Grounded Constraints and The Consonants of Setswana☆

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Abstract

The article examines the phonology and phonetics of Setswana obstruents and the well known and controversial post-nasal devoicing rule, which has been cited as a counterexample to the claim that markedness constraints are phonetically grounded (Hyman 2001). We re-examine the case of Setswana and argue that it must be analyzed in terms of grounded constraints. Our evidence comes from two sources. First, we report on the results of a phonetic study of six speakers of the Sengwato dialect of Setswana. We found that some of our speakers did not have voiced obstruents in any context. Those speakers that did devoice post-nasally also devoiced in other contexts. Thus, a phonetic examination of the purported counterexample to phonetically grounded constraints fails to support the traditional descriptions. Second, we examine the larger phonological context in which the Setswana alternations occur. Setswana has a gapped system of laryngeal contrasts, so the evidence for post-nasal devoicing comes almost entirely from labial stops. The language also has a series of so-called strengthening alternations that affect consonants such as liquids and fricatives post-nasally—alternations that we propose to analyze in terms of the Syllable Contact Law.

Keywords: Voicing, ejectives, post-nasal voicing, substantive grounding, prominence scales, phonetic scales, markedness, Syllable Contact Law, Setswana, Tswana

1. Introduction

1.1. Setswana and Grounded Constraints

One of the most important unsettled issues in phonological theory is how phonology is connected to phonetics. In the most extreme functionalist view, there is no need for a special phonological component at all—what some call phonology is just an artifact of phonetics, perception, and historical change. In the most extreme formalist view, the phonological grammar is completely dissociated from any sort of substantive grounding. The middle ground is to hypothesize that at least some of the phonological constraints are grounded in acoustic and articulatory principles. The framework of Optimality Theory (Prince and Smolensky 1993/2004, McCarthy and Prince 1993 et seq.) does not

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take an official stand on this issue, but much of the work in OT has taken the middle ground on the phonetics-phonology interface. The earliest example in this vein is Prince and Smolensky's proposal for sonority-based constraints on syllable peaks and margins, which are derived from the sonority hierarchy and which are special in that their ranking is universally fixed. Another well-known case is Pater's (1996, 1999) aerodynamically grounded constraint *NC̥, which prohibits voiceless obstruents after nasals. Pater's cross-linguistic survey finds that the constraint has a wide variety of effects, from the relatively obvious post-nasal voicing to the less expected, including deletion of nasals, deletion of obstruents, and nasal-stop fusion. One pattern that is completely unexpected, however, is devoicing only after nasals, and this is exactly what is reported to happen in the Bantu language Setswana (Schaefer 1982, Dickens 1984, Cole 1985, Kruger and Snyman 1988, Hyman 2001). According to traditional descriptions, initial prevoiced stops alternate with voiceless stops[1] when the nasal first person singular prefix is attached:

(1) Setswana post-nasal laryngeal alternations, according to traditional descriptions

bat'a	'look for'	m-p'at'a	'look for me'
direla	'do something for'	n-t'irela	'do something for me'

Hyman (2001) is the first to note the significance of Setswana to the issue of phonetic grounding and constraints such as *NC̥, which he views with some skepticism. The problem he points out is that no constraint seems to favor alternations just post-nasally, and constraints such as *NC̥ actively disfavor such a mapping. Cases such as this feed skepticism of the Optimality-Theoretic approach to phonological typology and phonetic grounding (Odden 2003, Yu 2004, Vaux and Samuels 2005, and others), and it is of utmost importance to examine the facts closely if theories are to rise and fall on them.

The goal of this article is to reconsider the evidence that Setswana presents against grounded constraints. We look at the phonology and phonetics of Setswana obstruents and conclude that not only do many speakers fail to devoice just postnasally, but it is also both possible and necessary to analyze the language in terms of constraints that are grounded in phonetic scales such as voicing and sonority (discussed in detail in the next section). Our evidence comes from two sources. First, we report on the results of a phonetic study of six speakers of Setswana. We found that some of our speakers did not have voiced obstruents in any context. Those speakers that did devoice post-nasally also devoiced in other contexts. Thus, a phonetic examination of the purported counterexample to phonetically grounded constraints fails to support the traditional descriptions. Second, we examine the larger phonological context in which the Setswana alternations occur. As it turns out, Setswana

[1] The literature on Tswana is inconsistent as to how non-voiced unaspirated stops are transcribed. Sometimes, what we transcribe as [mp'at'a] 'look for me' is written [mpata], but there is general agreement that these stops are weakly/variably ejective (see the works cited above). In Tswana orthography, stops in the ejective series are written <p, t, k>. An acoustic study of these stops is described in §3.3.

has a peculiarly gapped system of laryngeal contrasts, so the evidence for post-nasal devoicing comes almost entirely from labial stops. The language also has a series of so-called strengthening alternations that affect consonants such as liquids and fricatives post-nasally—alternations that we propose to analyze in terms of the Syllable Contact Law (Hooper-Bybee 1976, Murray and Vennemann 1983, Gouskova 2004). Syllable Contact concerns sonority, and there is some evidence that sonority distinctions can hinge on laryngeal features. An analysis in a similar spirit has been proposed before (Schaefer 1982), but ours is the first proposal that analyzes Setswana alternations in terms of a universal sonority hierarchy.

1.2. Grounded Constraints and Laryngeal Features

In this article, we will argue for a middle ground view of the phonetics-phonology interface. Markedness constraints are based on scales of well-formedness, which arrange linguistic structures from best to worst (Prince and Smolensky 1993/2004 et seq.). The relationship between constraints and scales is mediated in Con by various mapping principles such as Harmonic Alignment (Prince and Smolensky 1993/2004, de Lacy 2002a, Kenstowicz 1996), Relational Alignment (Gouskova 2004), and functional filters (Smith 2002). Thus, there is a relationship between the constraint set and substantive principles, but it is not the case that phonology *is* phonetics.

Substantively grounded constraints can be broadly divided into two types. The first type includes markedness constraints based on phonetically defined scales of "difficulty." A prime example of this type is *[g], a constraint against voiced dorsal stops. This constraint reflects the aerodynamic challenges of producing a voiced velar: the cavity between the glottis and constriction is so small that it does not allow sub-glottal pressure to be higher than supra-glottal pressure for very long. Voiced labials, on the other hand, are easier to produce, since the oral cavity is large and there is more pliable tissue that can expand and allow aiflow to continue (Ohala 1983, Westbury and Keating 1986, see especially Hayes 1999 for a proposal that encodes this difference in phonological constraints). We will see that Setswana provides evidence for this constraint in its inventory: it lacks voiced [g] entirely, even though [b] and [d] do occur, at least for some speakers. Pater's (1999) *NC̥ falls squarely into this type of constraint, as well.

The second type of markedness is also based on phonetically defined scales, but it has more to do with how a sound is suited to its phonological role than with articulatory difficulty. A classic example of this type is constraints on the sonority of syllable nuclei and margins (Prince and Smolensky 1993/2004). Sonority is a phonetically defined scale, corresponding to intensity (Parker 2002, 2008). It is not a scale of difficulty, however—there is nothing inherently difficult about producing the least sonorous segment (stop) as opposed to the most sonorous one (vowel). Sonority becomes relevant to markedness only in the context of phonological positions. Prince and Smolensky (1993/2004) capture the well-known restrictions on the syllable roles of segments of various sonority levels in their constraint hierarchies that penalize highly sonorous segments in relatively non-prominent positions (e.g., a syllable onset filled by a vocoid) and non-sonorous segments in relatively prominent positions (e.g., a syllable nucleus filled by an obstruent). Prince and Smolensky's formalism, Harmonic Alignment, has been extended to the relationship of sonority to tone (de Lacy 2002b), moraic weight (Zec 1995, Morén 1999), and stress (Kenstowicz 1996). A related proposal extends Harmonic Alignment to sequences of prominent and non-prominent positions, deriving relational constraint hierarchies such as the Syllable Contact Law (Murray and Vennemann 1983) from the same scales (Gouskova 2004). The Syllable Contact Law states that the more sonority falls across a syllable boundary, the better the contact between the syllables. As we will see, Setswana shows effects of the Syllable Contact Law both in its laryngeal phonology and in the behavior of other consonants. Thus, Setswana presents ample evidence of both types of constraints: its inventory of contrasts reflects constraints grounded in aerodynamic principles, and its morphophonemic alternations arise in response to phonological constraints grounded in the sonority hierarchy.

The remainder of the article is structured as follows. In section 2, we provide some phonological background on the dialect of Setswana that is the focus of our study. Section 3 reports on a phonetic production study of Setswana obstruents. As we demonstrate, some aspects of the system are quite stable, whereas others vary a lot by speaker. In particular, section 3.4 examines the realization of stops that are written as voiced and shows that these stops are not true voiced stops in all contexts for any of our speakers. We then move on to develop a phonological analysis of our speakers' grammars in section 4. Section 4.6 addresses some criticisms of purely phonological analyses of Setswana, and section 5 concludes the article.

2. Background on Setswana

Our discussion of Setswana focuses on the Sengwato dialect, spoken in north-central Botswana. The consonant inventory usually reported for Setswana (adjusted for Sengwato[2]) is given in (2). We focus here on the laryngeal contrasts among obstruents. There is a full series of unambiguously aspirated stops. There is also a series of stops traditionally described as ejective, though, as we will show in the next section, their bursts are rather weak, and they freely alternate with plain unaspirated stops (as noted by Dickens 1984 and others). As for voicing, Setswana has a gapped inventory, which reflects a familiar aversion to voicing in obstruents (see §1.2). All sources agree that voiced dorsals are completely absent. The coronal [d] occurs only as an allophone of /l/, as explained later in this section. The voiced labial is reported to occur (Schaefer 1982, Dickens 1984, Cole 1985, Kruger and Snyman 1988, Janson and Tsonope 1991, Coetzee et al. 2007), though, as we will show in the next section, it is far from clear that voicing is contrastive even for this place of articulation for all speakers.[3] The evidence for post-nasal devoicing therefore comes primarily from labials—the only place of articulation where there is a three-way laryngeal contrast among stops.

[2] Sengwato is unusual among Setswana dialects in having labio-coronal fricatives and affricates ([ɸ͡ʃa] 'burn,' [mp͡ʃa] 'dog'), which correspond to postalveolars in other dialects ([ʃa], [nt͡ʃa]). See Cole (1985) and Zsiga and Tlale (1998). Sengwato also lacks lateral obstruents. For more details on clicks and other features of the consonantal inventory of Sengwato Setswana, the reader is referred to Cole's discussion and to Tlale (2005).

[3] In this section, we write the so-called voiced stops of Setswana as [b] and [d] to be consistent with older work on the language, which typically uses a pseudo-orthographic transcription. As we show later on, this is not an accurate transcription for some speakers.

Also relevant is that all fricatives are voiceless, and some affricates are as well, though the postalveolar and labio-coronal affricates can be voiced. Non-labial consonants may contrast in rounding, e.g., [k'ala] 'branch' vs. [k'^{w}ala] 'write.' We leave out rounded counterparts of the consonants here to save space, but in regard to laryngeal contrast, they pattern exactly like their unrounded counterparts.

(2) Sengwato consonant inventory as described in Cole (1985), Tlale (2005)

	labial and labio-velar	dental/ alveolar	palatal and postalveolar	velar	glottal	labio-coronal
plosive	p^h p' b	t^h t' (d)		k^h k'		
fricative	ɸ	s	ʃ	x		ɸ͡ʃ
affricate		t͡s^h t͡s	t͡ʃ^h t͡ʃ d͡ʒ	k͡x^h		p͡ʃ^h p͡ʃ b͡ʒ
nasal	m	n	ɲ	ŋ		
approximant		r l			h	
glides	w		j			
clicks		ŋ͡ǀ	ŋ͡ǁ			

The phonology of [d] is unusual compared to the rest of the obstruents. As shown in (3), [l] and [d] are in complementary distribution: [d] occurs before the high vowels [i] and [u], and [l] occurs elsewhere. There are morphophonological alternations between [l] and [d] (see (4); alternating consonants are underlined, with non-alternating forms given in the right-hand column for comparison). All data are from the third author, unless otherwise indicated.

(3) Complementary distribution of [l] and [d]

dip'a	'stubbornly refuse to move'	*lip'a	but:	lep'a	'observe something'	*dep'a
dup'a	'diagnose'	*lup'a		lop'a	'ask for something'	*dop'a
				lap'a	'get tired'	*dap'a

(4) Alternations of [l] and [d]

xo-bol-a	'to rot'	bod-ile	'rotted'	cf.	xo-t'ab-a	'to stab'	t'ab-ile	'stabbed'
xo-bal-a	'to count'	bad-ile	'counted'		xo-bu-a	'to speak'	bu-ile	'spoke'
xo-sɛl-a	'to find'	sɛd-ile	'found'					

Further evidence for the marginal status of [d] comes from loans (see (5)). In loanwords, source /l/ surfaces as either [l] or [d], according to Sengwato phonotactic constraints. Source [d], on the other hand, is consistently borrowed as a voiceless stop, even in environments where [d] may occur in native Sengwato words. As we will see in the phonetic study in the next section, [d] behaves somewhat differently from labials in our data, as well.

(5) Borrowing of source [l] and [d]

bibela	'bible'		t'uru	'expensive'	(from Afrikaans [dyr])
xalasi	'glass'	(from Afrikaans [xlas])	t'ip'i	'dip'	
p'odisi	'police'		k'at'i	'guard'	
			k'ɛnt'ele	'candle'	

Setswana syllables are always open, (C)V. There are no tautosyllabic consonant clusters.[4] Pre-consonantal nasals are obligatorily syllabic, and liquids such as [l] and [r] can only be syllabic as the first half of a tautomorphemic geminate, e.g., [l̩.l]. Stress is always on the penult, and sonorant consonants can bear both tone and stress. Words such as [p'à.ŋ̩̀.k'à] are trisyllabic, with stress on the nasal (see Coetzee 2001, Tlale 2005 for discussions of the phonology of this unusual pattern).

(6) Syllabic sonorants in Setswana

m̩.ma.la	'color'	p'a.ŋ̩.k'a	'to walk bow-legged'
l̩.la	'cry'	m̩.p^{h}a.ɲa	'slap me'
r̩.re	'sir'	mʊ.na.ŋ̩	'mosquito'

Obstruents are always in onset position in Setswana, in one of three contexts:

(7) Distribution of obstruents in Setswana

(a) In absolute word-initial position
(b) Intervocalically
(c) Post-nasally

Another important bit of background of the phonology of Setswana is that there are severe restrictions on what consonants can occur post-nasally. Simply put, only stops can occur in that position—be they ejective, aspirated, or strident (i.e., affricates). Sonorants map to corresponding obstruents postnasally, so /l/ → [t'], /w/ →[k^{w}], and so on. We discuss and analyze this post-nasal fortition process in section §4.

Existing descriptions of the consonant inventory of Setswana raise some questions that must be answered before any further discussion of post-nasal devoicing. First, it is important to verify that there really is a voicing contrast in Setswana. An examination of the phonology suggests that it is limited. Furthermore, traditional descriptions are impressionistic rather than instrumental, and

[4] There are some s+voiceless stop sequences, which are either borrowed or created by high vowel deletion in casual speech. Tlale (2005, §4.4.3) provides some phonological evidence that these are not tautosyllabic.

it can be difficult to hear non-native VOT distinctions (Abramson and Lisker 1970 et seq.). Two recent phonetic studies (Zsiga et al. 2006, Coetzee et al. 2007) have found a considerable amount of variation with respect to voicing (we discuss the latter study in a bit more detail in section 4.4.5). Second, it is necessary to confirm whether laryngeal distinctions are neutralized post-nasally. To foreshadow our results, we found that none of our speakers have the exact inventory shown in (2). Each speaker produced plain voiceless stops in at least some contexts—segments which are sometimes not even reported to be a part of the Setswana inventory. Further, while we did find evidence of a post-nasal alternation for some speakers, the change cannot be consistently described as [+voice] mapping to [−voice]. Rather, the alternation is better characterized as post-nasal fortition, which sometimes—but not always—involves a voicing change.

3. Phonetic study

3.1. Design, participants, and measurements taken

We report here on an experiment that examines the acoustic realization of obstruents in Sengwato Setswana. The data were collected by One Tlale Boyer, a native speaker of Setswana, as part of her dissertation research (Tlale 2005). Six speakers of the Sengwato dialect, three women and three men, were recorded in their home village of Shoshong in north-central Botswana. The speakers were asked to read word lists and sentences illustrating the consonants, vowels, and tones of the language. Each speaker produced three repetitions of each word. Tlale (2005) provides a full analysis of the phonetics and phonology of this dialect; here we discuss only the data for obstruents in words spoken in isolation. Each stop in each environment (word-initial, intervocalic and post-nasal) is represented by two lexical items. There are therefore 6 tokens in each cell for each speaker: two lexical items times three repetitions each. To the extent possible, the consonants to be studied were followed (and preceded, in the intervocalic context) by non-high vowels (usually [a]). This was not possible with [d], since the stop allophone occurs only preceding [i] and [u]. A list of tokens is given in the Appendix. The recordings were digitized at 40kHz and analyzed using the Praat signal analysis program (Boersma and Weenink 2006). Because the recordings were made in the field, there was some background noise (signal to noise ratio: 30 dB), but all crucial acoustic landmarks were evident. All tokens were transcribed by Tlale Boyer and at least one of the other two authors. Disagreements on transcriptions were resolved by consensus.

The following acoustic measurements were made for each token, based on both the waveform and spectrogram. All the measurements are in milliseconds.

1. Consonant duration: from the end of the preceding sonorant, defined by discontinuities in amplitude and waveform complexity, to release into the following vowel, defined by a release burst, or, in the absence of a burst, by abrupt increase in amplitude and onset of higher formant structure. Consonant duration could not be measured for initial consonants. Duration was measured only for post-nasal and intervocalic contexts.
2. Closure duration: that portion of the consonant duration during which the waveform and spectrogram indicate complete closure of the vocal tract: very low amplitude, no frication,

and no formant structure. Closure duration was measured only for post-nasal and intervocalic contexts.

3. Voice onset time (VOT): from release of the consonant to the onset of voicing for the following vowel. VOT includes the duration of the release burst, if any. VOT is positive if there is a voicing lag. VOT is negative if there is pre-voicing, that is, voicing during the consonant that continues into the vowel.
4. Voice perseveration time (VPT, for post-nasal and intervocalic contexts): interval of voicing that continues from the preceding sonorant into the consonant. For a fully voiced consonant, VPT is the same as its negative VOT, and lasts through the consonant's duration.
5. Presence or absence of release burst was noted, and the duration of the burst, if any, was measured.

We discuss our results starting with the most straightforward finding, the aspirated stop inventory (see §3.2), and then moving on to the ejective series (see § 3.3) and the orthographic voiced stops (see §3.4).

3.2. The Phonetics of Aspirated stops

In the phonetic study of Setswana aspirates, our main goal was to establish a baseline description of their acoustic properties. In particular, we wanted to find out whether aspirates had the same acoustic characteristics in initial and intervocalic contexts as in the post-nasal context, since it is a special position in Setswana phonology.

Examples of aspirated stops in each position are shown in (8). Aspirated velars are rare in non-initial position. In the few words that have them, it is difficult to control for rounding of the consonant and for vowel quality, so we did not collect any tokens of non-initial [kʰ]. (The word [ŋkʰʷaɲa] 'tap me' is not in the data set we considered; see the Appendix for a full list of our stimuli and glosses.)

(8) Distribution of aspirated stops

	Word-initial	Intervocalic	Post-nasal
pʰ	pʰala	kxʰapʰa	mpʰaɲa
tʰ	tʰaɲa	latʰa	ntʰaɲa
kʰ	kʰawa	kʰukʰʷaɲi	(ŋkʰʷaɲa)

Our results are shown in Table 1 on page 9, accompanied by our phonological interpretations ("transcription"). The stops are clearly aspirated for all of our speakers. Interestingly, though, even these voiceless aspirated stops show some post-nasal voicing. Voice perseveration time (VPT) is significantly longer following nasals than following vowels: 14.4 ms in intervocalic position (12% of oral closure) vs. 27.6 ms in post-nasal position (26% of closure); a one-way ANOVA with VPT as the dependent variable and position as the independent variable shows that this difference is significant

(F(1, 111)=10.7, $p < .001$). While the oral closure in both cases remained mostly voiceless, some degree of post-nasal voicing is entirely consistent with the cross-linguistic tendency to voice rather than devoice in post-nasal position (Pater 1999, Hayes 1999).

		Word-initial	Intervocalic	Post-nasal
/p^h/	Closure	n/a	128	94
	Burst	11	13	12
	VOT	78	79	87
	VPT	n/a	20	30
	transcription	[p^h]	[p^h]	[p^h]
/t^h/	Closure	n/a	119	122
	Burst	11	14	13
	VOT	67	90	71
	VPT	n/a	11	25
	transcription	[t^h]	[t^h]	[t^h]
/k^h/	Burst	12	n/a	n/a
	VOT	83	n/a	n/a
	transcription	[k^h]	n/a	n/a

Table 1: Measurements for aspirated stops, in ms.

3.3. *The Phonetics of Ejective stops*

In (9) are examples of ejective stops in various contexts. The main questions for our study were (a) whether these stops are truly ejective and (b) whether their realization varies by position.

(9) Distribution of ejective stops

	Word-initial	Intervocalic	Post-nasal
p’	p’ala	ap’a:	mp’exa
t’	t’ala	lat’a	nt’amola
k’	k’ala	sɛk’a	ŋk’op’a

		Word-initial	Intervocalic	Post-nasal
/p'/	Closure	n/a	154	126
	Burst	7	7	8
	VOT	13	10	14
	VPT	n/a	16	25
	transcription	[p]/[p']	[p]/[p']	[p]/[p']
/t'/	Closure	n/a	142	120
	Burst	7	8	9
	VOT	11	12	13
	VPT	n/a	7	22
	transcription	[t]/[t']	[t]/[t']	[t]/[t']
/k'/	Closure	n/a	121	97
	Burst	12	13	16
	VOT	24	33	27
	VPT	n/a	16	31
	transcription	[k]/[k']	[k]/[k']	[k]/[k']

Table 2: Measurements for ejective stops, in ms.

It is important to understand the phonetics of Setswana ejectives, because ejectives are reported to be the result of the post-nasal devoicing rule (Schaefer 1982:150, Dickens 1984:97). We therefore analyze these measures in detail, in order to have a baseline for looking at the orthographic voiced stops. For all three places of articulation in all three positions, the ejective series are clearly voiceless stops with a short-lag positive VOT.[5] Oral closure was on average 83% voiceless (mean VPT of 20 ms into a mean closure duration of 126 ms). Mean VOT was 17 ms. Analysis of variance, however, did reveal some significant effects of both place and position. Analyses of variance were carried out with independent variables place and position and dependent variables burst, VOT, closure duration, and VPT. Results of the ANOVAs are shown in Table 3 on page 11. For significant effects with more than two levels, a Student-Newman-Keuls post-hoc analysis was conducted to determine which groups were significantly different.

[5]Cross-linguistically and even within a single language, ejective stops vary quite a bit in their acoustic characteristics (Lindau 1984, Kingston 1985, Warner 1996, Kingston 2005, Wright et al. 2002, Gallagher 2010). Based on burst strength, closure duration, VOT, and other characteristics, ejectives are sometimes classified into "stiff" and "slack" (Lindau (1984) et seq.). In stiff ejectives, release of oral closure produces a sharp burst, which is then followed by a short period of silence—an indicator of continued glottal closure. Slack ejectives may have a normal burst and shorter VOT, but they may differ from non-ejective stops in having a lower F0 and creaky voice at vowel onset, as well as longer closure duration. Although we did not measure voice quality or F0, our measures of VOT and duration for the Sengwato stops suggest that the stops are weak slack ejectives.

	Factors	d	F	p	direction
Consonant duration	**POA**	2,203	21.49	p<.001	p', t'>k'
	environment	1,203	42.00	p<.001	VCV>NC
	POA*env	2,203	0.61	p=.543	
Burst	**POA**	2,287	31.5	p<.001	k'>p', t'
	environment	2,287	4.40	p=.013	NC>#CV
	POA*env	4,287	0.37	p=.827	
VPT	**POA**	2,203	3.58	p=.03	k'>t'
	environment	1,203	20.52	p<.001	NC>VCV
	POA*env	2,203	0.41	p=.665	
VOT	**POA**	2,287	114.2	p<.001	k'>p', t'
	environment	2,287	1.65	p=.195	
	POA*env	4,287	4.83	p=.001	see text

Table 3: Analyses of variance on ejective stop measures

There are significant main effects of place of articulation on all four measures. Velars have longer VOT and bursts than labials or alveolars, which is unsurprising since velars are produced with a smaller intra-oral cavity and therefore higher intra-oral pressure (Javkin 1977). Conversely, /k'/ had the shortest duration, and its VPT was significantly longer than that of /t'/. The shorter duration of /k'/ may be related to the tendency of velars to lenite more than other places of articulation (Foley 1977, though cf. Kirchner 1998). The reason for the very short VPT for /t'/ is not clear.

Environment had a main effect on three measures. There is a main effect of environment on VPT: there is more perseveratory voicing in stops post-nasally than post-vocalically. (Recall from §3.2 that we found similar perseveratory voicing post-nasally in aspirates, as expected under phonetic explanations for postnasal voicing (Ohala 1983, Westbury and Keating 1986, Pater 1999, Hayes 1999)). There is a main effect of environment on burst duration: it is slightly longer following a nasal than in initial position. The effect of environment on consonant duration is that closures are longer in intervocalic position than in post-nasal position. All consonants are lengthened, though velars are lengthened to a lesser extent than labials and alveolars.

We did not find a main effect of environment on VOT. There is, however, an interaction of environment and place of articulation: VOT increases in intervocalic position for velars, but not for labials or alveolars. The increased VOT of velars is unsurprising, given the aerodynamics of ejectives, but it is not clear why this should happen in intervocalic position. It might be that velars build up more pressure behind the longer intervocalic constrictions, but this pressure build-up is only having a significant acoustic effect for the constriction furthest back.[6]

The answer to one of the two questions we posited at the beginning of this section is that there

[6] The increased duration (and for /k'/, VOT) in intervocalic position may be due to several factors, but it is unlikely to be due to stress. In our data, most morphemes are disyllabic CV́CV, with penultimate stress. Thus, intervocalic consonants are usually onsets to unstressed syllables. Onsets of stressed syllables actually tended to be shorter than unstressed syllable onsets, which goes counter to the expected tendency of stressed syllable strengthening. We hesitate to draw significant conclusions from these findings, however—the effects of stress on Setswana consonants would have to be tested in a separate, specially designed study.

is indeed some phonetic variation in the realization of the ejective stops, mostly along the lines predicted by known phonetic tendencies: longer VOT and stronger burst for velars, more phonetic voicing post-nasally. There were a few tokens that showed some partial phonetic lenition. One token of /t'/ was lenited to [ð͡t] (first half fricated and voiced), and 6 tokens of /k'/ were lenited to [k͡x] (second half fricated and voiceless). These seven partially-lenited tokens were in intervocalic position. Only 2 tokens, /k'/ in post-nasal context as pronounced by subject 6, had a negative VOT: 4 ms in both cases. There is no evidence, however, of a phonological category change according to environment: excepting the rare partial lenitions, all the stops in this series in all position are realized as short-lag voiceless stops.

In the remainder of this section we address the other question, whether the stops in this series are truly ejective in Setswana. Dickens (1984) and others observe impressionistically that ejectives in Setswana are quite weak. We confirmed this instrumentally: in many cases, the stops were ambiguous between plain voiceless unaspirated stops and ejectives.[7] The clearest indication of a "slack" ejective is a period of silence after the burst—a sign of glottal closure—rather than a period of breathiness, a sign of glottal opening. In some cases, our recordings clearly showed such glottal closures in the waveform and spectrogram, and the token could be unambiguously transcribed as ejective. In other cases, however, voicing began immediately upon cessation of the burst noise (VOT = burst duration): there was neither silence nor breathiness. These tokens were all predominantly voiceless during the closure, but it could not be determined from the acoustic record whether the voicelessness in these tokens was a result of glottal closure or glottal opening. Such tokens, where VOT was equivalent (within 2 or 3 ms) to burst duration, were transcribed as ambiguous between ejective and plain unaspirated.

Below, we break down the distribution of ambiguous and unambiguous ejectives by place of articulation (Table 4), environment (Table 5), and speaker (Table 6). As can be seen in Table 4, the most unambiguous ejectives were velar, and the most unambiguous plain stops were likely to be labial. These place effects are consistent with the smaller supra-glottal cavity for velars. Even so, both ambiguous and unambiguous tokens could be found at all three places of articulation. As shown in Table 5, environment had no effect on the ambiguity. Different speakers, however, realized stops differently, as shown in Table 6. All six subjects showed some variation, but subjects 5 and 6 were less likely to produce unambiguous ejectives. Subject 6 also tended to lenite velars.

	bilabial	alveolar	velar
no burst	5	3	0
burst duration = VOT (ambiguous)	48	48	16
clear glottal closure (ejective)	47	54	66
other (lenited and/or voiced)	0	1	8

Table 4: Transcription of ejective stops, by place of articulation

[7] This is not unheard of cross-linguistically—see Warner (1996), Wright et al. (2002).

	#CV	VCV	NC
no burst	4	1	3
burst duration = VOT (ambiguous)	28	43	41
clear glottal closure (ejective)	53	54	60
other (lenited and/or voiced)	2	4	3

Table 5: Transcription of ejective stops, by environment

	S1-F	S2-F	S3-F	S4-M	S5-M	S6-M
no burst	7	1				
burst duration = VOT (ambiguous)	8	9	10	18	41	26
clear glottal closure (ejective)	36	30	40	36	10	15
other (lenited and/or voiced)			1			8

Table 6: Transcription of ejective stops by subject

In sum, though there was variation by subject and by place, there were some stops that were clearly ejective and some that were ambiguous for all subjects, all places of articulation, and all environments. We return to the phonological interpretation of these findings in §3.5.

3.4. The Phonetics of Voicing: three types of speakers

The distribution of orthographic voiced stops, as traditionally described, is shown in (10), along with their ejective counterparts in post-nasal position. Recall from §2 that the alveolar stop occurs only as an allophone of [l] before high vowels, and that there are no voiced velars.

(10) Distribution of orthographic voiced stops

	Word-initial	Intervocalic	Post-nasal
b	bala	aba	mp'ona
d	disa	mosidi	nt'ira

The participants of our experiment varied so much in how they realized this series that it would be meaningless to report aggregate quantitative measures. We examine the speakers' productions in detail in the subsequent sections, but as an overview, we present the transcriptions for these stops in each position for each subject (see Table 7). Based on the transciptions, the speakers can be placed into roughly homogenous subsets, within which quantitative measures can be interpreted.

	"b"			"d"		
	initial	intervocalic	post-nasal	initial	intervocalic	post-nasal
traditional descriptions	b	b	p'	d	d	t'
S2 (leniter)	b	β	b	d	ð	d
S4 (general devoicer)	p	p	p	d	t^h	t
S6 (general devoicer)	p	p	p	d	t	t
S3 (positional devoicer)	b	b͡p	p	d	d͡t	t
S5 (positional devoicer)	b	p	p	d	d͡t	d͡t
S1 (mixed devoicer)	p	p	p	d	d͡t	t^h

Table 7: Allophones transcribed for voiced stops

As can be seen from these results, none of the speakers have exactly the distribution described in the literature. No speaker has consistently voiced stops in initial and intervocalic position and voiceless stops in post-nasal position.

Rather, speakers can be divided into three groups: leniters, general devoicers, and positional devoicers. S2 is a leniter: she produces voiced sonorants instead of voiced stops in intervocalic position, and produces no voiceless stops in any position. S4 and S6 are general devoicers. With the exception of [d] in initial position, these subjects do not produce voiced stops at all. Nor do these speakers produce ejective stops instead—our measurements suggest that they maintain a contrast at least in some positions. S3 and S5 may be termed positional devoicers: they produce voiced stops in initial position and voiceless stops post-nasally, but their intervocalic stops are either partially or completely devoiced. S1 has a mixed phonology: she patterns with the general devoicers for labials and with the positional devoicers for alveolars. Finally, altogether, our speakers produced more voiced alveolars than labials. This may be surprising given the aerodynamics of voicing, but it makes a lot of sense in the context of Setswana phonology, where [d] is an allophone of /l/. Before presenting the analysis in §4, we justify our transcriptions by presenting the phonetic data for each group of speakers in turn.

3.4.1. The Leniter

Subject 2, a woman in her 80s, pronounced voiced stops in all positions. Acoustic measures for this subject are shown in Table 8. All of the measurements are the same as the ones we discussed earlier, except for % of duration with closure, which we noted only for this speaker. This measurement is obtained by dividing closure duration by consonant duration.

		Word-initial	Intervocalic	Post-nasal
b	Consonant duration	n/a	111 ms	124 ms
	% of duration w/closure	n/a	0%	100%
	Burst duration	0	0	15 ms
	VOT	-123 ms	=VPT	=VPT
	VPT	n/a	111 ms	91 ms
	% of dur w/voicing	n/a	100%	73%
	Transcription	b	β	b
d	Consonant duration	n/a	80 ms	155 ms
	% of dur w/closure	n/a	0%	100%
	Burst duration	5 ms	0	30 ms
	VOT	-89 ms	=VPT	=VPT
	VPT	n/a	80 ms	145
	% of dur w/voicing	n/a	100%	94%
	Transcription	d	ð	d

Table 8: Measurements for voiced stops, S2

This speaker has voiced consonants in all positions: note the long negative VOT in initial position and long positive VPT in post-sonorant positions. Depending on the environment and place of articulation, the consonants may be stops or continuants. In initial position, we transcribe voiced stops [b] and [d]. In intervocalic position, this speaker produces voiced continuant sonorants: consonants not only with full voicing, but also with high amplitude, formant structure, and no bursts. In post-nasal position, and initial position for [d], the consonants have bursts and lack formant structure.

Some of the other speakers occasionally produced lenited [β] and [ð] intervocalically, as well, but lenition is only systematic for this speaker. Other speakers were more likely to produce lenited tokens in sentence contexts, particularly in the vicinity of /u/ for the labial and preceding /i/ for the alveolar. Since this study focuses on words pronounced in isolation, with consonants in the environment of non-high vowels, these lenited tokens are not included in the acoustic measures reported here for any other subjects, though it is important to note that this option is available. None of the other speakers produced consistently voiced consonants in post-nasal position, however.

3.4.2. General Devoicers

We now turn to our general devoicers. These speakers (a woman and a man in their 30s and a man in his 40s) produce the labial as voiceless in all three positions. The two men (S4 and S6) produced voiceless alveolar stop allophones, [t], in intervocalic and post-nasal position. Table 9 gives averaged measures.

		Word-initial	Intervocalic	Post-nasal
b	(S1, S4, S6)			
	Consonant duration	n/a	90 ms	101 ms
	% of dur w/closure	n/a	100%	100%
	Burst	5 ms	7 ms	9 ms
	VOT	5 ms	4 ms	11 ms
	VPT	n/a	6 ms	11 ms
	% of dur w/voicing	n/a	7%	11%
	Transcription	p	p	p
d	(S4)			
	Consonant duration	n/a	74 ms	84 ms
	% of dur w/closure	n/a	100%	100%
	Burst	22 ms	10 ms	11 ms
	VOT	-82 ms	136 ms	24 ms
	VPT	n/a	9 ms	9 ms
	% of dur w/voicing	n/a	12%	11%
	Transcription	d	t(ʰ)	t
d	(S6)			
	Consonant duration	n/a	72 ms	91 ms
	% of dur w/closure	n/a	100%	100%
	Burst	28 ms	5 ms	15 ms
	VOT	-73 ms	4 ms	35 ms
	VPT	n/a	4 ms	6 ms
	% of dur w/voicing	n/a	5%	7%
	Transcription	d	t	t

Table 9: Measurements for voiced stops, in ms, general devoicers. Data for /b/ averages over S1, S4 and S6; data for the coronal is presented separately for S4 and S6 only.

All three speakers pronounced the labial stop consistently in all three positions as a voiceless stop with short-lag VOT. VOT for the labial is never negative. Bursts are weak and often non-existent, especially in initial and intervocalic position. As was the case for aspirates and ejectives, we found some evidence of post-nasal fortition, with slight increases in duration and VOT in post-nasal position. Voice perseveration is also slightly longer in post-nasal position, although stop closure remains almost entirely voiceless. A one-way analysis of variance (see Table 10) showed that the difference between the intervocalic and post-nasal environments was significant for VOT and approached significance for duration and VPT.

Measure	*d*	*F*	*p*	direction
VOT	1,33	10.26	p=.003	NC>VCV
Duration	1,33	3.02	p=.091	NC>VCV
VPT	1,33	1.65	p=.092	NC>VCV
Burst	1,33	1.02	p=.321	

Table 10: Effect of environment on labials, general devoicers (intervocalic vs. post-nasal position)

For the alveolars, speakers S4 and S6 produced voiceless stops intervocalically and post-nasally and a voiced stop initially. These two subjects were very similar on all measures except one: S4 had a very long VOT in intervocalic position. The representative token here was [mosidi] (with two tonal patterns, meaning 'person who grinds' and 'soot'). S4 in fact devoiced the entire last syllable. It cannot be determined from the phonetic record whether this should be attributed to aspiration on the consonant or to phrase-final devoicing of the vowel. Since we did not find intervocalic aspiration of orthographic voiced stops in any other case, we lean toward the latter. The consonant itself was clearly voiceless, however.

Orthographic voiced stops tend to undergo post-nasal fortition for general devoicers. This is realized as longer duration and VOT for both S4 and S6, and VPT for S6, as shown in Table 11.

Measure	*d*	*F*	*p*	direction
VOT	1,21	6.53	p=.018	NC>VCV
Duration	1,21	6.08	p=.022	NC>VCV
VPT	1,11	7.47	p=.023	NC>VCV
Burst	1,21	.045	p=.834	

Table 11: Effect of environment on pronunciation of alveolars, general devoicers (intervocalic vs. post-nasal position)

In initial position, however, these speakers pronounced the alveolar stop as clearly voiced. There is a long negative VOT (mean 78 ms) and a clear burst. Maintaining voicing in initial position but not intervocalically or post-nasally cannot be a phonetic effect. Aerodynamically, of the three positions where obstruents can occur in Setswana, word-initial position is the most difficult for initiating voicing, which is reflected in phonetically grounded markedness constraints on laryngeal features. In our phonological analysis, we will argue that this effect is due to positional faithfulness to voicing word-initially.

The finding that orthographic voiced stops are actually voiceless for some speakers and some positions raises the question of whether the contrast between this series and ejectives is neutralized here. Acoustic measures for the two series of stops are compared in Table 12. As in Table 9, measures for the labials average over S1, S4 and S6; measures for the alveolars average over S4 and S6 only. VOT data for the alveolars are given for S6 only. Differences found to be significant by t-test are shown in bold. The difference in VOT in initial position for the labials approached significance (p = .057).

	Initial		Intervocalic		Post-nasal	
	p	p'	p	p'	p	p'
Consonant duration			**90**	**135**	101	111
Burst	5	5	6	7	8	9
VOT	**5**	**9**	**4**	**19**	11	13
VPT			6	8	11	21
			t	t'	t	t'
Consonant duration			**73**	**121**	87	91
Burst			8	9	14	13
VOT			**4**	**9**	35	12
VPT			6	10	7	20

Table 12: Comparison of unaspirated stops: orthographic voiced vs. ejective series

Intervocalically, orthographic voiced and ejective stops are distinguished by consonant duration, and, to a lesser extent, by VOT. The underlyingly ejective stops for these subjects were transcribed as unambiguous ejectives in only 16 of 30 tokens, but the ejectives are on average 157% longer than the orthographic voiced consonants, and they have significantly longer VOT. There is no indication that the distinction here is one of voicing.

In initial position, our data do not point to a firm conclusion. We excluded meaures for initial alveolars, since they are clearly voiced for these speakers. For the labials, VOT is longer for underlying ejectives, but the difference is on the cusp of significance. Closure duration cannot be compared for initial consonants, since words were recorded in isolation. Thus, it cannot be conclusively said that contrast is maintained in initial position, although there is a weak indication that it is.

The distinction is not maintained, however, in post-nasal position. In post-nasal position, no significant difference was found on any measure between the orthographic voiced and ejective stops for these speakers. Nor could the authors, including the native speaker, hear any consistent difference (though we did not conduct controlled perceptual experiments with naïve listeners). Stops were transcribed as unambiguous ejectives at about the same ratios: 15 of 30 tokens for orthographic voiced, and 12 of 30 tokens for ejective.

To summarize, our findings are consistent with descriptions in the literature in that these speakers maintain a laryngeal contrast intervocalically but neutralize it post-nasally. Crucially, however, there is no evidence that this laryngeal contrast is one of voicing—rather, the change is from plain to ejective.

3.4.3. Positional Devoicers

Finally, we turn to our last group of speakers, whom we term "positional devoicers." These are subjects 3 and 5 (a woman in her 40s and a man in his 80s), and, for alveolars only, subject 1 (woman in her 30s). Data for their acoustic measures of the orthographic voiced series are shown in Table 13.

		Word-initial	Intervocalic	Post-nasal
b	Consonant duration	n/a	129 ms	157 ms
	% of dur w/closure	n/a	100%	100%
	Burst duration	3 ms	3 ms	8 ms
	VOT	-103 ms	2 ms	7 ms
	VPT	n/a	57 ms	32 ms
	% of dur w/voicing	n/a	44%	20%
	transcription	b	b͡p	p
d	Consonant duration	n/a	95 ms	150 ms
	% of dur w/closure	n/a	99%	100%
	Burst duration	16 ms	16 ms	12 ms
	VOT	-87 ms	13 ms	28 ms
	VPT	n/a	60 ms	33 ms
	% of dur w/voicing	n/a	63%	22%
	transcription	d	dt	t

Table 13: Measurements for voiced stops, positional devoicers. Data for /b/ averages over S3 and S5; data for /d/ averages over S1, S3, and S5

These speakers produce voiced stops for both /b/ and /d/ in initial position. There is a long negative VOT, and bursts are usually present, though they are weak for the labials. There was no formant structure during the closure. For these speakers, voicing is strongest in initial position, again contradicting phonetic tendencies (see §3.4.2). The analysis here is the same as for /d/ for the general devoicers: faithfulness to underlying voicing in prominent initial position.

As was the case for the general devoicers, it is the contrast between intervocalic and post-nasal position that is the most interesting and informative. Significant effects are shown in Tables 14 and 15.

Measure	d	F	p	direction
Duration	1,22	4.13	$p = .054$	NC > VCV
Burst	1,22	12.60	$p = .002$	NC > VCV
VOT	1,22	5.20	$p = .033$	NC > VCV
VPT	1,22	6.01	$p = .023$	VCV > NC

Table 14: Effect of environment on pronunciation of /b/, positional devoicers, intervocalic vs. post-nasal position

Measure	d	F	p	direction
Duration	1,33	24.20	$p < .001$	NC > VCV
Burst	1,33	2.37	$p = .133$	
VOT	1,33	2.20	$p = .147$	
VPT	1,33	13.74	$p = .001$	VCV > NC

Table 15: Effect of environment on pronunciation of /d/, positional devoicers, intervocalic vs. post-nasal position

Table 13-15 show the same post-nasal fortition we found for the other speakers. For the labials, duration, burst and VOT are longer in post-nasal position (though the effect on duration does not quite reach significance). For the alveolars, post-nasal stops are significantly longer.

The distribution of voicing is contrary to phonetic expectations. From an aerodynamic standpoint, we expect the most voicing post-nasally, an intermediate amount intervocalically, and none or very little initially. Instead, for these speakers, voicing is strongest in initial position, and for both labials and alveolars, there is significantly more voicing intervocalically than post-nasally. Initial and intervocalic positions are not the same, however: in intervocalic stops, voicing continues only about half-way through the closure. Releases are consistently voiceless, and VOT is consistently positive. Moreover, intervocalic and post-nasal stops always had perseverative voicing, and VOT was always positive, while in initial position, VOT was strongly negative.[8]

Because these patterns contradict phonetic trends, we will argue for differing phonological specifications for the stops in the three positions for these speakers. Initial stops are phonologically voiced, whereas intervocalic stops are plain and undergo passive perseveratory voicing. Post-nasal stops undergo fortition to [+cg]. A full analysis follows in §4.

3.5. Summary of findings and discussion

To summarize, our phonetic study confirmed some of the impressionistic descriptions of Setswana stops but disconfirmed others. First, we confirmed that aspirated stops were consistently voiceless during closure and had large positive VOT in all three positions. Post-nasal aspirates had significantly more perseveratory voicing than in other positions, and there was some (weak) evidence of intervocalic lenition. Second, we confirmed the impressionistic descriptions of Setswana ejectives as weakly ejective. These stops were consistently voiceless during closure and had short positive VOT in all three positions. Whether these stops were clearly ejective, however, varied by subject and place of articulation. Some tokens were unambiguously ejective, with glottal closure continuing after the release burst, whereas others were ambiguous. In this, Setswana is similar to Hausa, Witsuwit'en, and other languages with weak ejectives (Lindau 1984, Wright et al. 2002).

(11) Summary of findings

	S1	S2	S3	S4	S5	S6	Traditional sources
Aspirates	C^h	C^h	C^h	C^h	C^h	C^h	C^h
Ejectives	C'	C'	C'	C'	C/C'	C/C'	C'∼C
"d", initial	d	d	d	d	d	d	d
"d", V_V	d͡t	ð	d͡t	t^h	d͡t	t	d
"d", N_	t^h	d	t	t	d͡t	t	t'
"b", initial	p	b	b	p	b	p	b
"b", V_V	p	β	b͡p	p	p	p	b
"b", N_	p	b	p	p	p	p	p'

Even though the realization of ejectives varied, we interpret them as phonologically ejective. Recall that for several of our speakers, these stops showed clear evidence of glottal closure at

[8]Recall also that ejectives and aspirates were phonetically unsurprising for these speakers.

release. Those stops must be phonologically specified as [+constricted glottis] (henceforth, [+cg]). For the ambiguous cases, there are two possible analyses. Either the [+cg] feature is phonologically absent, or it is phonologically present but not phonetically realized in such a way as to leave a clear acoustic trace. Five arguments point to the latter analysis:

1. There is positive evidence that at least some stops must be [+cg],
2. There is no positive evidence of breathiness upon release, which would be a sign of glottal opening rather than closure,
3. The place effects (strongest ejective releases for velars, weakest for labials) are in the direction predicted by phonetic tendencies for ejectives,
4. Clear ejective release is phonetically difficult to realize,
5. There are other phonetic cues that a phonological contrast in [+cg] is maintained even in the absence of a clear burst (such as additional length in intervocalic position, shown in Table 2).

We conclude that all stops in the series are phonologically [+cg], and that their weakening is phonetic.[9]

Our key finding that contradicts impressionistic descriptions is that the stops written as “b” and “d” varied widely by subject and position. For one speaker, these stops were voiced throughout, including in post-nasal position. Some of our speakers produced stops that were voiceless in all positions (except [d] word-initially), and at least in some positions, the voiceless stops were distinct from the ejectives. For still other speakers, voicing depended on position in a phonetically unexpected pattern: the stops were voiced in initial position but partially or completely voiceless intervocalically and post-nasally.

Despite this variation, there were some shared trends in the production of orthographic voiced stops. All speakers produced a stronger allophone in post-nasal position. This could be a stop rather than an approximant (S2, the leniter), a fully voiceless stop rather than a partially voiceless stop (S1, S3, S5), or an ejective stop rather than a plain stop (S4, S6). Conversely, in intervocalic position, all speakers produced a weaker allophone. This could be an approximant rather than a stop (consistently for S2 and occasionally for the others), a short plain stop rather than a long ejective stop, or a partially voiced stop rather than a completely voiced or voiceless stop. Finally, all speakers singled out [d], which was voiced in initial position for everyone. This is consistent with the special status of [d] in the phonology of Setswana. Two of the six subjects also produced [b] in initial position but not elsewhere.

We will thus argue that the consonant alternations of Setswana, which have been described in the literature as post-nasal devoicing, are not really about voicing at all. Voiced or voiceless status is a side-effect of other factors, namely, initial faithfulness, intervocalic lenition, and post-nasal fortition.

[9] A reviewer suggests that these stops are underlyingly underspecified for [cg]. A lack of underlying specification for [cg] would not by itself explain why ejection surfaces variably in the output, however, and such an analysis is vulnerable to the familiar criticisms of underspecification (McCarthy and Taub 1992, Steriade 1995).

4. Phonological analysis

4.1. Introduction

We now turn to the phonological analysis of the patterns described above. The phonology of aspirates and ejectives is analyzed in §4.2. In §4.3, §4.3.3, and §4.3.4, we establish the phonology of post-nasal fortition as it applies to fricatives, sonorant consonants, and affricates. With this background, we then turn to our analysis of the orthographic voiced stops, taking each place of articulation in turn. Because our speakers differ in their treatment of coronals and labials, we analyze the phonologies of the leniter, general devoicers, and positional devoicers separately. Although the data are complex, we conclude that all alternations can be accounted for by the ranking of grounded constraints that have cross-linguistic support.

Throughout this section, for each constraint, we provide the phonetic scale it is based on, along with the typological motivation for the constraint. This underscores our main point: the phonology of Setswana can be understood in terms of substantively grounded and cross-linguistically motivated constraints.

4.2. The Phonology of Aspirates and Ejectives

The phonological analysis of the aspirated stops is straightforward: Setswana always maintains a contrast in aspiration, which suggests that faithfulness to [+spread glottis], IDENT[sg], is undominated and ranked above all relevant markedness constraints, such as *[sg] and *NC̥. A constraint against the [sg] feature is needed to account for languages that lack aspirated consonants entirely (Russian) or restrict their distribution (Cuzco Quechua, Beckman 1998 and references therein).

(12) Constraints relevant to aspiration:

IDENT[sg]: "Segments that stand in correspondence must have identical specifications for [spread glottis]." (after McCarthy and Prince 1995)
*[sg]: "Assign a violation mark for every segment associated with [+spread glottis]." (Beckman 1998:198)
scale: C[−spread glottis] ≻ C[+spread glottis]
Note: "≻" means "is more harmonic than"

As shown in tableau (13),[10] a contrast in aspiration will be maintained post-nasally as well as initially in this grammar.

[10] We use hybrid tableaux, which represent both the traditional violation marks and the information about each constraint's preference for the winner (W) or the loser (L) in every loser's row. For example, in tableau (13), Ident[sg] prefers the winner [pʰaɲa], since the winner is faithful to spread glottis and the loser [paɲa] is not. On the other hand, *[sg] prefers the loser, since it has no aspirated consonants. *NC̥'s column is blank in this comparison, since it is satisfied to the same extent by both candidates. For a ranking to obtain in such a tableau, each L has to be preceded by at least one W. See Prince (2000) for more on comparative tableaux, as well as McCarthy (2008) and many others for their uses in OT.

(13) A contrast in aspiration

	/p^{h}aɲa/	Ident[sg]	*[sg]	*NC̥
a.	☞p^{h}aɲa		*	
b.	paɲa	*!W	L	
	/n-p^{h}aɲa/			
a.	☞mp^{h}aɲa		*	*
b.	mbaɲa	*!W	L	L

In our examination of ejectives in §3.3, we argued that the ejective series of stops are always phonologically [+cg], even though they sometimes lack clear bursts due to phonetic factors. The analysis of this series is simple as well: Ident[cg] dominates *[cg], the constraint against glottalic consonants (see tableau (15)). The motivation for this constraint is analogous to that of *[sg].

(14) Constraints relevant to glottalization:

Ident[sg]: "Segments that stand in correspondence must have identical specifications for [constricted glottis]." (after McCarthy and Prince 1995)
*[cg]: "Assign a violation mark for every segment associated with [+constricted glottis]." (Beckman 1998:198)
scale: C[−constricted glottis] $\succ$ C[+constricted glottis]

(15) A contrast in glottalization

/k'ala/	Ident[cg]	*[cg]	*NC̥
☞k'ala		*	
kala	*!W	L	
/n-k'ala/			
☞ŋk'ala		*	*
ŋgala	*!W	L	L

Recall that ejectives have weak bursts in Setswana, but some of our speakers (e.g., the devoicers—see §3.4.2) do maintain a duration and VOT contrast between ejectives and other stops, at least in intervocalic position. This is an argument against analyzing the plain/ejective stop distinction as phonological free variation (whereby Ident[cg] and *[cg] are in a varible tied ranking—see Anttila 2002 and others for formal implementation). Free variation between plain and ejective stops is, however, a plausible analysis of our leniting speaker's phonology. This speaker (S2) produced plain voiceless stops only as variants of ejectives. Devoicing subjects may also have variation between plain and ejective stops in initial position: see §4.4 for further discussion.

4.3. *The Phonology of Post-Nasal Fortition*

This section is dedicated to the phonology of the orthographic voiced stops—specifically, to the restrictions on consonants in post-nasal position in Setswana. Recall that all speakers maintain some sort of a difference between post-nasal stops and corresponding obstruents in other positions. As we will see, the restriction is a general one in Setswana, so we will look at it in a larger context. We start by quickly summarizing the relevant facts that we have not already introduced, and then move on to the phonological explanation for these facts.

4.3.1. *A quick overview of post-nasal alternations in Setswana*

The following generalization holds for Setswana non-geminate consonants:

(16) The only non-geminate heterosyllabic consonant sequences in Setswana consist of a nasal followed by an aspirated, ejective, or strident stop.

This is true as a static phonotactic restriction, but it is also enforced by a range of alternations. These are summarized in (17) and illustrated in (18). (We give more extensive examples in subsequent sections.)

(17) Alternations in post-nasal position

a. Fricatives become stops or affricates

b. Sonorants become obstruent stops

c. Voiced affricates and aspirated stops do not alternate

d. Plain and voiced stops become ejectives (for general and positional devoicers)

(18) Examples of post-nasal alternations, in brief

a.	/n-sup'a/	nt͡sʰup'a	'point at me'	sup'a	'points'
b.	/n-rut'a/	ntʰut'a	'teach me'	rut'a	'teaches'
c.	/n-d͡ʒɛla/	ɲd͡ʒɛla	'eat for me'	d͡ʒɛla	'eats'
d.	/n-pat'a/ or /n-bat'a/	mp'at'a	'look for me'	xopat'a	'to look for'

We will argue that the key to understanding the alternations and generalizations shown here is a sonority-based constraint hierarchy known as the Syllable Contact Law. This constraint hierarchy explains both what happens in sonorants and in the so-called voiced stop series of Setswana. In a nutshell, the argument is that consonants undergo alternations in post-nasal position in response to the Syllable Contact Law; changing the laryngeal features of some consonants is just a consequence of this more general requirement. This is not an entirely new analysis, but we will argue that our treatment improves on earlier analyses (such as Schaefer 1982) because it allows us to understand Setswana in terms of cross-linguistically motivated constraints.

4.3.2. Fortition and the Syllable Contact Law

In §1.2, we suggested that grounded constraints come in two varieties: constraints based on phonetically motivated scales of difficulty, such as *NC̥, and constraints that are derived from phonetically defined scales but do not encode difficulty directly, such as sonority/prominence constraints. The Syllable Contact Law (SCL) is a sonority/prominence constraint hierarchy. According to the SCL, sonority should fall rather than rise or be flat across a syllable boundary: [al.pa] is better than [at.pa] or [ap.la]. Moreover, the greater the difference between a coda and the following onset, the better: [al.pa] is better than [am.pa] (Hooper-Bybee 1976, Murray and Vennemann 1983, Vennemann 1988). Gouskova (2004) and Baertsch (2002) propose to derive Syllable Contact from two related harmony scales: ideal codas are as sonorous as possible, and ideal onsets have the least sonority. In Gouskova's version of the Syllable Contact constraint hierarchy, the relevant positional dimension is not codas and onsets but rather moraic segments and non-moraic segments. There is independent evidence for a phonological requirement for moraic segments to be as sonorous as possible from stress, tonal systems, and syllable structure (Blevins 1995, Zec 1995, Gordon 1999). This is what we will assume here: recall that in Setswana, sonorants can be moraic when they are syllabic, so the nasal-obstruent context shown in (18) is subject to the SCL. Of course, vowels can be syllabic/moraic, too, but for reasons we will get to shortly, vowel-consonant sequences are not considered to be subject to the SCL.

Whether the sonority scale has a phonetic grounding has been somewhat controversial (see Parker (2002) for an extensive literature overview). Parker (2008) makes a convincing case, based on a series of acoustic studies, that sonority is tightly correlated of what he terms "sound protrusions": maximal intensity peaks for vowels, and intensity valleys for consonants. We take these studies to refute the claim that there is no physical basis for sonority (contra Ohala 1990, Harris 2006). They also provide a phonetic underpinning for a phonological assumption that has until now been somewhat arbitrary, namely, that vowels and consonants have separate sonority scales (Gouskova 2004:212). Intensity is the main correlate for both vowel and consonant sonority, but the scales can be split based on the peak-valley distinction. Only "valley" segments, or consonants, are subject to the SCL.[11]

The exact ranking of segment types in the sonority hierarchy is a matter of considerably more disagreement (see Parker 2002, Jany et al. 2007, Parker 2008, and references therein). Almost everyone agrees on something like the following ordering, from most sonorous to least:

(19) A relatively uncontroversial sonority scale: vocoids > liquids > nasals > obstruents (Clements 1990)

[11] A reviewer asks whether it is necessary to separate the sonority scale into two separate scales for consonants and vowels. The reason for this separation is this: if vowels and consonants were on the same sonority scale, we would expect interactions between adjacent vowels and consonants based on sonority: for example, in some languages, obstruent codas should be banned after high vowels but not after low vowels. Such patterns have not, to our knowledge, been reported to exist. There is also a phonetic motivation for the separation; see Kingston (2008) and Parker (2008) for related discussion.

As for finer-grained distinctions within these classes, controversies abound concerning the relative ranking of rhotics vs. lateral sonorants, fricatives vs. stops, the exact place of affricates, and the role of laryngeal distinctions in sonority.[12] The issue of laryngeal features is most important to what happens in Setswana, so we want to be explicit about our assumptions here. It is usually assumed that if any laryngeal feature matters for sonority, it is voicing, and that voiced segments are more sonorous than voiceless ones (Jespersen 1904, Alderete 1995, Boersma 1998, Smith 2002, Gouskova 2004, Gordon 2005, Parker 2008). Phonetically, truly voiced segments have a higher intensity than voiceless unaspirated ones (Parker 2008). On the other hand, the phonological evidence for this sonority ordering is scant, especially since some of the languages cited as evidence (Icelandic, Faroese—Gouskova 2004) distinguish plain vs. aspirated stops rather than voiced vs. voiceless stops. We will assume that what is relevant for the sonority of plosives is the strength of the occlusion. Bursts are the evidence of a build-up of pressure behind the closure, so plosives with clear bursts in their prototypical realizations (aspirates, ejectives) are least sonorous (cf. Morén 1999, who assigns the same sonority/moraicity distinction to aspirated vs. plain stops).[13] This is reflected in the following sonority scale:[14]

(20) A more fine-grained sonority scale: glides > rhotics > laterals > nasals > voiced fricatives > plain/voiced stops > voiceless fricatives > aspirated/ejective stops

Abbreviated as: w > r > l > n > z > d > s > t

Note: ">" means "is more prominent than"

This sonority scale is converted to the SCL constraint hierarchy as follows. Through Harmonic Alignment (Prince and Smolensky 1993/2004), the sonority scale is interleaved with a simple positional prominence scale of moraic/nonmoraic elements, yielding a pair of harmony scales for moraic and non-moraic positions. Moraic positions (i.e., nuclei and weight-bearing codas) are most harmonic when filled with most sonorous segments, and non-moraic positions (i.e., onsets, etc.) are

[12]There has been some disagreement as to whether place distinctions are relevant to sonority, as well (see Blevins 1995 for some discussion). We take a strong position that they are not relevant. Place of articulation can play a role in the sorts of patterns that often constitute evidence for sonority, such as onset cluster phonotactics, but onset cluster restrictions are affected by a number of factors that are orthogonal to sonority (Gouskova 2002, de Lacy 2002a, Gouskova 2004, Smith 2007, Parker 2008).

[13]A few other cases have been cited in support of sonority distinctions between voiced and voiceless stops. In Imdlawn Tashlhiyt Berber (Dell and Elmedlaoui 1985), voiced stops are preferred to voiceless ones in syllabic nuclei, and the language does have a true voiced/voiceless contrast. Its voiceless stops are audibly released, consistent with our conjecture. Parker (2008) cites Koine Greek as another example: it allows [pn] and [kn] as onset clusters but not [bn] or [gn]. Nothing definite is known about the phonetics of Koine Greek stops, but modern Greek lacks [b] and [g] in any context other than post-nasally, and there is considerable dialectal variation in how the voiceless stops are realized (Adamantios Gafos, p.c.), so Greek is not the strongest case. Finally, Pirahã stress has been described as onset-sensitive (Everett and Everett 1984, Smith 2002, Gordon 2005): it is attracted to syllables with voiceless stop onsets more than ones with voiced stop onsets. There are no published instrumental descriptions of Pirahã that we know of, either.

[14]A reviewer raises an objection to our claim that [r] is more sonorous than [l]. This particular position is not unique to our analysis, however (see Jespersen 1904, Selkirk 1984, Blevins 1995, and others), and there is evidence for it even in Standard American English: rhotics can be syllabic in stressed position, whereas lateral liquids cannot. The issue is somewhat peripheral to our analysis, however, since the only crucial distinction is the one between nasals and other liquids, which is uncontroversial.

most harmonic when filled with the least sonorous segments. These resulting scales of positional well-formedness are further translated to apply to adjacent sequences of the relevant structures. This scale is shown in (21). According to the scale, the best syllable contact is one between a glide and a voiceless/aspirated stop, as shown in the leftmost column. The intermediate columns show sequences that have less extreme degrees of sonority drop and moderate sonority rise. The worst syllable contact (rightmost column) is formed by a voiceless stop followed by a glide, with a sonority rise of 7 steps on the sonority scale. To aid the reader, we boldface the sequences that are crucially distinguished in Setswana: the sequence of a nasal followed by an aspirated or ejective stop, such as [nt^h] or [nt'], is preferred to a sequence of a nasal followed by a voiceless fricative, plain stop, or a liquid. These disallowed sequences are boldfaced and starred.

(21) The Syllable Contact Scale (Gouskova 2004)

most harmonic			≻	…	≻ intermediate ≻…						≻	least harmonic		
w.t	w.s	w.d	w.z	w.n	w.l	w.r	w.w	r.w	l.w	***n.w**	z.w	d.w	s.w	t.w
	r.t	r.s	r.d	r.z	r.n	r.l	r.r	l.r	***n.r**	z.r	d.r	s.r	t.r	
		l.t	l.s	l.d	l.z	l.n	l.l	***n.l**	z.l	d.l	s.l	t.l		
			n.t	***n.s**	***n.d**	n.z	n.n	z.n	d.n	s.n	t.n			
				z.t	z.s	z.d	z.z	d.z	s.z	t.z				
					d.t	d.s	d.d	s.d	t.d					
						s.t	s.s	t.s						
							t.t							
−7	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	+7

The scale corresponds to the constraint hierarchy shown in (22). Each of the constraints in this hierarchy bans a distinct column in the Syllable Contact Scale: for example, *Dist-3 is violated by any of the sequences that have a sonority drop of 3 points, including {r.z, l.d, n.s, z.t}.

(22) Syllable Contact Hierarchy: *Dist+7 ≫ *Dist+6 ≫ *Dist+5 ≫ *Dist+4 ≫ *Dist+3 ≫ *Dist+2 ≫ *Dist+1 ≫ *Dist 0 ≫ *Dist−1 ≫ *Dist−2 ≫ *Dist−3 ≫ *Dist−4 ≫ *Dist−5 ≫ *Dist−6 ≫ *Dist−7

According to this constraint hierarchy, post-nasal position is ideally filled by a voiceless, bursty stop. This is in fact what we find in Setswana: in post-nasal position, only bursty stops are allowed. If we assume that sonority must drop at least four points in a sequence of two consonants, the alternations in (17) can be understood as a consequence of the interaction of *Dist-3 and various faithfulness constraints. This is the basis of the analysis we develop in the subsequent sections.

Before moving on to the analysis, a word is in order regarding the relationship between scales such as (21) and phonetic difficulty scales such as the one that *NC̥ is based on. The constraints appear to demand opposite things, but they are really orthogonal: there are some circumstances when only one of the constraints is relevant. For example, Syllable Contact does not apply to a configuration of a nasal followed by a voiceless stop where both consonants are non-moraic, say, if both are in an onset or if one of them is a word-initial prosodic word appendix. *NC̥ would still be relevant in this configuration, however, since its definition does not mention prosodic position. Thus, a syllable with the onset [mp] would violate *NC̥ but not *Dist−3. As we will see, *Dist−3 is a key player in the phonology of Setswana, while *NC̥ is not. Other phonetic difficulty-based constraints do play a role, however, so the system is entirely consistent with the view that phonology is phonetically grounded.

4.3.3. Postnasal Fortition of Fricatives

Fricatives in Setswana are always voiceless, and they occur freely in initial and intervocalic position. Post-nasally, fricatives become stops: strident ones (ʃ, s, ɸ͡ʃ, x) are realized as aspirated affricates, and non-strident fricatives (ɸ, h) surface as aspirated stops:

(23) Realization of fricatives

Initial		Intervocalic		Post-nasal	
ɸ͡ʃa	'burns'	xoɸ͡ʃa	'to burn'	mp͡ʃʰɛla	'burn for me'
sup'a	'points'	xosup'a	'to point'	nt͡sʰup'a	'point at me'
ʃap'a	'hits'	xoʃap'a	'to hit'	ɲt͡ʃʰap'a	'hit me'
xap'a	'captures'	xoxap'a	'to capture'	ŋk͡xʰap'a	'capture me'
ɸula	'shoots'	xoɸula	'to shoot'	mpʰula	'shoot me'
humisa	'makes rich'	xohumisa	'to make rich'	ŋkʰumisa	'make me rich'

Post-nasal hardening of fricatives is well-attested cross-linguistically and is usually analyzed as a response to a constraint prohibiting sequences of nasal followed by [+cont]: *NS (Padgett 1991, Bakovic 1994). This analysis is consistent with the fricative alternations in Setswana, but it does not generalize to the sonorant and stop cases. We analyze post-nasal fortition as a more general effect of the Syllable Contact hierarchy: there is a greater sonority distance in an n.t sequence than in n.s or n.d (where "s" is a fricative and "t", "d" are stops).

We assume that fricatives map to aspirated stops because voiceless fricatives are [+sg] (Harris 1994, Vaux 1998, Davis 1999). Faithfulness to [+sg] is ranked high in Setswana, as we established in §4.2. Fricatives map to affricates in some but not all cases because affricates are strident stops, or, in terms of features, [−cont], [+strident] (Rubach 1985). The surface allophones of fricatives always preserve their underlying stridency.

Post-nasal fortition comes at the cost of violating faithfulness to [cont]; moreover, the newly created affricates are marked with respect to the low-ranked constraint against affricates, which requires stridents to be [+cont] (that is, fricatives). This constraint is ranked below faithfulness to [strident].

(24) *Spread[cont]: The feature [cont] is associated with no more than one root node.

(25) No-Affricates: *[+strident, −cont] Stridents are not [−continuant].

The relevant constraint interactions are illustrated in (26) and (27). The faithful candidate is ruled out by the SCL constraint *Dist−3, which militates against the sequences {n.s, z.t, l.d, r.z}—of which Setswana only has alternation evidence for *[ns]. The SCL constraint would be satisfied equally well by an aspirate or an ejective, but ejective affricates are ruled out by undominated constraints in Setswana: recall from (2) that they do not occur in the language.

(26) Post-nasal hardening of fricatives

/n-sup'a/	*Dist−3	Ident[cont]	*Spread[cont]
☞nt͡sʰup'a		*	*
nsup'a	*!W	L	L

Strident fricatives surface as affricates rather than stops because there is a pressure to preserve the strident feature. The two candidate in the following tableau are tied on *Dist-3 as both satisfy it, so the tie is broken by Ident[strident]. The more faithful [nt͡sʰup'a] wins. Underlying non-strident fricatives, on the other hand, map to non-strident stops under this analysis, because where faithfulness to underlying [+strident] is not an issue, affricates are disfavored:

(27) Affricates vs. stops

/n-sup'a/	*Dist−3	Ident[strident]	No-Affricates
☞nt͡sʰup'a			*
ntʰup'a		*!W	L
/n-ɸula/			
☞mpʰula			
mp͡ɸʰula			W*

As for underlying affricates, they surface without alternations in all positions in Setswana:

(28) Realization of affricates

Initial		Intervocalic		Post-nasal	
p͡ʃʰat’a	‘to crush’	mp͡ʃʰap͡ʃʰa	a S. delicacy	mp͡ʃʰa	‘new’
p͡ʃa	‘to shine’	nap͡ʃa	‘to be scratched’	mp͡ʃa	‘dog’
b͡ʒala	‘plant/sow’	ab͡ʒa	‘to be given away’	mb͡ʒalɛla	‘plant for me’
t͡sʰabana	‘afraid of each other’			lant͡sʰa	‘to fight someone’
t͡sala	‘friend’	lat͡sa	‘cause to lie down’		
t͡ʃʰaba	‘nation’	mat͡ʃʰa	‘lakes’	ɲt͡ʃʰaɲa	‘hit me’
t͡ʃamp’a	‘haughty person’	mat͡ʃap’a	‘hard work’	ɲt͡ʃalorosa	‘give me some beer’
d͡ʒɛla	‘eat’	mad͡ʒako	‘offer one’s services’	ɲd͡ʒɛla	‘eat for me’
k͡xʰala	‘dry up’	ak͡xʰa	‘dangle’	ŋk͡xʰap’a	‘capture me’

Our analysis predicts this to be the case for aspirated affricates. As we showed in §2, the inventory of affricates in Setswana also includes plain and voiced affricates, however, and those also do not alternate in post-nasal position. There are a few possible reasons for their lack of alternation. First, it could be that, as stops with very audible bursts, affricates are sufficiently unsonorous to satisfy the relevant Syllable Contact constraint because they achieve the required sonority drop after nasals. Most proposals that assign affricates their own sonority level place them as intermediate between stops and fricatives, but the evidence for this position is inconclusive (Parker 2008). To argue for the position of affricates on the sonority scale based on phonological patterning alone is also somewhat circular. We will pursue another analysis: a nasal-voiced affricate sequence does indeed violate *Dist−3, just like a nasal-voiced stop sequence, but mapping to an aspirated or an ejective affricate is ruled out by other constraints. There is some evidence for this analysis. As we showed in §2, ejective affricates are absent in Setswana. This is not unexpected, since frication requires a strong sustained airflow, which is difficult to produce with the glottalic egressive airstream. For the same reason, fricatives are never glottalized in Setswana, either. We assume that the constraint against glottalized affricates is undominated:

(29) No-Glot-Aff: “Assign a violation mark for every segment that is [−cont], [+strident], [+cg].”

A similar constraint against aspirated affricates, No-Asp-Aff, is dominated by faithfulness to [sg], which allows for contrast. It can still be ranked sufficiently high to block the creation of new aspirated affricates in post-nasal position in order to satisfy *Dist−3. The phonology would then work as illustrated in (30). Glottalized affricates are ruled out across the board, whether they are faithful to the input (as in the hypothetical example (30e)) or newly created (as in the failed candidate (30a)). Aspirates are allowed to surface if they are present underlyingly (see (30d)), but aspirated affricates are not created just to satisfy *Dist−3 (see (30b)). Thus, devoicing of affricates is blocked by a collusion of markedness and faithfulness constraints.

(30) Voiced affricates do not devoice

/n-dʒɛla/	No-Glot-Aff	Ident[sg]	No-Asp-Aff	*Dist−3	Ident[voice]	Ident[cg]
a. ☞ɲdʒɛla				*		
b. ɲtʃ'ɛla	*!W			L	*W	*W
c. ɲtʃʰɛla		*!W	*W	L		
d. ɲtʃɛla				*	*W	
/mpʃʰa/						
e. ☞mpʃʰa			*			
f. mpʃa		*!W	L	*W		
/mpʃ'a/						
g. ☞mpʃa						*
h. mpʃ'a	*!W					L

The analysis of obstruent fortition is thus almost in place—we will return to the highly variable phonology of plain/voiced stops after dealing with sonorants.

4.3.4. Postnasal Fortition of Sonorants

Post-nasal hardening is not limited to fricatives: non-nasal sonorants also undergo it. The result of hardening is always a stop, and the place of articulation of the entire nasal-stop sequence is determined by the underlying place feature of the second segment.[15]

(31) Realization of sonorants

Initial		Intervocalic		Post-nasal	
rut'a	'teaches'	xorut'a	'to teach'	ntʰut'a	'teach me'
lat'a	'follows'	xolat'a	'to follow'	nt'at'a	'follow me'
wɛla	'falls on'	xowɛla	'to fall on'	ŋkʷ'ɛla	'fall on me'

As shown in tableau (32), the constraint *Dist+1, which militates against sequences such as [n.l], dominates faithfulness to [sonorant] and [continuant], as well as the prohibition against shared [continuant]. (The ranking of *Dist+1 above Ident[cont] follows through transitivity from (26), since *Dist+1 dominates *Dist-3 in the Syllable Contact hierarchy).[16] The winning candidate for

[15] Verbs that are vowel-initial in isolation also occur with an ejective stop following a nasal prefix: [araba] 'answers,' [xo-araba] 'to answer', [ŋk'araba] 'answer me'. We forego a full analysis of vowel-initial roots here, but these roots are usually assumed to have an underlying initial voiced velar sonorant, which is consistent with our analysis of post-nasal hardening of sonorants.

[16] In this tableau, we assumed that /l/→[t'] violates Ident[cont], but it is not crucial to our analysis. In fact, the analysis requires no commitment to the [continuant] specification of /l/ and /r/: they both harden in post-nasal position because they are sonorants, not because they are continuants. The continuant specification of /l/ is controversial (Mielke 2005). Setswana /r/ is denti-alveolar, and it alternates between a tap intervocalically and a trill

the input /n-wɛla/ has a nasal-stop sequence with shared [−cont] and dorsal place of articulation, and the winner for /n-lat'a/ is [nt'at'a].

(32) Post-nasal hardening of sonorants

/n-wɛla/	*Dist+3	*Dist+1	Ident[son]	Ident[cont]	*Spread[cont]
☞ŋk^{w}'ɛla			*	*	*
ŋwɛla	*!W		L	L	L
/n-lat'a/					
☞nt'at'a			*	*	*
nlat'a		*!W	L	L	L

From the point of view of Syllable Contact, the best post-nasal consonants are [+cg] or [+sg]. Faithfulness to ejectives is overall ranked lower in Setswana than faithfulness to aspirates, so sonorants generally map to [+cg] stops post-nasally. We are assuming, as before, that plain stops are ruled out post-nasally by *Dist−3.

(33) Hardening results in post-nasal ejectives

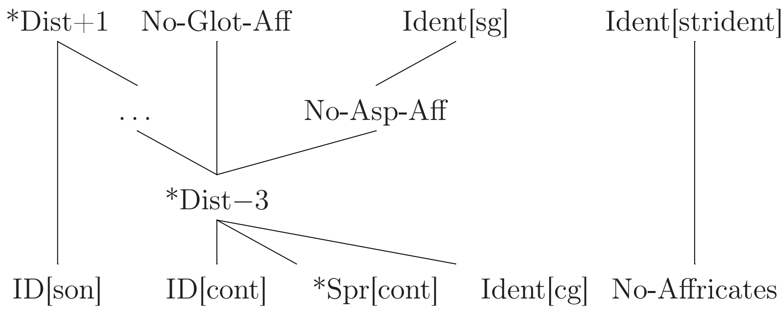
/n-wɛla/	*Dist+1	*Dist−3	Ident[sg]	Ident[cg]
☞ŋk^{w}'ɛla				*
ŋk^{wh}ɛla			*!W	L
ŋk^{w}ɛla		*!W		L

To conclude the analysis of postnasal alternations of sonorants, we now consider the difference between the liquids /l/ and /r/. The anomaly in the phonology is that /r/ maps to [t^{h}] rather than [t']—recall from (30) that mapping to an ejective stop is the preferred outcome of postnasal fortition in Setswana. We will not present a full analysis of the difference between /r/ and /l/, but we would need to assume that the mapping of /r/ to [t^{h}] comes about under pressure to maintain contrast with /l/, which is realized post-nasally as [t'] (see Flemming 1995, Łubowicz 2003 and other work on contrast preservation in OT). Under our view of the sonority scale, both [t'] and [t^{h}] are equally "strong", so both outputs satisfy the relevant SCL constraints.

A summary of the constraint rankings needed for post-nasal fortition is given below.

initially; as a non-approximant, it is probably best analyzed as [−cont]. This is not a crucial feature for the analysis to work, however.

(34) Rankings for fortition



4.4. The Phonology of Voicing

With the analysis of postnasal alternations in place, we now turn to voicing in stops. This section is divided into three parts. The first part disposes of the velars, which violate the undominated constraint against voiced dorsal consonants. The second part deals with the phonology of labials, which follow different patterns for different speakers. Finally, the third part deals with the phonology of coronals and the chain shift described in §2. For the most part, the speakers we examined fall into one of three groups with respect to the patterns they follow: lenition, wholesale devoicing, and positional devoicing.

4.4.1. Velars

The voiced velar stop never occurs in surface forms in Setswana. This is a point on which our results agree with traditional descriptions of the language. In loanwords, source [g] is borrowed as a voiceless stop: English "bangle" is [<b>εŋk'ele],[17] and "guard" is [k'at'i]. This absence of [g] is unsurprising, given the aerodynamics of voicing (see §1.2), so the grounded constraint *g, which encodes the markedness of voiced velars (see Hayes 1999), is undominated in Setswana:

(35) No [g]

/<b>εŋgel/	*g	Ident[voice]
☞<b>εŋk'ele		*
<b>εŋgele	*!W	L

[17] We write the labial as <b> for now, since its realization varies by speaker. We also do not analyze the status of ejectives in loanwords such as [k'at'i]. First, we do not have any phonetic data on these words for our speakers. Second, these ejectives may be due to spelling pronunciation: in Setswana orthography, the only voiceless orthographic symbols available are associated in the native phonology either with the ejective or aspirated series. The point here is that source [g] and [d] do not map to voiced stops in loanwords.

A reviewer asks what evidence there is to think that the input to the loanword phonology includes voiced consonants. Afrikaans has been reported to have regressive voicing in its obstruents (Van Rooy and Wissing 2001).

4.4.2. Analysis of voicing in labials: leniter

The realization of voicing varies by speaker in Setswana, and therefore the phonologies are different, as well. We start with our leniting speaker. Speaker S2 produced voicing throughout,[18] as shown in (36) (repeated from table 7):

(36) Leniter: allophones of "b"

	initial	intervocalic	post-nasal
S2	b	β	b

The relevant new constraints are defined in (37) and (38), and the phonology is analyzed in (39)-(41). The constraint *VCV penalizes plain stops in intervocalic position, favoring lenition. The constraint *β targets consonants such as [β ð ɣ]. Speaker 2 ranks faithfulness to underlying [voice] high—voicing contrasts in all positions, including post-nasally, initially (see (39b, c)), and intervocalically (see (40)). In initial position, these consonants retain their voicing, as required by high-ranking IDENT[voice], but they cannot map to [β], since this violates *β. They map to [b] instead, violating the dominated *b, which militates against voiced labial stops. Intervocalically, voiced obstruents are lenited, suggesting a ranking of *VCV over IDENT[continuant] (see (40)). Furthermore, post-nasally, the consonant surfaces as [b], and mapping to [mp'at'a] is ruled out by high-ranking *IDENT[voice] (see (41)).

(37) *VCV: "No plain stops between vowels." (cf. Kirchner (1998) on lenition)

(38) *β: *[+voice][+cont]. "No voiced continuants."

[18] Some tokens of /b/ even had formant structure, consistent with either [β] or [ɓ]. The implosive interpretation is supported by the sharp rise time from the consonant to the following vowel (Demolin 1995, thanks to John Kingston for suggesting this interpretation). Whether this speaker has implosives, sonorants, or regular voiced stops in initial position, the pattern provides no evidence of post-nasal devoicing and is consistent with an analysis that ranks faithfulness to voicing high, since this speaker's consonants are voiced in all positions.

(39) Leniter: voicing and continancy

/bat'a/	Ident[voice]	*β	*b	Ident[cont]
a. ☞bat'a			*	
b. βat'a		*!W	L	
c. p'at'a	*!W		L	
/mbat'a/				
d. ☞mbat'a			*	
e. mp'at'a	*!W		L	
/mβat'a/				
f. ☞mbat'a			*	*
g. mβat'a		*!W	L	L

The voiced continuant [β] only surfaces intervocalically, as mandated by the ranking of *VCV ≫ *β ≫ Ident[cont]: no voice approximants except in the lenition context.

(40) Leniter: intervocalic context

/aba/	Ident[voice]	*VCV	*β	*b	Ident[cont]
a. ☞aβa			*		*
aba		*!W	L	*W	L
/βat'a/					
b. ☞bat'a				*	*
βat'a			*!W	L	L

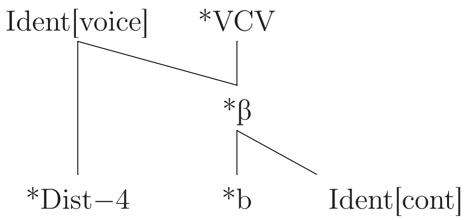
For this speaker, the SCL constraint *Dist−4 (which is violated by [n.d]) must be ranked below Ident[voice], since post-nasal stops do not change to ejectives.[19]

(41) Leniter: no post-nasal ejectives

/mbat'a/	Ident[voice]	*Dist−4
☞mbat'a		*
mp'at'a	*!W	L

[19]Recall that for all speakers, /r/ is described as mapping to [t^h]. The contrast preservation constraints responsible for this mapping must outrank Ident[voice], assuming /r/ is featurally specified as [voice].

(42) Leniter: constraint ranking



High ranking of faithfulness to voicing in this idiolect results in voiced consonants in all positions, including post-nasal. Even for this speaker, *NC̥ is dominated, however, because she has voiceless aspirated and ejective stops post-nasally.

4.4.3. General devoicers

Three of our speakers (S1, S4, and S6) realized orthographic "b" as an unaspirated voiceless stop in all positions:

(43) Devoicers: allophones of "b"

	initial	intervocalic	post-nasal
S1, S4, S6	p	p	p'

Far from supporting post-nasal devoicing or *ND (Hyman 2001), these speakers appear to follow the simple and typologically common pattern of complete neutralization between voiced and voiceless stops. This pattern suggests the basic neutralization ranking of markedness over faithfulness: *b dominates Ident[voice]. It also dominates *NC̥, so no voicing is allowed to surface in any contexts, including post-nasally:

(44) Devoicers: no voiced labial stops anywhere

/bat'a/	*b	Ident[voice]	*NC̥
☞p'at'a		*	
bat'a	*!W	L	
/mbat'a/			
☞mp'at'a		*	*
mbat'a	*!W	L	L

Ejectives arise post-nasally because this is a position where Syllable Contact is relevant. The SCL constraint *Dist−2 assigns a violation mark to a nasal-plain stop sequence or a nasal-voiced stop sequence, but not to a nasal-ejective sequence. This supports the ranking of the SCL constraint *Dist−2 above faithfulness to [voice] and [sg]. Faithfulness to [sg] above [cg], consistent with the analysis of fricative fortition in §4.3.3, produces ejectives rather than aspirates. Plain stops are ruled out post-nasally by the SCL, but intervocalically, there is a contrast. (Recall that our results were inconclusive for initial position, but this analysis predicts a plain/ejective contrast in initial position, all other things being equal).

(45) Devoicers: post-nasal fortition

/mbat'a/	*Dist−2	Ident[sg]	Ident[voice]	Ident[cg]
☞mp'at'a			*	*
mbat'a	*!W		L	L
mp^{h}at'a		*!W	*	*
mpat'a	*!W		*	L

We give voiced inputs here to show what happens if Richness of the Base (Prince and Smolensky 1993/2004) is assumed, but the analysis will produce voiceless surface forms regardless of whether the stops are voiced or voiceless. (Indeed, under Lexicon Optimization, there should be no reason, apart from spelling pronunciation, why these speakers would even entertain voiced stops in the inputs for these forms.)

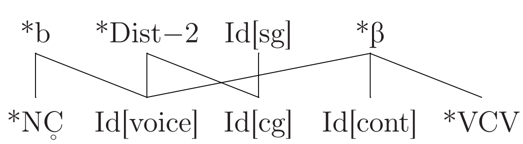
Unlike the leniter, these speakers do not have voiced continuants in any position, so we assume that *β dominates the lenition-favoring constraint *VCV and faithfulness to [continuant]. Plain stops are the optimal outputs for hypothetical /β/ since they are featurally unmarked and faithful to [sg] and [cg]. The faithfulness constraints will prevent voiced approximants from mapping to ejectives or aspirates (except post-nasally, as shown earlier) no matter where they are ranked. Since we assume that voiceless fricatives are [+sg], the mapping of /β/ to [ɸ] is likewise ruled out by undominated Ident[sg] (not shown).

(46) Devoicers: no consonantal sonorants anywhere

/aβa/	*β	*b	*VCV	Ident[cont]	Ident[voice]
☞apa			*	*	*
aβa	*!W		L	L	L
aba		*!W	*	*	L

The summary ranking for the devoicing speakers is thus as follows:

(47) Ranking for devoicers



4.4.4. Positional devoicing

We characterized the remaining two speakers, S3 and S5, as positional devoicers. They have true voicing in labials only word-initially. Intervocalically and post-nasally, the allophones are either mostly or entirely voiceless, as shown in (48) (repeated from Table 7).

(48) Positional devoicers: allophones of “b”

	initial	intervocalic	post-nasal
S3	b	b͡p	p’
S4	b	p	p’

This pattern cannot be attributed to markedness: of the positions where consonants can occur in Setswana, word-initial position is aerodynamically the hardest for voicing (see §3.4.3). Since we are not aware of any markedness constraint that would favor voicing over voicelessness in initial position, we attribute initial voicing to faithfulness instead. Thus, we posit a high-ranking faithfulness constraint Ident[voice]$_{initial}$, which preserves the voiced stop in initial position (Lombardi 2001, Beckman 1998). This constraint dominates *b, preserving voicing word-initially. Since *b dominates *NC̥, voiced stops devoice post-nasally:

(49) Positional devoicers: initial vs. post-nasal position

/bat’a/	Ident[voice]$_{initial}$	*b	Ident[voice]	*NC̥
☞bat’a		*		
pat’a	*!W	L	*W	
/mbat’a/				
☞mp’at’a			*	*
mbat’a		*!W	L	L

If we only look at initial and post-nasal position, then this pattern looks like post-nasal devoicing, but the behavior of intervocalic consonants points to a different analysis: initial and post-nasal positions are the ones set apart for special consideration in the grammar of these speakers. Under this positional neutralization ranking, devoicing applies everywhere but word-initially—and, since Setswana only has consonants in two other positions, intervocalic position presents the crucial evidence.

(50) Intervocalic and not just post-nasal devoicing

/aba/	Ident[voice]$_{initial}$	*b	Ident[voice]	*NC̥
☞aba			*	*
apa		*!W	L	L

With the exception of the positional faithfulness constraint, the rankings of positional devoicers are identical to the rankings of the general devoicers (see (47))—voicing neutralizes due to *b dominating Ident[voice] and *NC̥. This is devoicing in non-initial contexts, not post-nasal ones.

In medial position, these speakers sometimes have partial voicing of the perserveratory variety. We would argue that this partial, gradient voicing is a phonetic and not phonological effect.

Certainly the tendency to voice intervocalically is not unexpected—see, for example, Jun's (1995) analysis of Korean, where she argues that the tendency to voice intervocalically is a phonetic effect due to reduction of the consonantal gesture.

4.4.5. Postnasal devoicers

We only identified three types of speakers in our sample of 6, but another recent study of Setswana, Coetzee et al. (2007), found yet another type: speakers that devoice only post-nasally. Coetzee et al. recorded twelve speakers of a South African dialect of Setswana, and their data clearly show that for four out of these twelve speakers, intervocalic voicing extends all the way through the stop.[20] We should note that the majority of the speakers examined in that study fell into the categories we identified: leniters, general devoicers, and positional devoicers. There is also a type related to leniters—speakers who produce voicing in all positions. So what do we make of the speakers who produce voicing in initial and intervocalic position but not post-nasally?

There are several possible explanations for the differences between our findings and those of Coetzee et al. (2007). First, it is possible that our smaller sample of six accidentally excluded post-nasal devoicers. Second, the difference may be dialectal: our speakers represent a northern dialect spoken in Botswana, whereas Coetzee et al. recorded South African speakers. Both dialects are described in Cole (1985), but the grammar does not mention any variation between them with respect to postnasal devoicing. In this respect, our findings are important, since they show that the pattern is at the very least very non-uniform, and is far from being established and general among the speakers of the language. Coetzee et al. come to the same conclusion in their study: if postnasal devoicing exists, it is unstable and probably on its way out. Third, Coetzee et al. identify some possible perceptual reasons for post-nasal devoicing. Post-nasal stops are not perceived as accurately when the stop is shortened (Beddor and Onsuwan 2003); therefore, devoicing is a way to make sure that the stop is perceived. This will explain why stops devoice, but not necessarily why they become ejective.

Our phonological account of positional devoicers and the leniting speaker suggests a different story. Even if these speakers generally maintain a contrast between voiced and ejective/aspirate stops, Syllable Contact constraints favor the neutralization of this contrast in the direction of stops with bursts. As we showed earlier, Syllable Contact is a grounded constraint, even though it does not reflect articulatory difficulty per se. The phonology of postnasal devoicers, then, requires faithfulness to voice not just in initial position but generally, and it is overridden just in Syllable Contact contexts, where the obstruent follows a nasal.

This is indeed what we found for some of our speakers, only not for labials but rather for coronals. Recall from §2 that [d] is subject to a special phonology in Setswana: there are reasons to believe that voiced coronals are phonologically derived from /l/. Our speakers also often showed

[20] Solé et al. (2010) report on an acoustic and laryngographic study of postnasal devoicing in Shekgalagari, another Bantu language of the Soto-Tswana family. The speaker studied in this article exhibits a similar pattern of post-nasal devoicing; the rule is apparently fully neutralizing in the same sense as it is neutralizing for our general devoicers.

more voicing in /d/ than in the labial series. We analyze the phonology of coronals in the following section.

4.5. The coronal chain shift

The goals of this section are twofold. First, we need to complete the account of our speakers' phonologies and show that a unified analysis of the entire system is possible. Second, we show that our constraint set can generate a pattern where voicing contrasts are neutralized only in post-nasal position, like the one found by Coetzee et al. (2007).

The coronal allophones produced by our speakers are repeated from Table 7 in (51). For the reader's convenience, we label all the speakers as leniters, devoicers, or positional devoicers based on their labial phonology.

(51) Coronal allophones for all speakers

	initial	intervocalic	post-nasal
S2 (leniter of labials)	d	ð	d
S4 (devoicer of labials)	d	t^h	t'
S6 (devoicer of labials)	d	t'	t'
S1 (devoicer of labials)	d	d	t^h
S3 (positional devoicer of labials)	d	d	t'
S5 (positional devoicer of labials)	d	d	d͡t

Some of the tendencies seen here are the same that we identified for labials: voicing is most likely to be found in initial position, just as for positional devoicers. On the other hand, voicelessness is most likely to occur post-nasally. Intervocalically, the coronal stop allophones range from lenited [ð] to aspirated [t^h] and the partially voiced [d͡t]. Since voicing persists for over half of the closure duration (63% on average), we consider these stops voiced.

We start our analysis of the phonology of coronal stops with the chain shift described in §2: /l/ maps to [d], and underlying /d/ maps to /t'/. Recall that [l] and [d] are in complementary distribution: [l] occurs before non-high vowels, and [d] occurs before [i] and [u] (see (52)). There are morphophonemic alternations between [l] and [d] (see (53)) as well as evidence from loanword phonology (see (54)), which suggests that this aspect of the phonology is fully productive and general:

(52) Complementary distribution of [l] and [d]

dip'a	'stubbornly refuse to move'	*lip'a	but:	lep'a	'observe something'	*dep'a
dup'a	'diagnose'	*lup'a		lop'a	'ask for something'	*dop'a
				lap'a	'get tired'	*dap'a

(53) Alternations of [l] and [d]

xo-bol-a	'to rot'	bod-ile	'rotted'	cf.	xo-tab-a	'to stab'	t'ab-ile	'stabbed'
xo-bal-a	'to count'	bad-ile	'counted'		xo-bu-a	'to speak'	bu-ile	'spoke'
xo-sɛl-a	'to find'	sɛd-ile	'found'					

(54) Borrowing of source [l]

bibela	'bible'		t'uru	'expensive'	(from Afrikaans *dur*)
xalasi	'glass'	(from Afrikaans *xlas*)	t'ip'i	'dip'	
p'odisi	'police'		k'at'i	'guard'	
			k'ɛnt'ele	'candle'	

The phonetic grounding of the *l/d* alternation lies in the contradictory tongue body positions required for /l/ and for high vowels. In order to produce lowering of the sides of the tongue, the tongue body must be lowered and retracted, while the tongue front is raised to the alveolar ridge (Sproat and Fujimura 1993). The phonetic incompatibility between laterals and high vowels is encoded in the following constraint:

(55) *li: "Assign a violation mark for every lateral-high vowel sequence"

In English, this contradiction is resolved by insertion of an "intrusive schwa" in high vowel-lateral sequences: [fiəɫ] 'feel', [p^{h}uəɫ] 'pool.' Setswana, on the other hand, sacrifices the lateral specification of /l/ but preserves its voicing and place.[21]

The question for any OT analysis of Setswana is why /l/ doesn't map directly to [t']. The intuition we will pursue in our analysis is a common one in OT analyses of chain shifts: the mapping from /l/ to [d] is in some sense more faithful than the mapping of /l/ all the way to [t'] (see McCarthy 2002: 162). We posit that underlying sonorants have to be voiced on the surface, whereas underlying obstruent stops do not. This is formalized in (56). A similar idea can also be encoded in locally conjoined Ident constraints (Kirchner 1996), faithfulness based on ternary scales (Gnanadesikan 1997), and input-oriented Ident constraints (Orgun 1996), as well as comparative markedness constraints (McCarthy 2003) and various derivational approaches (see McCarthy 2007 for a detailed overview).[22]

[21]It is unclear what role is played by the order of the lateral and the high vowel. Sproat and Fujimura (1993) show that the dorsal retraction gesture is timed to occur before the alveolar raising gesture in English, but this timing is not necessarily universal: Gick et al. (2006) found at least two different timing patterns for liquids in their cross-linguistic study.

[22]There are known issues with constraints such as (56). For one thing, while sonorants are voiced in the unmarked case, nothing in the form of the definition requires that the input and the output features be thus related; it would be just as easy to require that a [+son] input segment correspond to a [−voice] output segment. Merely requiring an underlyingly [+son] segment to be faithful to its voicing specification is also not sufficient, becaus there is no requirement that underlyingly [+son] consonants be voiced. Sonorants can devoice in some languages, e.g., Istmus

(56) IDENT$_{son}$[voice]: 'For all x, y such that x$\Re$y, x$\in$S$_1$ and y$\in$S$_2$, if x is [+son], then y is [+voice].'[23]

The other constraints relevant for the chain shift are *li, *d, *l, IDENT[lateral], and IDENT[voice]. *d, which penalizes voiced coronal stops, is part of the phonetically grounded hierarchy *g≫*d≫*b, which we discussed in §1.1 and §4.4.

The analysis is developed in the following tableaux. First of all, we must ensure that /d/ cannot map to [d], but rather to [t']. For this, *d must outrank faithfulness to voice, as shown in (57).

(57) Underlying /d/ maps to [t]

/dur/	*d	IDENT[voice]
☞t'uru		*
duru	*!W	L

On the other hand, because /l/ surfaces before non-high vowels, faithfulness to the lateral specification must outrank *l, as shown in (58). Before high vowels, /l/ de-lateralizes, so *li must dominate IDENT[lateral] and *d.

(58) Mappings of underlying /l/

/lap'a/	*li	IDENT[lateral]	*l	*d
☞lap'a			*	
dap'a		*!W	L	*W
/lip'a/				
☞dip'a		*		*
lip'a	*!W	L	*W	L

In order to block the mapping of /l/ to [t'], faithfulness to the voicing specifications of underlying sonorants must be ranked above *d, as shown in (59). This forces the chain shift: [d] is allowed only where it is derived from an underlying sonorant; otherwise, underlying /d/ maps to [t'].

Nahuat (Kenstowicz and Kisseberth 1979) and Russian (Hayes 1984), but they rarely if ever contrast in voicing. It is possible that constraints of this type are subject to a substantive filter (Hayes 1999, Smith 2002) or arise from a phonetic scale (cf. Steriade 2001, Kawahara 2006).

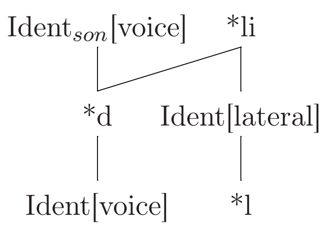
[23] A reviewer asks why underlying sonorants have to be voiced on the surface, if they don't surface as sonorants, and goes on to speculate that this is an example of a historical residue rather than a syncronic functional motivation, since there is no phonetic explanation for this pattern. We agree that this chain shift is not phonetically motivated. Rather, it is motivated by faithfulness, which requires some aspects of an underlying distinction to be preserved on the surface. The pattern of sonorants mapping to voiced obstruents in a chain shift is actually fairly common in languages other than Tswana; see Gnanadesikan (1997) for examples. Moreover, if this chain shift is truly due to historical residue, it should not be productive in loanwords, but it is.

(59) The chain shift /li/ →[di], /d/ →[t']

/lip'a/	*li	Ident$_{son}$[voice]	Ident[lat]	*d	Ident[voice]
☞dip'a			*	*	
lip'a	*!W		L	L	
t'ip'a		*!W	*	L	*W
/duru/					
☞t'uru					*
duru				*!W	L

The general ranking for the chain shift is summarized in (60).

(60) Ranking for the chain shift



This ranking, with the introduction of the input-oriented faithfulness constraint, makes it possible for /l/ to appear as [d]. We have yet to account for the findings of our phonetic study: that for most speakers, the fully voiced stop allophone is consistently found only in initial position. Our next goal, then, is to fine-tune this analysis to fit to each speaker's phonology.

4.5.1. Analysis of coronal phonologies

As with the labials, our analysis of the coronals relies on special faithfulness to voicing in initial position. We assume that, like all Ident constraints, Ident$_{son}$[voice] has a version relativized to word-initial position: Ident-Initial$_{son}$[voice]. This constraint is undominated for all of our speakers, since all produce a voiced [d] in initial position.

Speakers S4 and S6 are full devoicers of labials and positional devoicers of coronals. Their coronal phonology is exactly the same as the labial phonology except for the additional factor of being faithful to the initial voicing for /d/ but not for /b/. Their ranking is as follows:

(61) Positional devoicing and chain shift only for coronals: speakers S4 and S6

/bat'a/	IDENT-INITIAL$_{son}$[voice]	*d	*b	IDENT[voice]
☞pat'a				*
bat'a			*!W	L
/lip'a/				
☞dip'a		*		
tip'a	*!W	L		*W
/mosili/				
☞mositi				*
mosidi		*!W		L

Speaker S2, the leniter, is actually quite consistent in her treatment of labials and coronals: she has voicing in all positions, and the ranking of the positional faithfulness constraint is not relevant for her. Her coronal phonology is sketched out below. In initial position, /l/ will map to [d]. (In the tableau below, *ð is exactly parallel to *β from the analysis of the leniter's phonology in §3.4.1.) Post-nasally, this speaker has a voiced [d], which is predicted by our analysis of her labial phonology without any additional rankings:

(62) Leniter: mappings for initial coronals

/lip'a/	IDENT[voice]	*ð	*d
☞dip'a			*
ðip'a		*!W	L
tip'a	*!W		L

(63) Leniter: intervocalic lenition

/mosili/	IDENT[voice]	*VCV	*ð	*d	IDENT[cont]
☞mosiði			*		*
mosidi		*!W	L	*W	L

(64) Leniter: post-nasal phonology

/n+lira/	IDENT[voice]	*DIST−2	*d
☞ndira		*	*
nt'ira	*!W	L	L

Finally, for both general and positional devoicers, the Syllable Contact law favors ejective rather than plain or voiced stops in post-nasal position—the same outcome as for labials. Because all non-nasal sonorants become ejective or aspirated stops after nasals, some SCL constraints must outrank the general constraint on faithfulness to the voicing of sonorants. This must be true at least for *Dist+2, which rules out [n.l], and *Dist−2, which rules out [n.d] and [n.t]. The positional faithfulness constraint Ident-Initial$_{son}$[voice] is irrelevant post-nasally and hence excluded from the following tableau. The ranking in (65) is the same as the one presented earlier for the chain shift; the only added constraint here is *Dist−2≫Ident$_{son}$[voice].

(65) Post-nasal devoicers of coronals: mapping to [t'] just post-nasally

/n+lira/	*li	*Dist−2	Ident$_{son}$[voice]	Ident[lat]	*d	Ident[voice]
☞nt'ira			*	*		*
nlira	*!W		L	L		L
ndira		*!W	L	*	*W	L
/mosili/						
☞mosidi					*	*
mosit'i	*!W		*W		L	L

Under this ranking, voicing of underlying /l/ will be preserved (though realized as [d]) in all positions except post-nasally, where fortition will apply instead. This is the phonology of S1, S3, and S5.

To summarize this section, the coronal phonology largely parallels the labial phonology, with the addition of constraints on faithfulness to voicing in underlying sonorants, particularly in initial position. With the analysis now in place, we are ready to address the results of Coetzee et al. (2007). We just demonstrated that it is possible to get devoicing, or, more accurately, fortition just in post-nasal position. This is what happens in the phonology of coronals for some of our speakers. The analysis presents the tools for analyzing post-nasal fortition for labials, as well. It is necessary to assume that some speakers have underlyingly voiced labials—our positional devoicers must have them, or we would not have seen voicing in initial position. If voicing is allowed underlyingly, as it must be in any case under Richness of the Base, then the ranking for post-nasal devoicers would be as follows:

(66) *Dist−2≫Ident[voice]≫*b

/ba/	*Dist−2	Ident[voice]	*b
☞ba			*
p'a		*!W	L
/aba/			
☞aba			*
ap'a		*!W	L
/m+ba/			
☞mp'a		*	
mba	*!W	L	*W

In this analysis, a voicing contrast is maintained in general but neutralized post-nasally, as required by SCL.

4.6. Summary and discussion

The goals of §4 were two-fold. First, we analyzed the phonologies of the six speakers in our study. We found considerable variation in how voicing plays out for different speakers, but this variation nonetheless lends itself to understanding in terms of well-known and cross-linguistically motivated phonological constraints.

One of these constraints reflects an aversion to voicing, which is expressed most strongly in the phonologies of general devoicers. The lack of voiced [b] in all positions follow straightforwardly from the ranking of *b over faithfulness to voicing. Another trend we found is faithfulness to word-initial consonants, which was manifest in the phonologies of the speakers we called positional devoicers. Third, one of our speakers did not devoice in any position—she simply maintained voicing in all positions, as required by faithfulness. Even her voiced stops were not entirely robust, however—they systematically lenited intervocalically.

All of our speakers had voicing in initial position for coronals. Some speakers, then, have a [d] but no [b]—which superficially goes against the phonetically based constraints on voicing by place of articulation. We showed that [d] is special in Setswana, however, in that it is derived from /l/. We proposed that faithfulness to the inherent voicing of sonorants is the key to understanding the phonology of coronal voicing.

A key finding of our phonetic study is that something happened post-nasally, though this rule is not the one previously reported in the literature. The speakers that we call "general devoicers" maintain a distinction between [p] and [p'] in intervocalic position, but they neutralize it to [p'] in post-nasal position. This is not post-nasal devoicing—rather, it is post-nasal ejectivization. Such neutralization is not explained by accounts that focus on devoicing (Hyman 2001, Coetzee et al. 2007). We analyzed this pattern as an effect of the Syllable Contact Law hierarchy. Syllable Contact demands a maximal drop in sonority between consonants separated by a syllable boundary. In Setswana, there is exactly one context where Syllable Contact is relevant: post-nasally. There is plenty of evidence for Syllable Contact alternations in Setswana even when laryngeal features are set aside: fricatives and liquids become ejective or aspirated non-continuants in post-nasal position. We propose that voiced and plain stops alike become ejective in post-nasal position because their laryngeal features correlate with sonority: ejective consonants are less sonorous than plain or voiced ones. This is a novel proposal, though we believe it is consistent with existing evidence on laryngeally-based sonority distinctions.

It should be noted our study is not the first one to note the relevance of Syllable Contact to Setswana. The insight can be traced to Schaefer (1982), who also analyzes Setswana in terms of Syllable Contact. There are important differences between Schaefer's analysis and ours, however. First of all, our analysis relies on a universal sonority scale: the only novel aspect of the scale is that we reinterpret the laryngeal distinctions relevant to sonority, which is not unprecedented (see §4.3.2). Schaefer's scale, on the other hand, is not meant to be universal—it is formulated specifically for Tswana, based on the phonology of post-nasal fortition:

(67) Scale from Schaefer (1982): vowel >glide >liquid >voiced stop >voiceless fricative >nasal >lateralized stop >voiceless stop >affricate

This kind of reordering of sonority levels has been (rightly) faulted for being circular (Dickens 1984), so we believe our proposal is an improvement in this regard. We maintain a universal sonority scale, and we derive the non-alternations of affricates, for example, by markedness blocking.[24]

It is appropriate now to address the criticisms of Dickens (1984), since some of them apply to our anlaysis as much as they apply to Schaefer's. The alternations we examined are based on generalizations that are more or less exceptionless in the native lexicon, but loanwords do not participate in the rule of post-nasal fortition (Dickens cites [mfonela] 'telephone me' as an example). We have not examined loanwords for our speakers, but Coetzee et al. (2007) do show that post-nasal fortition is indeed productive on pseudo-words. We find Coetzee et al.'s arguments convincing: fully incorporated loanwords and nonce words do undergo postnasal fortition, suggesting that the process is productive. Some recent loanwords may fail to undergo the rule simply because they are not fully incorporated into the phonology.

Another known problem for any phonogical analysis of post-nasal alternations is that they are triggered by some prefixes that usually do not end in nasals. These include [i-] 'reflexive' and [di-] 'plural (class 11/10)', as well as a null affix for the singular of the 9/10 class. These do surface with a nasal in certain contexts, so it is possible to construct an opaque derivational analysis where the nasal triggers fortition and subsequently deletes. This is indeed how Schaefer analyzes the problem. Conversely, it is not really clear what Dickens's own proposal would be for these cases—he simply says that they are "morphologized." Taken at face value, this seems to require positing extensive stem allomorphy (cf. Green 2006 on mutation in Celtic). The Setswana pattern does bear some similarities to mutation (see Wolf 2007 on post-nasal mutations in the Bantu language Aka), but we do not believe that stem allomorphy is a plausible account of such cases. For one thing, allomorphy cannot account for productive application to non-words of the type that Coetzee and colleagues found. Moreover, suppletive root allomorphy needs to be put in the context of morphology. Many morphological theories do not allow for extensive suppletive root allomorphy (see Bobaljik 2000 for discussion). In our view of the pattern, it is phonological, though it has an opaque component—the triggering context is sometimes deleted. There are plausible phonological alternatives that we have not entertained here, such as an autosegmental floating feature account, but we do not really have the space here to give this alternative justice. Our goal in this article is to show that a phonological

[24]Schaefer's analysis can be summarized, with some oversimplification, as follows: everything to the left of the nasal on the scale has to change to something on the right of the nasal. The requirement is that sonority fall across the syllable boundary, so only stops and affricates will surface post-nasally. There are various complications to this story to account for the behavior of /r/ and /l/ and the non-participation of vowels. Note also that we turned Schaefer's strength scale into a sonority scale. He uses these terms somewhat interchangeably (cf. Murray and Vennemann 1983).

account is indeed possible, and ours is the only analysis we know of that addresses the full range of variation found in the Setswana population.

Even though the constraints used in our analysis are grounded, this does not mean that the phonology of Setswana is completely natural. It includes morpheme-specific opacity and chain shifts that are productive even in loanwords. There is no need for anything like Hyman's (2001) *ND, however: the effects ascribed to *ND follow from the interaction of faithfulness and grounded markedness.

5. Conclusion

This article has developed the idea that phonological constraints are grounded in phonetic scales. We examined a case that has been famous and contentious in the literature: post-nasal devoicing in Setswana, which goes against the well-established constraint against postnasal voiceless consonants. Since we were interested in the phonetic underpinnings of the rules in Setswana, we conducted a phonetic study, which returned some surprising results. First of all, the very existence of extensive variation in the laryngeal phonology of Setswana puts into question the value of the language in the *NC̥ debate. We found that some speakers realized the orthographic voiced stops as voiceless in contexts other than post-nasal. To the extent that there was post-nasal neutralization of laryngeal contrasts, it wasn't in the direction of voicelessness but rather in the direction of aspirates and ejetives. For one of our speakers, the consonants were voiced throughout, and for some others, the consonants were voiced only initially.

We developed a detailed analysis of the phonology of Setswana that accounts for our speakers' patterns. The markedness constraints we used are all grounded in phonetic scales. Setswana shows evidence for phonetically grouned constraints on voicing in its consonant inventory: there are no voiced velars, and voicing is absent in fricatives. We also afforded a central role to the Syllable Contact constraint hierarchy, which is based on the phonetic sonority scale. Syllable Contact requires that sonority fall across a syllable boundary between two consonants, and the greater the sonority distance, the better. Syllable Contact has a range of effects in Setswana, all of which enforce the preference for ejective and aspirated stops in post-nasal position. We attributed the ejectivization of voiced stops to their relatively low sonority.

Appendix: Tokens recorded for the acoustic experiment

The words are written in broad pseudo-orthographic transcription: ejective release is not indicated, and voiced stops are written as "b" and "d." Tones are shown only for tonal minimal pairs, with grave for Low and acute for High.

p^{h}	p^{h}ala	'impala'	**p**	pala	'unmanageable'	**b**	bala	'read'
	kxap^{h}a	'smear floor with dung'		paka	'carry provisions'		bapa	'next to'
	mp^{h}aɲa	'slap me'		bapa	'next to'		peba	'mouse'
	mp^{h}ut^{h}a	'fold me'		apaa	'to cook'		aba	'give away'
				mpexa	'give me a ride'		mpona	'see me'
				mpitsa	'call me'		mbitsa	'call me'
t^{h}	t^{h}aɲa	'wake up'	**t**	tàlá	'green'	**d**	disa	'herd (v.)'
	t^{hw}aɲa	'crackle'		tàlà	'hunger'		dupa	'be pregnant (animal)'
	lat^{h}a	'throw away'		bata	'look for'		nduba	'confuse me'
	mput^{h}a	'fold me'		lata	'to follow'		ndira	'do me'
	lant^{h}a	'first time'		ntamola	'squeeze me'		mòsídì	'person who grinds'
	sant^{h}a	'firstly'		banta	'belt (v.)'		mòsìdì	'soot'
k^{h}	k^{h}awa	'mist'	**k**	kala	'tree branch'			
	k^{h}uk^{hw}aɲi	'beetle'		paka	'carry provisions'			
				seka	'go to court'			
				ŋkopa	'ask me'			
				paŋka	'walk bow-legged'			

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