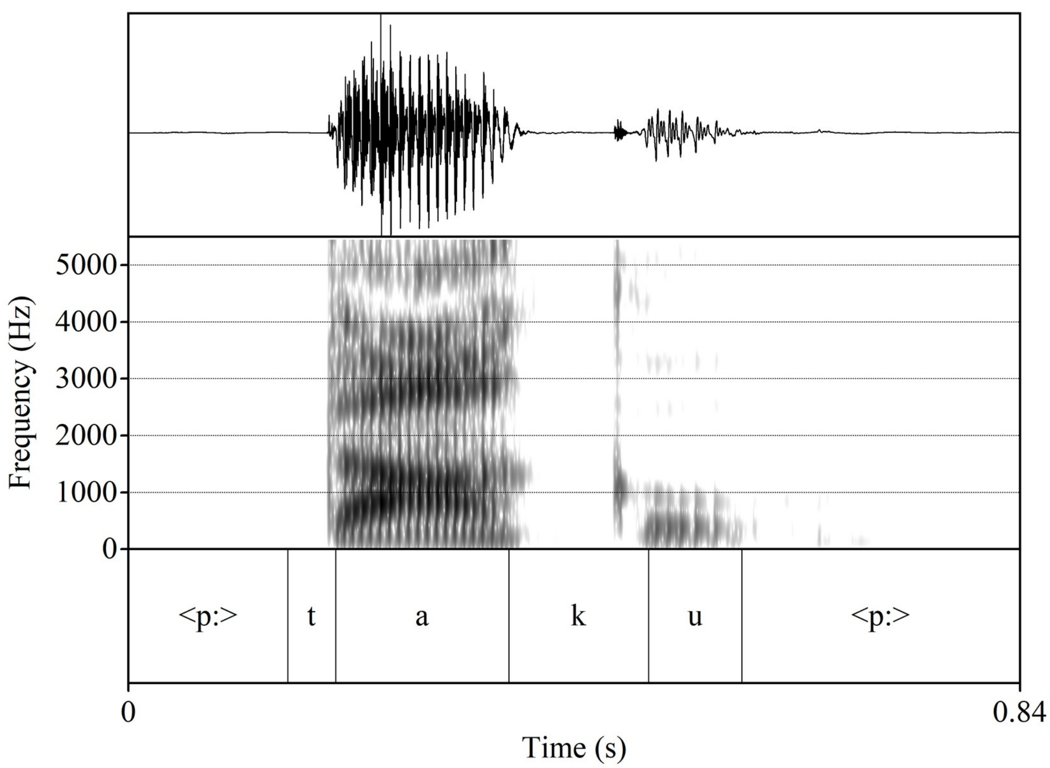
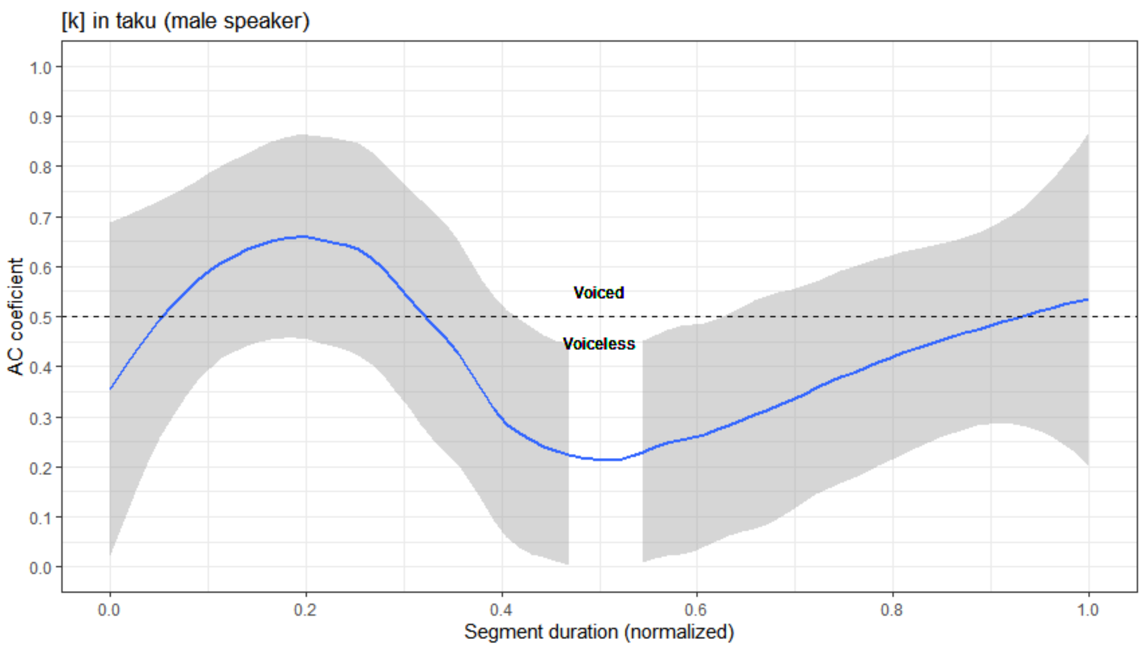
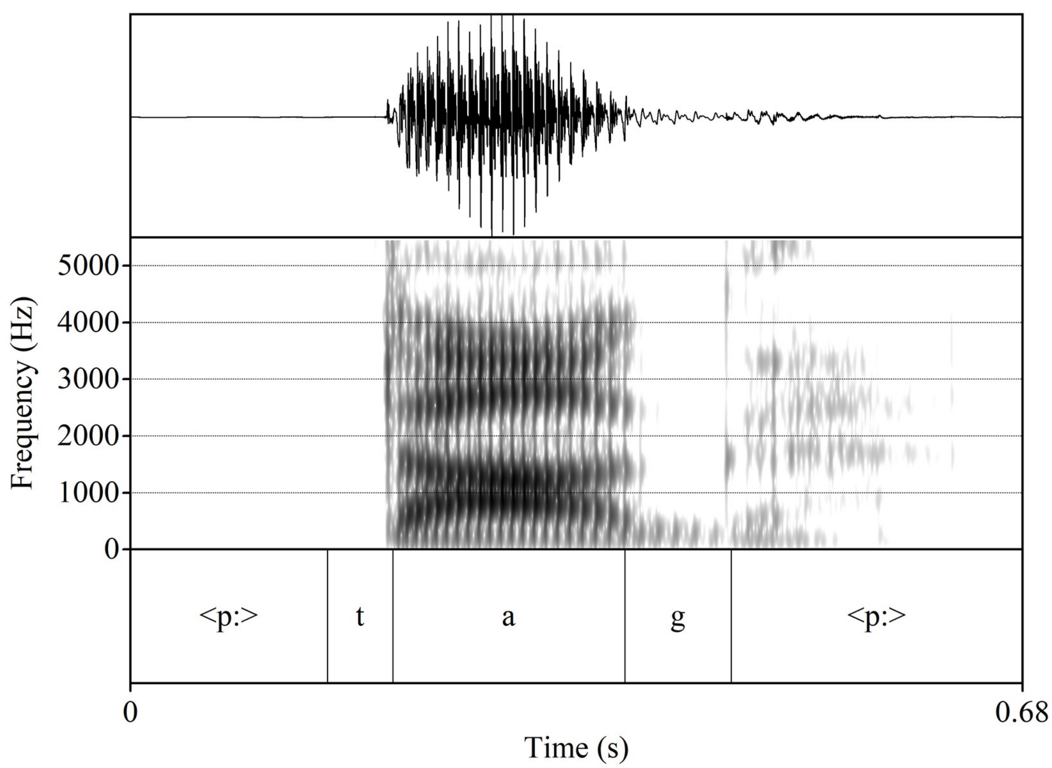


Figure 7a - Comparison of alternating consonants in morpheme-alternant pairs: topa (M) 'four' vs. tob (M) 'four (CONT)'




[k] in taku (male speaker)
AC coeficient
Segment duration (normalized)
Voiced
Voiceless
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0
0.2
0.4
0.6
0.8
1.0


Frequency (Hz)
5000
4000
3000
2000
1000
0
<p:>
t
a
g
<p:>
0
0.68
Time (s)

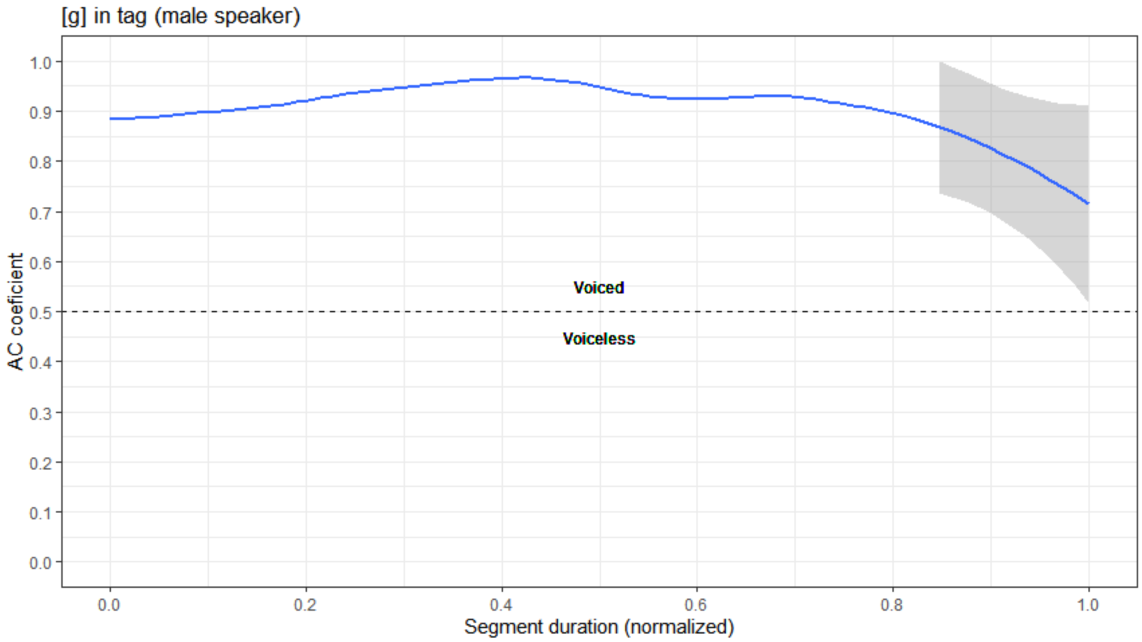
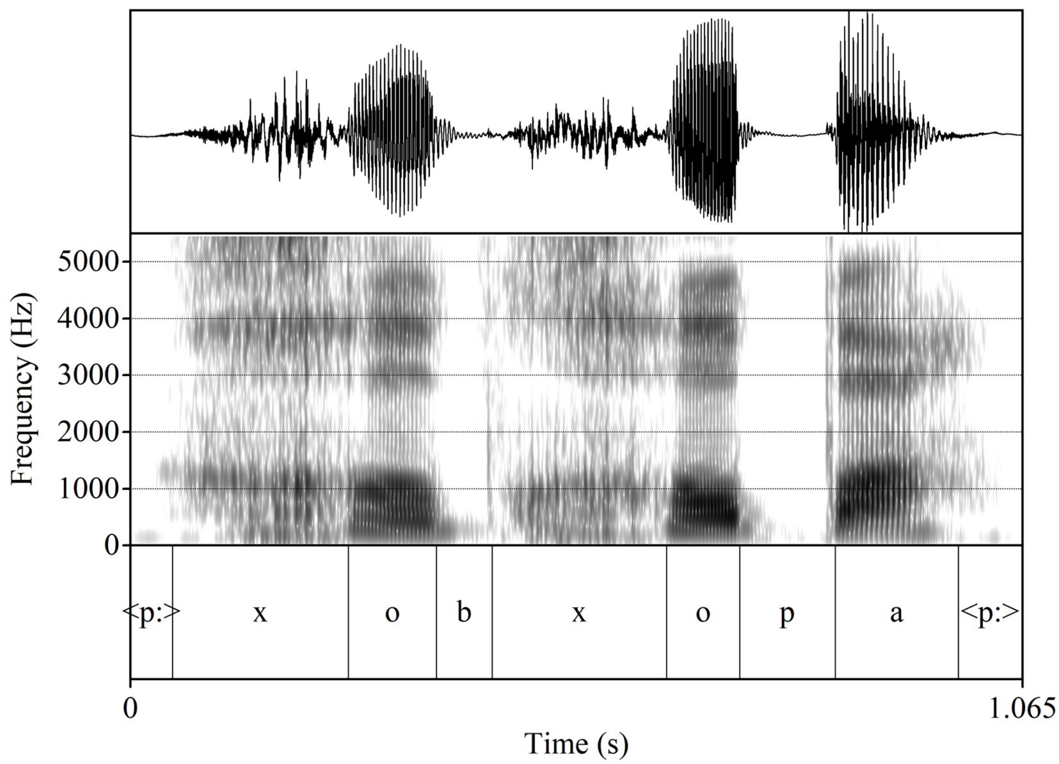
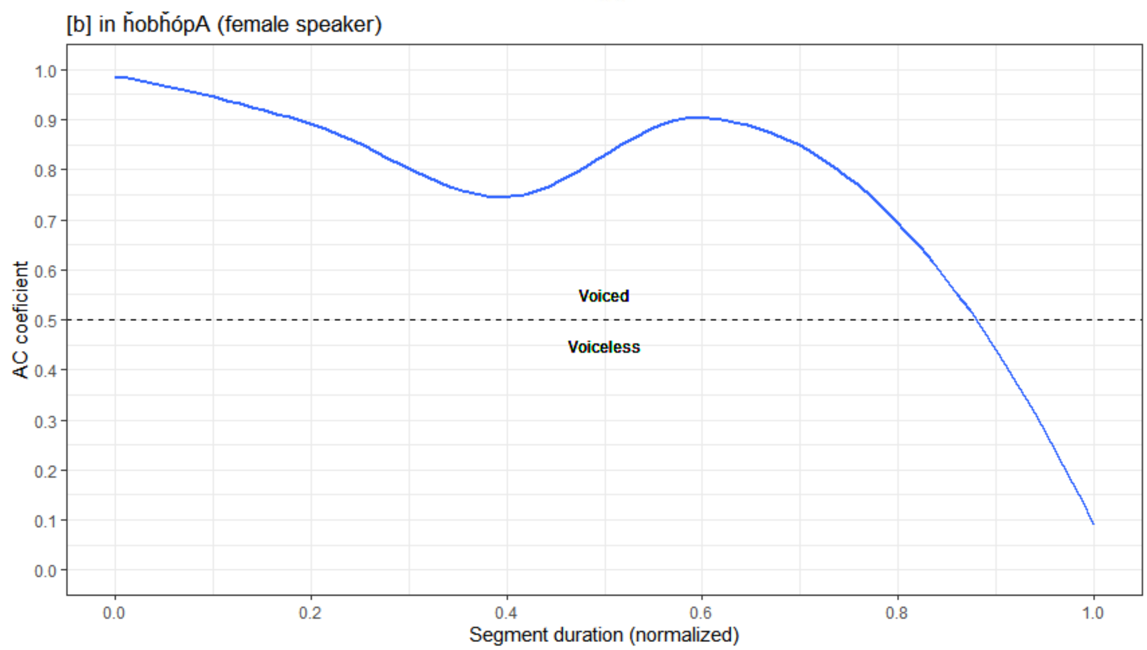


Figure 7b - Comparison of alternating consonants in morpheme-alternant pairs: taku (M) 'what ' vs. tag (M) 'what (CONT)'

In Figures 7a,b, the comparison between voiced and voiceless stops shows that, whereas prototypical intervocalic voiceless stops show a decrease in voicing that follows carry-over voicing from the previous vowel (and spans most of the duration of the stop), word-final voiced stops do not show any significant decrease in voicing until the end of the segment. This comparison can also be made in reduplicated forms, where the first morpheme appears in its reduced form (with coda stop voicing) preceding the full form (with an intervocalic voiceless stop). Figure 8 shows the reduplicated form *ȟobȟópA* 'to be extremely attractive' as produced by the female speaker.


Frequency (Hz)
5000
4000
3000
2000
1000
0
<p:>
x
o
b
x
o
p
a
<p:>
0
1.065
Time (s)


[b] in ȟobȟópA (female speaker)
AC coeficient
Voiced
Voiceless
Segment duration (normalized)

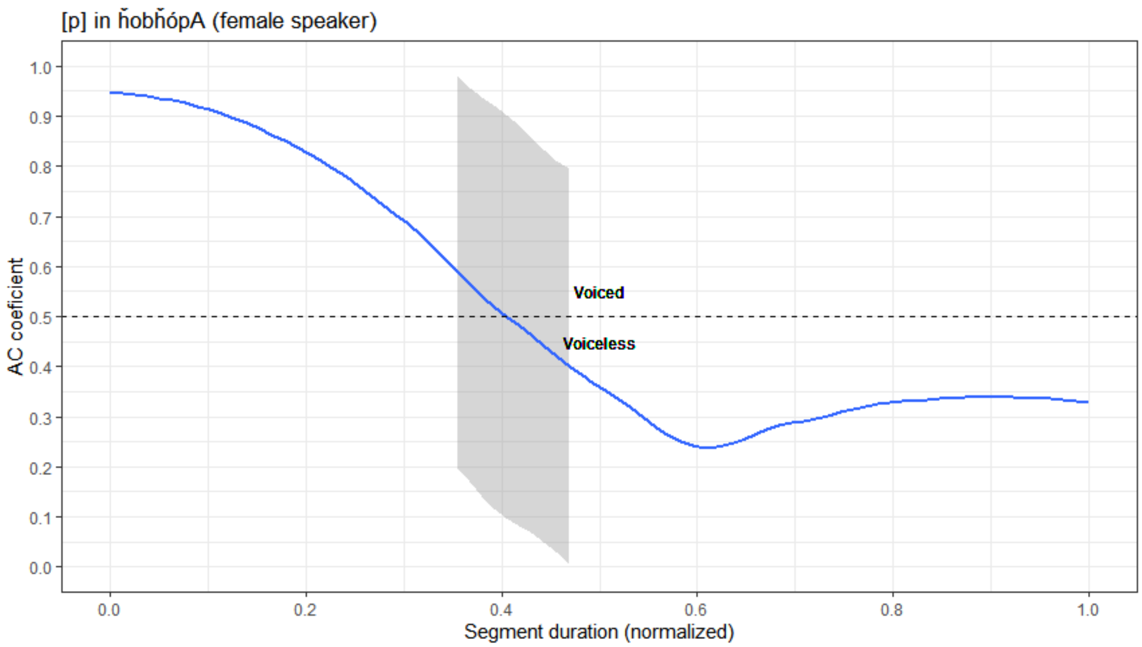


Figure 8 - Comparison of alternating consonants in reduplicated words: ȟobȟópA (F) 'to be extremely attractive'

3.4 Summary of acoustic analysis

Our acoustic analysis of voicing during oral stop closure presented in 3.1 is compatible with the view that Lakota oral stops /p/ and /k/ are voiced in coda position. This voicing is sometimes obscured by devoicing processes, including phrase-final gradient devoicing, assimilation to voicelessness before voiceless obstruents and /h/ (which may be coupled with resyllabification into onset), and devoicing that occurs with optional fusion with a following glottal stop, yielding an ejective. In order to support the view that voiced /p/ and /k/ are oral stops, 3.2 presented an array of acoustic properties consistent with stop production. Sounds that were categorized as fully voiced codas in 3.1 were shown in 3.2 to have significant closure durations in the range of normal for voiced stops, absence of fricative noise during closure, release bursts, and low energy levels that are all characteristic of oral stops in contrast to fricatives, taps/flaps, glides or other sonorant sounds. Section 3.3 presented morphologically related word pairs with voiceless and voiced alternants highlighting the differences in voicing in a given stop with regard to its phonological context (intervocalic vs. word-final). In sum, there is acoustic evidence that Lakota has a sound pattern of oral stop coda voicing, supporting the impressionistic descriptions of earlier researchers.

4. Hypothesized origins of Lakota obstruent voicing patterns.

Recall from Section 1 that certain phonological markedness accounts like that of Kiparsky (2006, 2008) predict the non-existence of synchronic final obstruent voicing sound patterns. In contrast, Evolutionary Phonology (Blevins 2006a, 2006b) suggests that such patterns may exist, but may be extremely rare due to the numerous phonetic factors that result in devoicing of obstruents in word-final position. One of Kiparsky's (2006) arguments against the Evolutionary approach involves historical pathways of change. He suggests that, were there no grammatical markedness constraint against final obstruent voicing, it could easily evolve by the succession of two independently common sound changes: (i) intervocalic voicing VTV > VDV; and (ii) final vowel loss VDV# > VD#. Since, he argues, no clear cases of this kind are in evidence, the absence of synchronic final obstruent voicing supports the existence of phonological markedness constraints which demand that unmarked (voiceless) obstruents are preferred in positions of neutralization. We have shown above that there is acoustic support for a synchronic sound pattern of final voicing in Lakota. While this, in itself, is enough to call markedness accounts into question, we continue to be interested in the question of why sound patterns of this type are uncommon, and how they might evolve.

To this end, we offer some hypotheses regarding the evolution of Lakota final obstruent voicing below. After introducing the Proto-Siouan sound system in 4.1, we suggest Lakota /l/ < *d in 4.2. With this sound change established, the synchronic alternation of /p/, /t/, /k/ with [b], [l], [g] can be seen to reflect a uniform historical voicing of oral stops /p/, /t/, /k/ > [b], [d], [g] prior to the *d > l sound change. In 4.3, we suggest that this voicing process was similar to the historical pathway suggested by Kiparsky (2006): where he suggests intervocalic voicing followed by final vowel loss, we suggest intervocalic stop voicing concomitant with vowel reduction as a consequence of anticipatory co-articulation of the final vowel gesture.

4.1 The Proto-Siouan sound system

Table 14. Proto-Siouan Consonants

	LABIAL	DENTAL	PALATAL	VELAR	GLOTTAL
STOPS					
voiceless *unaspirated* (*postaspirated*) (*preaspirated*) (*glottalized*)	 *p (*ph) (*hp) (*p’)	 *t (*th) (*ht) (*t’)		 *k (*kh) (*hk) (*k’)	 *’ = [ʔ]
FRICATIVES					
voiceless (*glottalized*)		*s (*s’)	*š (*š’)	*x (*x’)	*h
RESONANTS					
sonorant *obstruent*	*w *W= [b]?	*r *R= [d]?	*y		

Proto-Siouan is reconstructed by Rankin, Carter and Jones (1998) with the consonant inventory shown in Table 14, a system which also underlies the Comparative Siouan Dictionary (Rankin et al. 2015), from which all reconstructions in this section are taken unless noted otherwise. The Proto-Siouan consonant system in Table 14 consists minimally of a series of voiceless unaspirated stops and fricatives, *p *t *k *s *š *x, laryngeals *ʔ and *h, three sonorants, *w, *r, and *y (which represent labio-velar, central rhotic, and palatal approximants respectively), and two "funny" resonants *W and *R, which are similar to *w and *r but more obstruent-like (Larson 2016).[19]

Given the numerous clusters in Proto-Siouan, and the clear status of many post-aspirates from heteromorphemic C+h clusters (Rankin, Carter and Jones 1998:2), it is possible that all of the sounds in parentheses in Table 14 constitute historical clusters, or, in the case of pre-aspirates, *hp *ht *hk, allophonic variants of voiceless unaspirated stops intervocalically before accented vowels (Rankin, Carter and Jones 1998:1; Larson 2016). Apart from *W and *R which we return to below, the most notable feature of this inventory is its lack of nasal stops, though /n/ and /m/ are contrastive sounds in all Dakotan languages.[20] Nasalization in Proto-Siouan is hypothesized to be a feature of vowels only, with vowels *i *e *a *o *u *į *ą *ų and their long counterparts. By the time of Mississipi Valley Siouan (MVS), resonants preceding nasalized vowels were all pronounced as nasal stops, and subsequent to this point, were phonologized as nasal stops when vowel nasalization was lost.[21] While Proto-Siouan might seem odd in having nasalized vowels but no nasal stops, the same pattern exists in Mandan, and at least one non-Siouan language of North America had a similar pattern. Eyak, an extinct Na-Dené language, had no distinct nasal stops, but did have nasalized vowels: phonetic [m] occurred as a variant of /w/ before nasalized vowels, while phonetic [n] occurred as a variant of /l/ in the same contexts (Maddieson 2013).

With the possible exception of *W and *R, there is no contrastive voicing in Proto-Siouan. Though marginal, the proto-phonemes *W and *R are sounds thought to have been like *w and *r, but more obstruent-like and with different reflexes: where *w is usually continued as /w/ or /m/ in most daughter languages, *W is continued as /w/, /b/, /mb/ or /p/, showing more obstruent-like behavior; and where *r is usually continued as /r/, /k/, /n/, /ð/ or /y/, *R is continued as /r/, /l/, /d/, /nd/, or /t/, also showing more obstruent-like behavior. Given this, it would not be unreasonable to interpret Proto-Siouan *W as weak [b] (a voiced oral labial stop or tap with short closure duration) and Proto-Siouan *R as a weak [d] (a voiced oral dental stop or tap with short closure duration), which might suggest a limited incipient voicing contrast for the bilabial and dental stops alone.

Earlier researchers (e.g. Rankin 2001; Rood 2016; Larson 2016) have focused on the singleton consonant reflexes of *W and *R as evidence of their obstruent-like phonetics in the proto-language. However, an additional piece of evidence for obstruent-like status of *W and *R is their behavior in clusters, and, more specifically, the apparent assimilation in voicing that occurs when a voiceless obstruent preceded one of these sounds. Cross-linguistically, voice assimilation in obstruent clusters is common, while voice assimilation between a sonorant and a preceding obstruent is rare (Mielke 2008,

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[19] Larson (2016:66) states that *W is reconstructed no higher than Mississipi Valley Siouan, but the Comparative Siouan Dictionary shows Proto-Siouan *Wa:si 'pine tree' and *Wá:te (?) 'boat'.

[20] In contrast, Mandan appears to have inherited the Proto-Siouan pattern without change: it has phonetic [n] and [m] only as allophones of non-nasal consonants adjacent to nasalized vowels.

[21] See Michaud, Jacques and Rankin (2012) for a detailed analysis of historical nasalization processes in the history of Siouan.

2013). If *W and *R are treated phonetically as voiced obstruents, we can better understand the source of the unusual process of pre-sonorant voicing in Lakota.

Recall that, in Lakota, /p/ and /k/ are pronounced as voiced [b] and [g] respectively before sonorants /w l m n/: [bl] from /pl/; and [gw], [gl], [gn] and [gm] from /kw/, /kl/, /kn/ and /km/ respectively ((2) and Table 8). In the non-shaded rows of Table 15, these Lakota clusters are compared with cognate clusters in other dialects.

Table 15. Voiced obstruents across the Lakota-Dakota dialect continuum

Proto-Siouan	pre-form[22]	Lakȟóta	Yanktonai	Yankton	Sisseton-Santee	Assiniboine	gloss
*i-Ró:te	***R**oté	**l**oté	**d**oté	**doté**	**d**oté	**noté**	'throat'
*sará:	*s**R**á	s**l**á	s**d**á	s**d**á	s**d**á	s**n**á	'greasy'
*parás-ka	***WR**aska	**bl**aská	**bd**aská,	**bd**aská,	**bd**aská, (†**md**aská)	**mn**aská	'to be flat & solid'
	*kWéza	**g**wéza	**g**béza	kbéza	hbéza	kméza	'rippled, ridged'
*kré:šE	*kReš-ka	**g**lešká	**g**dešká	kdešká	hdešká	knešká	'spotted, striped'
*karą́škV	*knaška	gnašká	gnašká	knašká	hnašká	knašká	'vermin'/ 'frog'
	*kma	**g**má	**g**má	kmá	hmá	kmá	'walnut'

The first shaded row illustrates *l/d/n* correspondences independent of cluster phonotactics, and the second shaded row shows that fricatives do not assimilate in voicing to a following consonant.[23] Of specific interest are the bolded singleton consonants and consonant clusters in Table 15. In the shaded cells, singleton *R and cluster *WR are continued as voiced singletons and clusters (whether sonorants or obstruents) respectively in all dialects. In the non-shaded cells, bolded singletons are the result of dialectal voicing processes. In Lakota, as already discussed, the pattern is one of pre-sonorant voicing as in ***g**wéza* < *kWéza. However, in Yanktonai, the pattern appears to be one of regressive voice-assimilation from a voiced oral stop to a preceding oral stop as in ***g**béza* < *kbéza < *kWéza. (Sisseton-Santee and Assiniboine show no evidence of obstruent voicing in parallel contexts.) In cases where a pre-form contains an initial *WR cluster, voicing is continued in both consonants independently, as in *bdaská, mnaská* < *WRaska. Returning to the typological observation above, cross-linguistically, pre-sonorant voicing in obstruent-sonorant (OR) consonant clusters is extremely rare. For example, in Indo-European, where OR clusters are reconstructed, there is no evidence in any of the 300+ languages of initial *kl > gl. In contrast, voicing assimilation between obstruents in tauto-syllabic clusters is the norm cross-linguistically (Mielke 2008, 2013), with notable exceptions in languages like Hebrew, Khasi, and Tsou (Kreitman 2008, Blevins 2010). Given these facts, a view of *W and *R as phonetically voiced obstruents is indirectly supported by their role in triggering voice-assimilation in word-initial

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[22] For the purposes of this discussion, we have replaced standard Proto-Dakota *r and *w with *R and *W to signal to the reader that these sounds may have had obstruent-like properties. Proto-Siouan *pr- and *wr- (from vowel syncope) merge as MSV *[b]r, and *wr merges with MSV *[b]r in Proto-Dakota, where [b] could be represented as *p, *b, *w, or *W, since there is no contrast in this context. We write these as *WR here.

[23] Since our interest is voiced obstruents, forms like Lakota-Dakota *mní* 'water' < *Wni < Proto-Siouan *wa-rį́:, where nasal-assimilation takes *bnį > mní in Proto-Dakota, are not included in Table 15.

clusters like those illustrated in Table 15. We conclude that one possible view of Proto-Dakota *r and *w (or, as written here, *R and *W) is that these sounds were voiced oral dental and labial stops *d and *b respectively, with short closure durations and weak bursts.

4.2 Lakota /l/ from *d

If Proto-Dakota *r/*R was pronounced something like [d], and Lakota /l/ is a regular reflex of this sound, then a sound change of *[d] > [l] is motivated.

Some support for Lakota /l/ < *d can be found in data related to the process of coda-voicing. Recall that in the modern language, /p/, /t/, /k/ are pronounced as [b], [l], [g] respectively in the coda when phrase-final devoicing and/or assimilation to a following voiceless obstruent are absent. If voicing had begun as a natural phonetic process, the voiced counterparts of /p t k/ would be [b], [d], [g], not [b], [l], [g].

Evidence for earlier coda *[d] might be found in what could be interpreted as old compound forms. Consider the compound, *lotkhú* 'the underjaw of animals' (Dakota *dotkhú*) from *loté* 'throat + *khúl* 'down, below, underneath'. Recall that the expected coda form of /t/ is [l], so we expect ***lolkhúl*, not the attested *lotkhú*. The attested form is consistent with earlier /t/ > [d] in the coda, followed by local regressive devoicing under resyllabification (5.iv). Loss of final /l/ of /khul/ may also be an indicator of the age of the compound. Another word that may represent an old compound, is the interjection *lotkȟúŋkešni* 'oh, by the way; incidentally; I forgot to mention; to go back to the subject', with a variant *lolkȟúŋkešni*. While the etymology of this term is unclear, final -*kešni* appears to be from /-kA-šni/ 'kind.of-not', while one might speculate that -*kȟuŋ*- could be the root of *kȟuŋyáŋ* 'quickly, promptly', an archaic term that usually begins a command. Here again, [t] can be interpreted as a devoiced/resyllabified instance of earlier *d, with the [l]-variant a continuation of coda *[d].[24] A final example of this kind is the pair of variants *pȟel'ížaŋžaŋ, pȟetížaŋžaŋ* 'lamp, light' from *pȟéta* 'fire' + *ižáŋžaŋ* 'to be lit, give light'. Here, [t] in *pȟetížaŋžaŋ* appears to be a reduction of [.t'] < [d.'], showing the stage prior to *d > l, while [l] in *pȟel'ížaŋžaŋ* is the modern (post *d > l) version of the same compound.

Another potential indicator of *d as the source of Lakota /l/ occurs in reduplicated forms. Recall that there is evidence for coronal dissimilation in reduplication: by rule (5iii) l.T → g.T, where T is a coronal consonant: from *lúta* 'red', we have *lugluta* 'red (inanimate plural)'. If we are correct in hypothesizing Lakota l < *d, the historic dissimilations (after coda-voicing) are *d.d > g.d (> gl), *dš > gš, *ds > gs, and *dč > gč. In contrast, assuming l < *l (or any coronal sonorant) implies dissimilations like *l.l > g.l, *l.š > gš, *l.s > gs, and *l.č > gč. Since dissimilation of place is more likely when the target consonants share manner features, and since a simple change of place (under place dissimilation) is more natural than a change of place and manner, the first set of dissimilatory changes seems more likely than the second set. Since forms with

[24] These [l]/[t] coda variants in pre-consonantal position should not be confused with [l']/[t] variants in compounds whose second members are vowel-intial. In arguably new compounds like *Lakȟóta-iyÀ* 'to speak Lakota' and *Lakȟóta-iyàpi* 'Lakota language', where the second member is vowel-initial, there are two common variants, one with intervocalic [l'] (often lenited to [l]) and one with [t], as in, e.g. *Lakȟól'iyà, Lakȟótiyà* 'to speak Lakota'. In these cases, the variant with [l'] is considered older and more formal than that with [t].

reduplicated coda [g] for /l/ are arguably old (in some cases, replaced with productive [l] forms), they are consistent with an earlier stage of the language where the voiced coda form of /t/ was [d]. Under this analysis *sótA* 'clean, clear' has the old reduplicated form *soksóta* (< *sog-sóta < *sod-sóta), supported by the fact that the base *sótA* 'clean, clear' is obsolete in modern Lakota. In contrast, *yusótA* 'to use something up, expend', shows a productive reduplication *yusólsota*, where, in the synchronic phonology, coda /t/ is realized as [l].

If we are correct in hypothesizing an earlier stage of Lakota where /p/, /t/, /k/ were realized as [b], [d], [g] in the coda respectively, with evidence for the persistence of voiced stops [b] and [g] presented in section 3, then a subsequent sound change *d > l is needed to account for the distribution of /l/ in the language. This sound change appears to be context free, and is supported by two kinds of evidence discussed above: compounds where first members have [t]- and [l]-final variants; and reduplicated forms where first members have [g]- and [l]-final variants. In both cases, obstruent-final variants reflect a stage of the language before the *d > l sound change: in compounds, *d > [t] in (resyllabified) complex onsets; and in reduplicated forms, *d > [g] under dissimilation with a following coronal obstruent. In sum, many instances of Lakota [l], including most of those in morpheme-initial and intervocalic position of inherited roots, are direct reflexes of Proto-Siouan *r or *R, which, we suggest, merged as *R, a voiced dental [d]-like obstruent, pre-Lakotan *d, which underwent *d > l.[25] Other instances of surface [l] are continuations of Proto-Dakota *t, pre-Lakota *t, which underwent regular voicing (see 4.3) to *d, and subsequent *d > l.

4.3 Precursors of final voicing in intervocalic coarticulatory voicing

If Lakota coda /l/ < *d, then there appears to be evidence of a historical obstruent voicing taking /p, t, k/ to [b], [d], [g]. Since final obstruent voicing is exceedingly rare cross-linguistically, and since we have evidence in all cases that these stops were historically medial, not final, it seems reasonable to investigate the possibility that synchronic coda voicing is somehow a transform of an earlier intervocalic voicing process.

As we demonstrated in section 2, syllable-final voicing in Lakota is associated with truncation (5i). Since Proto-Dakota had only open syllables, the closed syllables created by truncation are new structures, not subject to any pre-existing constraints on codas in the language. Nevertheless, there are conditions on truncation: in Lakota, truncation only occurs in non-compound forms when the final vowel is preceded by a single consonant (not a cluster), and when that single consonant is an obstruent or /l/ (not /n/, /w/, or /y/).[26] The picture becomes more complicated when truncated forms are compared across dialects, with representative data in Table 16, where '?' marks suspect forms from the published literature that require audio verification.

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[25] In a few cases, Dakota /l/ continues Proto-Dakota *y-.

[26] Here again, we see /l/ patterning with the obstruents, suggesting historical *d. For pre-vocalic /m/, there is only one example where truncation may be observed: the proper noun *Iktómi* 'the trickster of Lakota myths' can be contracted to *Iktó*.

Table 16. Truncation patterns across dialects

	MEDIAL ONSET	TRUNCATION/ WORD-FINAL	TRUNCATION/ MEDIAL PRE-CONSONANTAL
p < *p	L *tó**p**a* 'four' Y *tó**p**a* S *tó**p**a* A *tó**p**a*	L *tó**b*** Y *tó**b*** S *tó**b*** A *tó**m***	L *tó**b**topa* 'by fours' Y *tó**b**topa* S *tó**b**topa* A *?tó**p**topa* (vs. *num.nu.pa* 'two')
t < *t	L *glusó**t**A* 'to use one's own up' Y *gdusó**t**A* S *hdusó**t**A* A *knusó**t**A*	L *glusó**l*** Y *gdusó**n*** S *hdusó**n*** A *knusó**n***	L *glusó**l**sotA* Y *gdusó**n**sotA* S *hdusó**n**sotA* A *?knusó**n**sotA*
k < *k	L *oglá**k**A* 'to tell one's own' Y *ogdá**k**A* S *ohdá**k**A* A *okná**k**A*	L *oglá**g*** Y *ogdá**g*** S *ohdá**g*** A *okná*[**g**]	L *oglá**g**khiyA* 'to let sb tell his/her own' Y *ogdá**g**khiyA* S *ohdá**g**khiyA* A *okná**k**khiyA*
l,d,n <*R	L *tȟa**l**ó* 'meat' Y *tȟa**d**ó* S *tha**d**ó* A *tȟa**n**ó*	L *buyáke**l*** 'with thuds' Y *buyáke**d*** S *buyáke**d*** A *muyáke**n***	L *tȟa**l**'ágnake* 'rigid goldenrod' Y (*tȟa**n**'ágnake*) S (*tha**n**'áhnake*) A *tha**n**'áknaŋke*
l,d,n <*R	L *lo**l**-*, *lo**t**-*'food' Y *do**d**-* S *do**d**-*		L *lo**l**'óphiye,* 'leather bag for storing *lo**t**óphiye* meat' Y *do**t**óphiye* S *do**t**óphiye*

Truncated forms in other dialects show voiced codas, though, as in Lakota, the voicing can be allophonic (as for /g/), phonemic (for /p/ to [b]), or phonemic and coupled with a shift from obstruent to sonorant (for /t/ to [n]). Two notes are in order regarding the Assiniboine data. First, there is a regular rule of coda-nasalization: /p/ and /t/ become [m] and [n] respectively when they are word-final, or when followed by a sonorant consonant; /k/ is unaffected, since there is no velar nasal in the language (Cumberland 2005:70-71). Second, there is some evidence that Assiniboine /n/ and /m/ were historically post-ploded nasals [n^{d}] and [m^{b}] when followed by oral vowels (Cumberland 2005:25-26). Where the (albeit functionally weak) constrast between intervocalic /t/ and intervocalic /l, d, n/ (< *R) is neutralized in Lakota and Assiniboine, the contrast is maintained in *d*-dialects by /d/ > [d], but /t/ > [n], where, perhaps, as in Assiniboine, [n] continues and earlier [n^{d}]. Though there have clearly been distinct paths of phonologization of voicing for coda consonants, we suggest a phonetic change of /p, t, k/ > [b, d, g] for Dakotan generally intervocalically before final unstressed (voiceless) vowels, supported by modern Assiniboine sound patterns, as discussed below.

The phonetic realization of /p, t, k/ > [b, d, g] for Dakotan that we hypothesize is one that is grounded in co-articulation of a weak final vowel. We suggest that the weak articulation of the vowel is, in part, manifestation of the anticipation of articulatory features from the vowel to the preceding consonant. Part of this anticipation yields voicing of the consonant. In other words, the weaker the articulation of the final vowel, the more vowel-like (in terms of voicing/sonority) the articulation of the preceding consonant. Ultimately, the final vowel may be devoiced, as described below for Assiniboine, or lost altogether, as described above for Lakota. Under our analysis, it appears that something close to Kiparksy's sequence of sound changes involving intervocalic voicing followed by final vowel-loss has occurred. What makes Lakota special, or unusual, is that when the final vowel is not reduced, there is no evidence of intervocalic voicing. It is only when final vowels are significantly reduced, or lost altogether, that voicing of the once-intervocalic derived coda is realized.

Our analysis of Lakota voicing as a modified version of intervocalic voicing is consistent with facts about the phonetics of closely related languages, and with our own data, where some voiceless stops show voicing between vowels. Many Siouan languages show intervocalic voicing of (voiceless) stops in running speech. One of these is Assiniboine (Nakota) as described by Cumberland (2005).[27] In Assiniboine, the voiceless unaspirated stops are voiced intervocalically, but voiceless elsewhere (Cumberland 2005:18). Of particular interest to this study is Cumberland's (op cit.) description of words like /t^{h}oka/ 'enemy', spoken in isolation. She transcribes this word as [tog^{a}] where the intervocalic /k/ of /t^{h}oka/ is voiced, and the final vowel of the same word is devoiced. Acoustic data is provided to support this analysis, and Cumberland (2005:78) is explicit in detailing a rule of word-final vowel devoicing, and in saying that "voiceless vowels will still trigger intervocalic voicing so that, even when the vowel is virtually inaudible, evidence of its presence may be seen in a preceding obstruent". Our phonetic study of Lakota revealed similar "intermediate" stages in some tokens where final voiced obstruents were released into voiceless vowels. Spectrograms illustrating final voiceless vocalic release can be reviewed in Figure 4. Though truncation typically eliminates final weak vowels in Lakota, we suggest that obstruent voicing, as a historical process, reflects an earlier stage of the language where voicing was non-contrastive, and intervocalic stops were voiced before unstressed, reduced final vowels, a pattern extended to all intervocalic stops in Assiniboine. As noted above, what makes Lakota unusual is that when final vowels are not reduced, there is no evidence of intervocalic voicing. This is why we view historical obstruent voicing in Lakota as a phonetic process concomitant with final vowel reduction and loss.

While we have only touched the surface of the history of obstruent voicing in the Dakotan languages, the evidence in sections 2 and 3 strongly suggest a synchronic sound pattern whereby Lakota /p/ and /k/ are voiced to [b], [g] in syllable-final position. We attribute the full set of alternations, including /t/ pronounced as [l] to an earlier sound change of intervocalic /p, t, k/ > [b, d, g] concomitant with reduction of final unstressed vowels, including vowel devoicing and loss. This sound change was followed by a context-free change of *d > l in Lakota, supported by data presented in 4.2.

[27] Recent work on the Stoney variant of Nakhóta by the third author of this paper suggests a similar sound pattern, with regular voicing of intervocalic stops.
There is at least one language, Gitksan, where an acoustic study demonstrates voiced allophones of voiceless unaspirated stops in pre-vocalic position (Rigsby and Ingram 1990).

5. Summary and implications for phonological theory

In section 2 we described Lakota sound patterns that appear to involve a synchronic process whereby stems ending in ...VTV, T a voiceless unaspirated stop or affricate, can be pronounced as ...VD, D a voiced consonant. Under this process, /p, t, k/ are pronounced as [b, l, g] in syllable-final position. Our laboratory phonology study in section 3 provides phonetic evidence that /p/ and /k/ undergo voicing, and maintain their obstruent quality. The segments reported as [b] and [g] in syllable-final position in the Lakota literature are not lenited segments: they are typically produced with significant closure duration, are voiced for the duration of closure when not in a devoicing environment, and have bursts consistent with production of oral stops. In cases where voicing was partial or absent, it was explained by context-sensitive devoicing: phrase-finally there is gradient devoicing, while before voiceless obstruents and /h/, voiced obstruents tend to be devoiced. The Lakota voicing process is an unusual one from a phonological perspective as it is neither wholly neutralizing nor wholly allophonic. In the case of /t/ to [l], a robust contrast exists, and so, final voicing can be seen as neutralizing, though, of course, this alternation can be viewed in terms other than final voicing. In the case of /p/ to [b], a weak contrast exists between /p/ and /b/; here voicing is neutralizing, but hardly. In contrast, for /k/ to [g], voicing is purely allophonic: Lakota, like other Dakotan languages, has /k/, but no /g/. Given the non-uniformity of the phonological alternations involved, the psychological reality of the process of final voicing may also be non-uniform. In this context, it is interesting to note that most orthographies represent [b] as <b> and [g] as <g> (e.g. *tópa, tób* 'four'; *íyotaka* 'sit down', *iyotagkhiya* 'to cause someone to sit down') (Rood and Taylor 1985), and further, that "the most widely used transcription systems do not consistently write these instances of /p/ and /k/ with *b* and *g* when a voiceless obstruent follows", suggesting that speakers could be aware of the contextual devoicing described in section 3 as well. Our historical discussion in section 4 provided support for a historical pattern of intervocalic /p, t, k/ > [b, d, g] before final unstressed vowels, concomitant with devoicing and/or loss of these vowels, as still found in modern Assiniboine, and some tokens in our Lakota database. Under this analysis, Lakota underwent a later *d > l change, distinguishing it from the *d*-dialects.

The historical source of Lakota final obstruent voicing in an earlier intervocalic stop-voicing process, followed by final vowel loss, is of theoretical import. Kiparksy (2006) adopts a general (violable) universal constraint prohibiting obstruent voicing in syllable codas on the basis of the following argument: if this general universal constraint did not exist, how could we explain the fact that, of the many languages with intervocalic voicing, and the many languages with final weak vowel loss, not one shows a progression whereby intervocalic voicing of /p, t, k/ to [b, d, g] is followed by final vowel loss, yielding a sound pattern where only voiced stops are found word-finally? In earlier work, Blevins (2006a, 2006b) suggested Somali as such a case modulo more recent final devoicing, but the argument from Lakota is stronger. In Lakota, we have clear phonetic data supporting voicing of /p/ to [b] and /k/ to [g] in the coda (see section 3), with comparative evidence from Assiniboine (Cumberland 2005) attesting intermediate stages of intervocalic voicing with final vowels intact, with final vowels devoiced, and with final vowels lost. Further, we can see why final voicing is precarious, and rarely attested. In Lakota, the process was rendered non-uniform by the *d > l change, and is currently evidenced only where later processes of phrase-final devoicing and regressive devoicing are not found. We are led to conclude that Kiparsky's (2006) argument is flawed. Consistent with Evolutionary Phonology (Blevins 2004, 2006a, 2006b, 2015), Lakota illustrates a possible, but fleeting instance of syllable-final obstruent voicing. In languages where intervocalic voicing of plain voiceless stops is the norm (Kakadelis 2018), loss of final vowels can yield final-voicing sound patterns as well. However, synchronic sound patterns of this kind may be rare due to the high frequency of final obstruent devoicing and voice-assimilation, two processes with well-studied phonetic bases.

We conclude that the Lakota language, as currently spoken, shows evidence of a rare pattern of syllable-final obstruent voicing. The oral stops /p/ and /k/ are voiced to [b] and [g] in syllable-final position, while /t/ is pronounced as [l] in the same position. Since we have only examined oral stops in the context of oral vowels, sound patterns in the context of nasalized vowels may differ and are deserving a further study. Obstruent devoicing is also in evidence. Fricatives /z ž ǧ/ are devoiced to [s], [ʃ] and [χ] in syllable-final position. In addition, there is evidence of variable initial stop devoicing, gradient phrase-final devoicing, and fairly regular regressive devoicing of [b] and [g] before voiceless obstruents and /h/. Our conclusion is consistent with earlier descriptions of Lakota phonology (e.g. Rood and Taylor 1985, 1996; Ullrich 2008, 2011, 2018, 2019; Ullrich and Black Bear Jr. 2016), building on these in three ways. First, we support the sound pattern of syllable-final stop voicing with acoustic analyses of syllable final stops in the language. Second, we use the same acoustic evidence to argue for gradient phrase-final devoicing and regressive devoicing before voiceless obstruents. Third, we offer a preliminary historical explanation for the final voicing process, and for its rarity: final voicing is a consequence of earlier, conditioned intervocalic voicing, preserved only when the final vowel was reduced or lost. Finally, we highlight the importance of the Lakota sound patterns to phonological theory. Traditional markedness accounts predict that such sound patterns do not and should not exist. In contrast, phonetic-historical accounts like Evolutionary Phonology explain skewed patterns of voicing in terms of common phonetically-based voicing and devoicing tendencies, allowing for rare cases of final-obstruent voicing like that found in Lakota.

Like many indigenous languages of the Americas, Lakota is endangered. The acoustic component of this study serves to highlight the central role of endangered language documentation in phonological description and theory (Blevins 2007) and the continued importance of producing high-quality recordings in language documentation, as exemplified by *The New Lakota Dictionary*. Independent of its scientific merit, we hope that this study of one indigenous language of the Great Plains will inspire other researchers to bring important data from indigenous languages to bear on central issues in linguistic theory, and encourage colleagues around the world to continue their excellent work in high-quality language documentation.

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