Journal of Phonetics 38 (2010) 604–615

Contents lists available at ScienceDirect

Journal of Phonetics

journal homepage: www.elsevier.com/locate/phonetics

Letter to the Editor

More on post-nasal devoicing: The case of Shekgalagari

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ARTICLE INFO

Article history:
Received 3 November 2009
Received in revised form
22 August 2010
Accepted 13 September 2010

ABSTRACT

Like other languages of the Sotho-Tswana subgroup of Bantu, Shekgalagari exhibits a process of post-nasal devoicing, a phenomenon which has been at the center of the debate on the phonetic grounding of phonology. The existence of post-nasal devoicing has been questioned, and it has been claimed that it is phonetically unnatural. In this paper, we provide instrumental data that post-nasal devoicing actually exists in Shekgalagari and suggest that it is not necessarily phonetically unnatural. Acoustic and laryngographic data indicate that post-nasal devoicing is a categorical process, i.e., devoiced stops do not differ from underlying voiceless stops in any of the durational, voicing and tonal parameters analyzed. Voiced stops differ from devoiced and voiceless stops in all these parameters. Secondly, the results show that in Shekgalagari (as in Tswana) voiceless stops do not have longer voicing into the closure postnasally than postvocally, in contrast with the findings for most languages. These results undercut the claim that the tendency towards postnasal obstruent voicing is present in all languages. We argue that the two patterns, postnasal voicing and devoicing, may not be as antagonistic as has been assumed, and that both may be derived from a common source, variations in the relative timing of the nasal and oral gestures.

1. Introduction

Post-nasal voicing is a typologically and historically common process. This process, by which voiceless obstruents become voiced after nasals, has a well-known aerodynamic and perceptual basis: (i) prolonged voicing into the stop closure, vis-à-vis post-vocalic stops, due to nasal leakage before full velic closure is achieved and oral cavity expansion due to the velum continuing to raise after velic closure has occurred (Hayes & Stivers, 2000; Rothenberg, 1968; Westbury, 1983), and (ii) the reinterpretation of these phonological voiceless stops, partially voiced and with a weaker stop burst, as voiced. This tendency to avoid voiceless stops after nasals is a supposedly universal tendency for which a *NT constraint has been proposed (Hayes, 1999; Pater, 1996, 1999).[1]

A number of Bantu languages, however, show a process of post-nasal obstruent DEVOICING which has been argued to provide evidence for a corresponding bias against nasal+voiced obstruent and the competing constraint *ND (Hyman, 2001), which is responsible for such alternations as [bɔ́n-a] 'see!' vs. [m.pɔ́n-a] 'see me!' in Tswana.[2] Although Hyman goes into great detail justifying *ND as an active synchronic constraint in Tswana and other languages, the proposal raises the following questions for those who assume that phonology must be "phonetically based" (Hayes, Kirchner, & Steriade, 2004):

(i) Can phonologies exploit an allegedly unnatural phonetic constraint such as *ND?
(ii) If so, what does this say about the apparent universal preference for ND over NT assumed by Hayes, Pater and others before them (e.g. Herbert, 1986)? In optimality theory terms, what would it mean to assume a universal ranking of the two "markedness" constraints, *NT $\gg$ *ND, if languages such as Tswana can reverse the ranking as Hyman proposes?

Since Hyman (2001) two groups of researchers have taken a new look at Tswana both from a phonetic and phonological point of view. While Coetzee, Lin, and Pretorius (2007) and Coetzee and Pretorius (2010) generally confirm the post-nasal devoicing process that has been noted for quite some time in languages of the Sotho-Tswana subgroup of Bantu, Zsiga, Gouskova, and Tlale

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[1] In this paper we use T to refer to voiceless obstruents vs. Pater's Ç. Similarly, D will be used to refer to voiced obstruents.

[2] Hyman (2001) also cites a number of non-Bantu languages which allow NT but not ND, including a dialect of Scots in which words such as *thimble, thunder* and *single* are pronounced with simple nasal consonants (Harris, 1994, pp. 85–86).

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doi:10.1016/j.wocn.2010.09.002

(2006, 2007) take issue with Hyman's analysis on two fronts. First, they cast doubt on the phonetic process of post-nasal devoicing on the basis that their speakers have variable realization of voiced stops (including devoicing) not only post-nasally but in other environments as well (vs. Coetzee et al., whose speakers produced the expected devoicing exclusively post-nasally). Second, they reject *ND as a phonological constraint and propose to attribute any tendency towards post-nasal devoicing to other constraints. On the one hand they view devoicing, in particular post-nasal devoicing, as a "strengthening" process, as in virtually all previous literature on the history and description of the group (e.g. Creissels, 1999; Dickens, 1977, 1984; Krüger & Snyman, n.d.; Tucker, 1929). In addition, recognizing that the preconsonantal nasal is always syllabic, they propose that the realization of /m.bɔ́n-a/ as [m.pɔ́n-a], which makes the onset [p] less sonorous, provides an improved syllable contact. They do not explain why /mʊ-bɔ́n-ɛ/ 'see him/her!' becomes [m.mɔ́n-ɛ] which has a worse syllable contact than *[m.bɔ́n-ɛ]. See below for a comparison with Shekgalagari.

In this paper we take a close look at the analogous phonetic and phonological properties of Shekgalagari, another language of the Sotho-Tswana group. One of the main aims of this study is to show that there is an unambiguous phonological process of post-nasal devoicing in this language, which is confirmed by instrumental phonetic analysis. A second and related aim is to investigate whether the neutralization of the voicing contrast post-nasally is complete or incomplete. In cases of complete neutralization, we might expect that devoiced and voiceless obstruents would merge, showing no phonetic differences between them in production. However, since incomplete neutralization has been demonstrated in devoicing processes (for a recent review, see Warner, Jongman, Sereno, & Kemps, 2004), phonetic differences in production between voiceless and devoiced stops might plausibly be found even if there is an active process of devoicing; but of course these segments would still be expected to be different from voiced stops.[3]

Another aim of this study is to explore whether post-nasal devoicing and the *ND constraint are phonetically motivated. Because post-nasal voicing and *NT have been shown to have a phonetic basis, the devoicing process in the exact same context has been considered phonetically anomalous. The acoustic study of a variety of parameters associated with the devoicing process suggests that post-nasal devoicing may not be a phonetically unnatural process, but rather a process that stems from differences in the relative timing of the nasal and oral gestures.

The properties of Shekgalagari are slightly different from those of Tswana in ways which bear directly on the issues involved. Specifically, while /ND/ is realized [NT] as in Tswana, unlike Tswana, Shekgalagari has a surface contrast between [NT] and [ND], the latter deriving from other sources. Such contrasts allow us to demonstrate the post-nasal devoicing process whose [NT] outputs must be maintained distinct from the various occurrences of [ND]. In the following sections we shall first present an overview of the relevant aspects of Shekgalagari phonology (Section 2), followed by the presentation of our instrumental phonetic studies (Sections 3 and 4). A brief conclusion in Section 5 considers the implications of our findings.

2. Phonological overview of Shekgalagari

As indicated in Section 1, Shekgalagari is one of the languages of the Sotho-Tswana group of Bantu languages originally designated as S.30 by Guthrie (1948). It is widely spoken in Botswana, particularly in the Kgalagari District and its outskirts, but also in some parts of the Kweneng, Ngamiland, Ghanzi and Southern Districts (Andersson & Janson, 1997; Monaka, n.d.). Although it has sometimes been included as a dialect of Tswana, it is certainly a separate language with its own dialect cluster (Janson, 1995), spoken by an estimated 272,000 speakers in Botswana (RETENG, 2006) as well as a smaller number of speakers in Namibia. Since it is of particular relevance to the present study we include the following table of consonant contrasts (Table 1).

As seen, the consonant system is quite complex. Significant for this study is the fact that the language has a three-way distinction among stops and affricates: voiceless aspirated, voiceless unaspirated (which are variably ejective), and voiced. This much is true of Tswana as well, with which we note the following important differences in Shekgalagari[4]:

(i) *Differences in the voiced stop system*: While both languages have /b/ and Tswana completely lacks /ɡ/, the Shekgalagari lexicon has only six roots with /ɡ/. This includes the verbs *-gag-* 'speak on behalf of' and *-gab-* 'carry on shoulder' whose initial /ɡ/ does not devoice after a nasal: [ŋ-ɡaɡ-ɛ́l-a] 'speak on behalf of me!', [ŋ-ɡab-á] 'carry me on the shoulder!'. While Tswana does not have a phoneme /d/, most dialects realize /l/ as [d] before /i/ and /u/. Shekgalagari, which realizes /li/ and /lu/ as [ri] and [ru], has a number of lexemes with contrastive /d/, e.g. *-dʊd-* 'respect', *-dáʒ-* 'fill (tr.)', *-dɛl-* 'bring (sth.) for'. Such cases of /d/, which devoice after a nasal (cf. [n-tʊd-á] 'respect me!'), generally correspond to Tswana unaspirated /tl/, hence *-tlʊtl-*, *-tláts-*, *-tlɛl-*. Shekgalagari also features voiceless and voiced palatal stops /c ɟ/, which generally correspond to Tswana /t/ and /dʒ/, respectively. Voiced palatals devoice after a nasal in the verb /ɟ-a/ 'eat' and derivatives (e.g., [ɟ-ɛ́l-a] 'eat for!', [ɲ.cɛ́l-a] 'eat for me!), but the other three verb roots which begin with /ɟ/ do not undergo post-nasal devoicing (for example [ɟábɛ́ts-a] 'cheat someone!', [ɲ-ɟábɛ́ts-a] 'cheat me!'). Thus, while Tswana has a stop voicing contrast only at the labial place, in Shekgalagari voiced and voiceless stops contrast at 4 places of articulation (though voiced velars are rare).

(ii) *Differences in the nasal+voiced stop system*: Within the Tswana lexicon there are only two exceptional cases of ND, both labial, one borrowed: [ám̀búlɛ́ǹsí] 'ambulance'; [bám̀báɲɛχ-a] 'scratch hard'. The Shekgalagari lexicon, on the other hand, has about 10 entries with labial or alveolar ND, e.g. [hômbé] 'today', [ma-ndóndó] 'plentiful', [ńde] 'perfective morpheme'. Most of these have been identified as borrowings: [mʊ-sámbíya] 'a person who comes from Zambia', [sílíndará] 'cylinder'. Most crucial in this context is the process by which /ʊ/ is deleted from /mʊ-/ prefixes when the root begins with

[3] Whereas incomplete neutralization or near mergers are problematic for traditional phonological approaches which assume that phonological representations are categorical, in exemplar models they may be interpreted as resulting from exemplar clouds of the voiceless and devoiced categories overlapping sufficiently (thus making the perceptual distinction difficult) but the category membership of the exemplars remaining distinct (i.e., with separate category means which result in distinct phonetic realizations). In contrast, cases of complete neutralization or mergers entail that the devoiced exemplar cloud overlaps completely with the voiceless exemplars and that exemplars previously classified under the voiced category end up being classified under the voiceless category (Solé, 2003; Yu, 2007).

[4] The lexical generalizations of Tswana are based on Creissels (1996) which contains 5809 entries, while those of Shekgalagari are based on Monaka (in preparation) for which a preliminary Filemaker Pro™ version of 6656 entries was available for this study. In general, verb forms are cited either as -CVC- roots, CVC-a stems or imperatives, as infinitives are preceded by the /χʊ-/ prefix. Hyphens indicate morpheme breaks, e.g. *-a* or *-ɛ* are inflectional vowels.

Table 1
Shekgalagari consonants based on Lukusa and Monaka (2008, p. 12).

	Bilabial	Dental	Alveolar	Post-alveolar	Palatal	Velar	Uvular	Glottal
Plosives	pʰ p b	tʰ t d			cʰ c ɟ	kʰ k ɡ	qʰ q	
Nasals	m	n			ɲ	ŋ		
Trill/tap			r					
Fricatives			s z	ʃ ʒ			χ	h
Approximants					j	w		
Lateral			l					
Affricates			tsʰ ts	tʃʰ tʃ dʒ				
Clicks	ʘ	ǀ						

Labialised consonants: ʃʷ, ʒʷ, tsʷ, tsʰʷ, tʃʷ, tʃʰʷ, cʷ, cʰʷ.

/b/. As seen in the example in (1), both languages devoice /b/ after the first person singular homorganic /N-/ prefix:

(1) Tswana, Shekgalagari /χʊ-m-bɔ́n-a/→ χʊ-m-pɔ́n-á[5] 'to see me'

However, the realizations are different with the class 1 (human singular) prefix /mʊ-/[6]:

(2) a. Tswana /χʊ-mʊ-bɔ́n-a/→ χʊ-m-m̲ɔ́n-á 'to see him/her'
b. Shekgalagari /χʊ-mʊ-bɔ́n-a/→ χʊ-m-b̲ɔ́n-á

As seen in (2a), when the vowel of /mʊ-/ is deleted, the expected output [mb] instead surfaces as [mm]. Hyman (2001, p. 160) takes this to mean that *ND functions as a conspiracy in Tswana: It not only is responsible for the devoicing of /b/ in (1), but also the nasalization of /b/ to [m] in (2a). As seen in (2b), the expected [mb] does surface in Shekgalagari, thereby creating surface exceptions to *ND. This, of course, is an instance of classic counterfeeding opacity: the [mb] sequence which results from vowel-deletion in (2b) is not allowed to feed into the devoicing process to become [mp]. Because of this, there is a surface contrast between [mp] and [mb] in Shekgalagari (but not in Tswana):

(3) a. /χʊ-m-bɔ́n-a/→χʊ-m-pɔ́n-á 'to see me'
b. /χʊ-mʊ-bɔ́n-a/→χʊ-m-bɔ́n-á 'to see him/her'

Since Shekgalagari also has underlying voiceless unaspirated stops, this means that the [mp] in (3a) represents a neutralization of the voicing contrast: As seen in (4a, b), [mp] can derive from /mp/ or /mb/:

(4) a. [mp] from /m+p/: m-palɛ́l-a 'refuse me!' /χʊ-palɛl-a/ 'to refuse'
b. [mp] from /m+b/: m-palɛ́l-a 'count for me!' /χʊ-bal-ɛl-a/ 'to count for'
c. [mb] from /mʊ+b/: m-balɛ́l-ɛ 'count for him/her!'

In other words, Shekgalagari gives us an additional window for acoustic analysis: We can compare not only the two sources of [mp], as in Tswana, to see if they have in fact merged, but also [mb], which is audibly quite different. The same arises to a lesser extent with respect to [nd], [ɲɟ], and [ŋɡ], as we will see in the next section. First, however, there is another issue to establish: that the alternation is "real".

As mentioned, Zsiga et al. (2006, 2007) cast some doubt on the phonetic reality of post-nasal devoicing (which we will address in Section 3). Another way of challenging whether there is an active rule of post-nasal devoicing would be to claim that devoicing such as in (1) is not a general or productive property of Tswana or Shekgalagari phonology, but rather either morphologically conditioned and/or historical residue. It is true that there are few homorganic nasal prefixes available to trigger devoicing, the one cited here being the first person singular prefix, but since this prefix is completely productive, the alternation is extremely common.[7] Hyman (2001, p. 159) answers the first critique by pointing out that the absence of ND is nearly complete in the Tswana lexicon, as we have noted. We have also said the same about intramorphemic ND sequences in Shekgalagari, which is limited mostly to borrowings. By contrast, there are numerous NT sequences of all sorts in both languages. It is therefore clear that *ND is involved in more than morpheme-specific alternations. Concerning the second critique, that *b*∼*p* alternations might simply be an historical residue, it should be noted that the few borrowed verbs which begin with /b/ undergo the change:[8]

(5) a. -bebí 'carry a baby on back' χʊ-m-pebí-ís-a 'to make me carry a baby'
b. -bɔ́r-a 'drill, bore' χʊ-m-pɔ́r-ís-a 'to make me drill'
c. -bánt-a 'belt, put on a belt' χʊ-m-pánt-is-a 'to make me put on a belt'

In fact, there can be little doubt about the phonological reality of the post-nasal alternations in Shekgalagari. As illustrated in (6), the first person singular *N-* prefix not only conditions devoicing, but also aspiration and affrication:

(6) a. χʊ-pak-a 'to praise' χʊ-m-pak-a 'to praise me'
χʊ-tʊt-a 'to respect' χʊ-n-tʊt-a 'to respect me'
χʊ-cʊ́b-á 'to beat' χʊ-ɲ-cʊ́b-á 'to beat me'
χʊ-kɛl-a 'to show' χʊ-ŋ-kɛl-a 'to show me'

[5] The forms in the examples presented without brackets correspond to broad phonetic transcriptions. Square brackets are used when citing examples in the text, and where phonetic realizations are contrasted with underlying forms, as in Table 2. Forms cited as -CVC- roots are not pronounceable and are in italics.

[6] The same alternations are found in both languages when a noun class 1 or 3 prefix /mʊ-/ is immediately followed by a noun (or adjective) stem, e.g. /mʊ-bín-i/ 'dancer' → Tswana [m-mín-i], Shekgalagari [m-bín-i] (cf. [χʊ-bín-á] 'to dance').

[7] The other major prefix is class 9 and 10 N- which conditions devoicing, but subsequently drops out, e.g. [pʊ́ʒo] 'question', from *-bʊ́ʒ-* 'ask'. While the nasal remains before a monosyllabic stem in Tswana, it fails to appear in the corresponding Shekgalagari forms which generally have an *i-* prefix: Tswana [n-tá], Shekg. [i-cá] 'louse' (< Proto-Bantu **n-dá*). The same process of post-nasal devoicing also affected root-internal *ND, but since the N drops out here as well, one cannot see the synchronic effect (cf. Proto-Bantu **-bʊ́mb-* > Tswana/Shekgalagari *-bʊ́p-* 'mould, create').

[8] Further evidence for the productivity of the devoicing process comes from Tswana. Coetzee and Pretorius (2010) provide psycholinguistic evidence from a 'wug test' showing that Tswana speakers productively apply the post-nasal devoicing process to nonsense forms.

b.	χʊ-bɔ́n-á	'to see'	χʊ-m-pɔ́n-á	'to see me'
	χʊ-dʊʒ-a	'to annoint'	χʊ-n-tʊʒ-a	'to annoint me'
	χʊ-ɟís-a	'to feed'	χʊ-ɲ-cís-a	'to feed me'
	χʊ-at-a	'to like'	χʊ-ŋ-kat-a /-gát-a/	'to like me'
c.	χʊ-hɪɲ-a	'to defeat'	χʊ-m-p^{h}ɪŋ-a	'to defeat me'
	χʊ-sup-a	'to point at'	χʊ-n-ts^{h}up-a	'to point at me'
	χʊ-ʃɛb-a	'to look at'	χʊ-ɲ-tʃ^{h}ɛb-a	'to look at me'
	χʊ-χán-á	'to refuse'	χʊ-ŋ-q$^{\chi h}$án-á	'to refuse me'
d.	χʊ-zíts^{h}-á	'to inform'	χʊ-n-tsíts^{h}-á	'to inform me'
	χʊ-ʒwɛ́l-a	'to tell'	χʊ-ɲ-tʃwɛ́l-a	'to tell me'

While the voiceless unaspirated stops in (6a) do not change, their voiced counterparts in (6b) become devoiced. Note that vowel-initial roots – [χʊ-at-a] in (6b) – reveal a [k] after a nasal, indicating that they contain an underlying initial /ɡ/, which drops out in the absence of a nasal (cf. Proto-Bantu **-gab-* > Tswana/ Shekg. *-ab-* 'give out, share'). In (6c) we see that /h/ alternates with [p^{h}], while the fricatives /s, ʃ, χ/ become affricated and aspirated. By contrast, the voiced fricatives /z, ʒ/ in (6d) remain unaspirated, but become devoiced and affricated after a nasal.

Now compare the same verbs in (7) whose stems have been reduplicated with the meaning 'do X a little here and there':

(7)	a.	χʊ-paka-paka	'to praise'	χʊ-m-paka-paka	'to praise me'
		χʊ-tʊta-tʊta	'to respect'	χʊ-n-tʊta-tʊta	'to respect me'
		χʊ-cʊ́bá-cʊ́bá	'to beat'	χʊ-ɲ-cʊ́bá-cʊ́bá	'to beat me'
		χʊ-kɛla-kɛla	'to show'	χʊ-ŋ-kɛla-kɛla	'to show me'
	b.	χʊ-bɔ́ná-bɔna	'to see'	χʊ-m-pɔ́ná-pɔna	'to see me'
		χʊ-dʊʒa-dʊʒa	'to annoint'	χʊ-n-tʊʒa-tʊʒa	'to annoint me'
		χʊ-ɟísa-ɟɪsa	'to feed'	χʊ-ɲ-císa-cɪsa	'to feed me'
		χʊ-ata-ata	'to like'	χʊ-ŋ-kata-kata	'to like me'
	c.	χʊ-hɪɲa-hɪɲa	'to defeat'	χʊ-m-p^{h}ɪŋa-p^{h}ɪŋa	'to defeat me'
		χʊ-supa-supa	'to point at'	χʊ-n-ts^{h}upa-ts^{h}upa	'to point at me'
		χʊ-ʃɛba-ʃɛba	'to look at'	χʊ-ɲ-tʃ^{h}ɛba-tʃ^{h}ɛba	'to look at me'
		χʊ-χáná-χana	'to refuse'	χʊ-ŋ-q$^{\chi h}$áná-q$^{\chi h}$ana	'to refuse me'
	d.	χʊ-zíts^{h}á-zɪts^{h}a	'to inform'	χʊ-n-tsíts^{h}á-tsɪts^{h}a	'to inform me'
		χʊ-ʒwɛ́la-ʒwɛla	'to tell'	χʊ-ɲ-tʃwɛ́la-tʃwɛla	'to tell me'

As seen in the forms on the right, the same alternations occur not only on the first stem which immediately follows the nasal prefix, but also on the second stem, a classic case of "over-application" in reduplication. Since there can be no doubt in (7b–d) that the initial consonant of the second stem has the very realization expected after a homorganic nasal in agreement with the post-nasal devoicing observed in the first stem, there is no way to deny the phonological reality of the alternations in question.

As clear as the process of post-nasal devoicing may be, there are some irregularities. While initial /b/ and /d/ always devoice, we have already alluded to the fact that the two verbs which exceptionally begin with /ɡ/ do not undergo post-nasal devoicing: [ŋ-ɡaɡ-ɛ́l-a] 'speak on behalf of me!' In addition, of the three roots which begin with the voiced palatal stop, only those derived from /ɟ-a/ 'eat' undergo devoicing:

(8)	a.	χʊ-ɟ-ís-a	'to feed (cause to eat)'
		χʊ-ɲ-c-ís-a	'to feed me'
	b.	χʊ-ɟábɛ́ts-a	'to cheat s.o.'
		χʊ-ɲ-ɟábɛ́ts-a	'to cheat me'
	c.	χʊ-ɟabú-ɛl-a	'to fetch water for'
		χʊ-ɲ-ɟabú-ɛl-a	'to fetch water for me'

In addition, note the following two alternations, which involve not only devoicing but also a change in place of articulation:

(9)	a.	χʊ-rʊ́m-á	'to send'	χʊ-ɲ-c^{h}ʊ́m-á 'to send me' (cf. Tswana χʊ-n-t^{h}ʊ́m-á)
	b.	χʊ-lʊ́m-á	'to bite'	χʊ-ɲ-cʊ́m-á 'to bite me' (cf. Tswana χʊ-n-tʊ́m-á)

The initial liquids of these roots correspond, respectively, to Proto-Bantu **t* and **d*, which underwent weakening to [ɾ̥] and [l], respectively (with [ɾ̥] subsequently becoming voiced). We therefore expect the realizations indicated in Tswana to the right. Instead, alveolar stops have become voiceless palatal stops post-nasally in Shekgalagari, as seen.[9] As expected, consonants which are underlyingly voiceless and non-continuant do not change after N-, whether they are aspirated, unaspirated and/or affricated.

With this phonological overview of the problem, the remaining issue is to provide an instrumental documentation of the devoicing process. Specifically, when a voiced stop is devoiced after a homorganic nasal, does it merge with the corresponding underlying voiceless unaspirated consonant? This question is taken up in some detail in Section 3.

3. Instrumental study of post-nasal devoicing in Shekgalagari

As was seen in Section 2, when the first person singular homoganic nasal prefix N- is attached to a verb that begins with a voiced stop, e.g. /b/, the stop devoices, e.g., [χʊ-bal-ɛl-a] 'to count for' vs. [m-pal-ɛ́l-a] 'count for me!'. The same /b/ does not devoice if an [mb] sequence is derived from the third person singular (class 1) prefix /mʊ-/: [m-bal-ɛ́l-ɛ] 'count for him/her!'. Since the language also has underlying unaspirated /p/, this means that there is potentially a three-way distinction between post-nasal voiceless, devoiced and voiced stops (cf. (4))[10]:

(10) a.	voiceless:	[m-palɛ́l-a]	'refuse me!'
		/χʊ-palɛl-a/	'to refuse'
b.	devoiced:	[m-pal-ɛ́l-a]	'count for me!'
		/χʊ-bal-ɛl-a/	'to count for'
c.	voiced:	[m-bal-ɛ́l-ɛ]	'count for him/her!'

A number of questions naturally arise. First, are post-nasal voiceless and devoiced stops identical, or do they differ from each other in some way? In other words, is the neutralization of voicing complete or incomplete? Second, are devoiced stops different from post-nasal voiced stops, as assumed, and if so, how are they different? Specifically, are [mp] (resulting from devoicing) and [mb] (resulting from /mʊ-b/) distinguished from each other in the same way as the [p] vs. [b] contrast found in other phonetic environments? Finally, is there any indication that voiceless and/ or devoiced stops are subject to the universal tendency for voiceless obstruents to become voiced after a nasal? Or, put in a different way, is post-nasal devoicing "un-phonetic" and "ungrounded" as claimed (Hayes, 1999, p. 263)?

3.1. Method

To test these and other questions, we collected acoustic and laryngographic data from one female Shekgalagari speaker (the

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[9] This situation is complicated by the fact that /l/ neutralizes with /r/ before the high tense vowels /i/ and /u/. The following inconsistency has been found: Whereas all instances of stem-initial [ri] are treated as if they were /li/, as in (i) below, some verb stems treat initial [ru] as if it were derived from /lu/ in (ii), while others treat initial [ru] as if derived from /ru/(< **tu*), as in (iii):

i.	χʊ-ribɛl-a	'to protect'	χʊ-ɲ-cibɛl-a	'to protect me'
ii.	χʊ-rúél-a	'to pay'	χʊ-ɲ-cúél-á	'to pay me'
iii.	χʊ-rúmʊ́l-a	'to provoke'	χʊ-ɲ-c^{h}úmʊ́l-a	'to provoke me'

Note finally that speakers of Shekgalagari typically pronounce the rhotic as a tap [ɾ] before /i/ and /u/.

[10] As noted in Table 1, there also are voiceless aspirated stops in Shekgalagari, e.g. [χʊ-p^{h}ál-ɛ́l-a] 'to excel over others for (some reason)'. Because it is only the voiced and voiceless unaspirated stops that neutralize post-nasally, while aspirated stops remain distinct from the other two stops, aspirated stops were not examined in our study.

third author)[11] producing voiced, devoiced, and voiceless stops post-nasally and voiced and voiceless stops post-vocalically at four places of articulation (labial to velar). Data for devoiced (post-nasal), voiced (post-vocalic) and voiceless alveolar and palatoalveolar fricatives/affricates was also collected (see Table 2). Three Shekgalagari (imperative) verbs – two verbs in the case of velars, see appendix – each beginning with voiced /b d ɟ g z ʒ/ and voiceless /p t c k ts tʃ/ were selected. Since the voiced fricatives /z ʒ/ devoice and affricate to [ts tʃ] post-nasally, as was seen in (6d), they were also compared to lexical voiceless affricates. The verbs had the same number of syllables, following vowel, and following tone within each voiced-voiceless-devoiced triplet or pair. Each of these verbs was placed in a carrier phrase (*Re ___ gatshi* [rɪ_χaːtsʰi] 'Say ___ again') with the first person singular prefix /N-/, and with the infinitive prefix /χʊ-/, producing examples such as in Table 2.

Because Shekgalagari marks devoicing in the spelling the relevant forms were elicited rather than read. This ensured that the speaker was not merely reading the orthographic symbols but rather accessing the form of interest from the verb paradigm.[12] The elicitation procedure consisted in instructing the speaker to read a sentence with an imperative (word-initial stop or fricative; 12a), and to then produce the same sentence with the first person singular prefix (N-; post-nasal devoiced; 12b), the third person singular prefix (m(ʊ)-; post-nasal voiced; 12c), and the infinitive (χʊ-; post-vocalic; 12d). The sentence was presented in the traditional Shekgalagari orthography. Each elicited token was repeated five times. Only the results for the elicited tokens are reported here. The two non-verbal forms (ń**d**e, man**d**óndó) were elicited by presenting the speaker with the English gloss and asking her to produce it in the frame sentence *Re ___ gatshi.*

(11) a. Re '**b**alela!' gatshi (imperative) READ
b. Re ____ gatshi (1st sing. object prefix+imperative) →Re [m.**p**alɛ́la] gatshi
c. Re ____ gatshi (3rd sing. object prefix+imperative) →Re [m.**b**alɛ́lɛ] gatshi
d. Re ____ gatshi (infinitive) →Re [χʊ**b**alɛla] gatshi

The acoustic and laryngographic data were recorded using National Instruments PCI-6013 data acquisition hardware and the Matlab Data Acquisition Toolbox (20 kHz sample rate per channel and 16 bits/sample). For the audio signal an AKG C520 microphone and M-Audio AudioBuddy microphone preamp were used; the laryngographic data was collected with Laryngograph Ltd. Portable. For each token we measured a number of parameters known to be associated with the voicing distinction. We measured the duration of the following intervals: (1) voice onset time, (2) voicing into the stop constriction (i.e., voicing continuation from the preceding nasal/vowel in the case of voiceless and devoiced obstruents), (3) consonant closure (for stops and the stop portion of affricates), (4) preceding nasal, (5) preceding VN sequence, and (6) for affricates, duration of the fricative portion (from stop release to onset of voicing for the vowel). For the voicing measurements (1) and (2), the beginning and end of voicing were marked on the laryngographic data (which closely correlated with the periodicity in the acoustic waveform and spectrogram). Measurements (3)-(6) were made on the acoustic records. The fundamental frequency (f0) of the vowel following voiced, devoiced and voiceless obstruents was measured at the first glottal pulse, and at 20, 40, 60, and 80 ms after stop release (vowels were typically 80–100 ms long). The f0 was obtained by measuring the period of the glottal pulse on the laryngograph trace at the specified points in time.

There were 140 post-nasal stops and 110 post-vocalic stops analyzed for these parameters: three tokens (two in the case of velars) × four places of articulation × three voicing specifications post-nasally (devoiced, voiceless and voiced—except for devoiced velars which do not occur) and two post-vocalically (voiceless and voiced) × five repetitions. 120 affricates, 60 post-nasal and 60 post-vocalic, were also analyzed (three verbs × two places of articulation × two voicing specifications (devoiced and voiceless post-nasally and voiced and voiceless post-vocalically) × five repetitions.

Unless otherwise specified, two-way ANOVAs were conducted to evaluate the effects of voicing (devoiced, voiceless, voiced for stops; devoiced and voiceless for fricatives) and place of articulation (labial, dental, palatal, velar for stops; alveolar, palatoalveolar for fricatives) on the dependent variables. For post-hoc comparisons between means, Scheffé's test was used.

3.2. Results

In the light of the variation in the realization of stops reported by other investigators (e.g., Monaka 2005a, 2005b; Zsiga et al. and Coetzee et al. for Tswana), even within individual speakers, it must be noted that our Shekgalagari speaker systematically devoiced stops post-nasally and produced voiceless unaspirated stops mostly as pulmonic stops, although occasionally as ejectives, especially [k].

3.2.1. Post-nasal stops and fricatives

The primary purpose of the study is to determine if there are phonetic differences between voiceless and devoiced obstruents in post-nasal position, therefore we focus on post-nasal tokens in this section. Figs. 1–5 show mean values and SD for different voice types calculated over the five repetitions of each of the three (or two) tokens for each place of articulation (devoiced velars are not shown because velars are rare and do not devoice post-nasally). Fig. 1 (left) shows that the duration of the nasal is longer preceding voiced than voiceless and devoiced stops, which do not differ from each other. This seems to be the case for all places of articulation. The same pattern was found for the duration of the preceding vowel+nasal interval (not shown in the Figures for reasons of space). This was confirmed by two-way ANOVAs (3 voicing states × 4 places of articulation) which showed significant main effects of voicing [$F(2, 130)=77.438$ for nasal duration and 49.481 for vowel+nasal duration, $p<.0001$] and place [$F(3, 130)=15.926$ for nasal duration and 15.528 for vowel+nasal duration, $p<.0001$], but no interaction effects. Follow-up pairwise comparisons among the three voicing conditions indicate that voiced stops have significantly longer preceding nasals and V+N intervals than voiceless and devoiced stops (Scheffé, $p<.05$). There were no significant differences between devoiced and voiceless stops in any of the two parameters. Follow-up comparisons to the main effect for place show significantly shorter nasals and V+Ns before dentals than before other places of articulation, and shorter V+Ns before labials than velars.

Fig. 1 (right) shows that, in a similar vein, voiceless and devoiced affricates (voiced affricates do not occur post-nasally)

[11] There are obvious limitations to this study since we analyzed only one speaker, and a speaker who was not naïve to the purposes of the study. Nevertheless, because the results for this speaker are consistent with traditional descriptions (Dickens, 1977, 1984 and other references to Shekgalagari), we feel confident that they are representative of most speakers of Shekgalagari. As for Tswana (Coetzee & Pretorius, 2010; Zsiga et al., 2006, 2007), we would not be surprised to find variation.

[12] In their Tswana study, Coetzee and Pretorius (2010) used a similar method of controlling for this confound and found no evidence for the influence of orthography.

Table 2
Examples of some of the stops and affricates elicited (see appendix for a full list).

	Postnasal		Postvocalic	
Stops				
Voiced	/mʊ+bɔ́hɛ́lɛ/	[m.bɔ́hɛ́lɛ] ‘tie for him/her!’	/χʊ+bɔ́hɛ́la/	[χʊbɔ́hɛ́la] ‘to tie for’
Devoiced	/m+bɔ́hɛ́la/	[m.pɔ́hɛ́la] ‘tie for me!’		
Voiceless	/m+pɔ́cɛ́la/	[m.pɔ́cɛ́la] ‘go around for me!’	/χʊ+pɔ́cɛ́la/	[χʊpɔ́cɛ́la] ‘to go around for’
Affricates				
Voiced			/χʊ+zípa/	[χʊzípa] ‘to zip up’
Devoiced	/n+zípa/	[n.tsípa] ‘zip up for me!’		
Voiceless	/n+tsíca/	[n.tsíca] ‘cover with a diaper for me!’	/χʊ+tsíca/	[χʊtsíca] ‘to cover with a diaper’

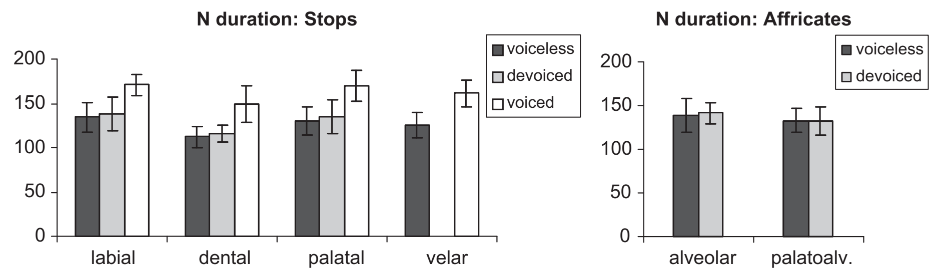

Fig. 1. Mean duration in ms of the preceding nasal for voiced, devoiced, and voiceless stops (left) and devoiced and voiceless affricates (right) at each place of articulation. For all figures, the error bars represent standard deviation. Each bar represents the mean of 15 observations (except for voiced dentals, voiced palatals and voiced and voiceless velars where $n = 10$).

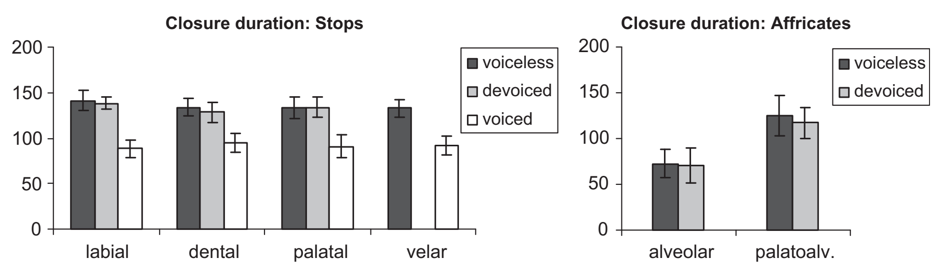

Fig. 2. Mean duration in ms of the consonant closure for voiced, devoiced, and voiceless stops (left), and of the fricative constriction for devoiced and voiceless affricates (right) at each place of articulation.

show comparable values for preceding nasal duration. The same is true for V+N duration. The results of the ANOVAs indicate a non-significant effect for voicing [$F(1, 56) = .069$ for nasal duration, $p = .793$; and .453 for V+N duration, $p = .503$], for place [$F(1, 56) = 3.228$ for nasal duration, $p = .078$; and 4.01 for V+N duration, $p = .070$], or for the interaction between voicing and place [$F(1, 56) = .165$ for nasal duration, $p = .686$; and 2.577 for V+N duration, $p = .114$].

Fig. 2 (left) shows that, as expected, voiced stops have a shorter closure duration than voiceless stops (Lisker, 1986). Closure duration values for voiceless stops, however, do not differ from those for devoiced stops. Two-way ANOVAs confirmed a significant effect of voicing [$F(2, 116) = 216.992$, $p < .0001$], a non-significant effect of place [$F(3, 116) = 1.636$, $p = .185$], and no interaction effects [$F(4, 116) = 2.40$, $p = .065$]. Post-hoc analyses indicated that voiced stops had a significantly shorter closure duration than either the devoiced or the voiceless stops. No significant differences were found between devoiced and voiceless stops.

Similarly, post-nasal devoiced and voiceless affricates show comparable closure duration (Fig. 2 right). The analyses show a non-significant effect of voicing [$F(1, 56) = 1.027$, $p = .315$], a significant effect of place [$F(1, 56) = 106.881$, $p < .0001$], with palatoalveolars having a longer stop constriction that alveolars, and no interaction effects [$F(1, 56) = .361$, $p = .550$].

Fig. 3 left presents Voice Onset Time for voiceless and devoiced stops. (Voiced stops show full voicing during the closure in Shekgalagari, see Fig. 4.) VOT values do not differ for voiceless and devoiced segments which, with the exception of palatals (range 7.25–25.85 ms), show very short VOT values (range 0–6.6 ms). Thus, in our Shekgalagari speaker unaspirated voiceless stops and devoiced stops have a short voicing lag and voiced stops are prevoiced. Two-way ANOVAs (2 voicing states $\times$ 3 places of articulation: labial, dental, palatal) on VOT values showed a non-significant effect of voice [$F(1, 88) = .684$, $p = .410293$], a significant effect of place [$F(2, 88) = 86.563$, $p < .0001$], and no interaction effects [$F(2, 88) = .996$, $p = .373$]. Post-hoc tests indicated that palatals had longer VOT than labials and dentals, most likely due to the more extended area of contact and the slower release of the tongue body, which delay the achievement of the pressure differential for voicing. Longer VOT values for palatal stops than for other places of articulation have also been found for other languages (e.g., Tiwi; Anderson & Maddieson, 1994).

Fig. 3 right presents the duration of the fricative portion of affricates. The Figure reveals a roughly similar duration of the

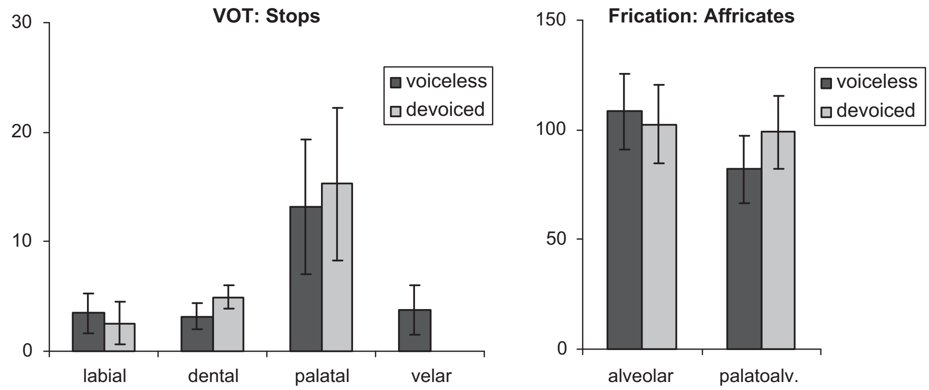

Fig. 3. Left: Mean duration in ms of +VOT for devoiced and voiceless stops at each place of articulation. (Voiced velars do not devoice post-nasally, therefore devoiced velars are not included.) Right: Mean duration of the fricative portion of devoiced and voiceless affricates.

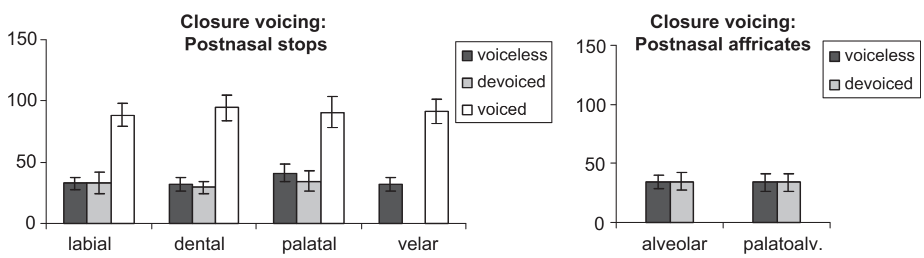

Fig. 4. Mean duration in ms of voicing into the consonant closure for post-nasal voiced, devoiced and voiceless stops (left), and voiceless and devoiced affricates (right) at each place of articulation.

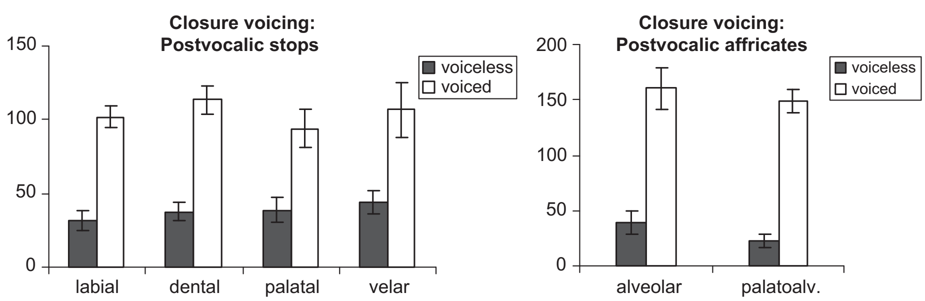

Fig. 5. Mean duration in ms of voicing into the consonant closure for post-vocalic voiced and voiceless stops (left) and affricates (right) at each place of articulation.

fricative component for devoiced and voiceless affricates, as shown by a non-significant effect of voice [$F(1, 56)=1.596$, $p=.212$], a significant effect of place [$F(1, 56)=11.964$, $p<.001$], with a longer fricative portion for alveolars than palatoalveolars (Scheffé, $p<.05$), and a significant interaction between voicing and place [$F(1, 56)=6.976$, $p<.05$]. Pairwise comparisons following the significant interaction showed a longer frication duration for devoiced vs voiceless palatoalveolars but not alveolars. However, the difference found is in the opposite direction than what would be expected if the voicing contrast was not neutralized (i.e., voiceless affricates would be expected to have a longer frication than (de)voiced affricates). In sum, the data show no principled difference in VOT or frication duration for devoiced vis-à-vis voiceless obstruents.

Vocal fold vibration during the stop/affricate closure was also measured. For voiceless and devoiced obstruents only the initial portion of the consonant closure was voiced, corresponding to voicing continuation from the preceding nasal. Fig. 4 (left) shows that voiced stops are fully voiced in Shekgalagari (voicing into closure=closure duration), and that in devoiced and voiceless obstruents voicing spills over for approximately 30–40 ms (about 20–25% of the duration of the consonant constriction).[13] Two-factor ANOVAs showed a significant effect of voicing [$F(2, 130)=747.841$, $p<.0001$), a non-significant effect of place [$F(3, 130)=1.985$, $p=.119$], and a non-significant interaction [$F(5, 130)=2.195$, $p=.064$]. Post-hoc tests indicated a significantly longer voicing during the constriction for voiced than for either devoiced stops or voiceless stops. No difference was found between devoiced and voiceless stops.

Devoiced and voiceless affricates (Fig. 4 right) show no difference in voicing into closure for alveolars or palatoalveolars. ANOVAs showed a non-significant effect of voicing [$F(1, 56)=.024$, $p=.877$], place [$F(1, 56)=.149$, $p=.701$], and no interaction [$F(1, 56)=.003$, $p=.959$].

[13] These are lower percent values than in Tswana, as found by Coetzee and Pretorius (2010), where voicing was around 30–40% of the closure. So in Shekgalagari these stops are even more clearly voiceless than in Tswana.

3.2.2. Post-nasal vs post-vocalic stops and fricatives

Because greater closure voicing has been reported for a variety of languages in post-nasal than in post-oral position (Hayes & Stivers, 2000), we analyzed voicing into the closure in post-nasal (Fig. 4) and post-vocalic stops and affricates (Fig. 5). Comparison of post-nasal and post-vocalic stops in Figs. 4 and 5 (left) shows that, in contrast with the findings for most languages, voiceless stops do not have longer voicing into the closure post-nasally than post-vocalically. That is to say, the voiced closure interval for voiceless and devoiced stops post-nasally show values between 30–40 ms, similar to (or slightly shorter than) those for post-vocalic voiceless stops. The same applies to affricates in Figs. 4 and 5 (right), which exhibit similar values of voicing into the closure for post-nasal and post-vocalic voiceless (and devoiced) segments. One-way analysis of variance showed no difference in voicing into the closure for post-nasal and post-vocalic voiceless stops [$F(1, 110)=2.515$, $p=.116$] or affricates [$F(1, 58)=.992$, $p=.323$].[14] (The similar values of voicing into the closure for post-nasal devoiced and voiceless stops and affricates was reported in the previous section).

These results are in accordance with the results obtained by Coetzee et al. (2007: Table 1) and Coetzee and Pretorius (2010) for Tswana (a closely related language). Coetzee et al. found that voiceless stops show longer voicing into the closure post-vocalically than post-nasally (and that post-nasal voiceless and devoiced stops do not differ from each other). In other words, the phonetic basis for post-nasal voicing is not present in Tswana or Shekgalagari, nor is the phonological post-nasal voicing process. Rather, these languages have the opposite process: post-nasal devoicing. The results suggest that the phonetic basis of post-nasal voicing may be language-specific.

3.2.3. f0 differences and obstruent voicing

The effect of obstruent voicing on the fundamental frequency (f0) of following vowels was also analyzed. Because the vowel was kept the same within each triplet, i.e., after the voiced, devoiced and voiceless stop, intrinsic f0 differences associated to vowel height are equally represented in the consonant voicing categories. Vowels with high and low tones were analyzed separately. For each token, the fundamental frequency was measured at the first glottal pulse after stop release, and at 20 ms intervals. To plot the f0 contours, these values were averaged across repetitions and items in the same tonal context. The results are given in Fig. 6. Each data point represents the average of 20–45 measurements. For the low tones, at time 0 (onset of voicing for the vowel) the f0 is considerably lower after a voiced stop than after voiceless/devoiced stops, which show comparable values. The average f0 difference at the onset of vowels following a voiced vis-à-vis a voiceless/devoiced stop is approximately 11 Hz for low tones (the average difference reported for English ranges between 5 and 15 Hz; Hombert, Ohala, & Ewan, 1979 and references therein). Although the greatest difference in the f0 curves is at vowel onset, for low tones the curves are still different 20 ms after vowel onset. Statistical analyses confirmed these observations. One-factor ANOVAs were used to examine the f0 differences in vowels following voiced, voiceless and devoiced stops at 0ms, [$F(2, 93)= 19.22$, $p<.0001$], 20 ms [5.71, $p<.05$], 40, 60, and 80 ms [n.s., $p>.05$]. Post-hoc pairwise comparisons revealed that, both at 0 and 20 ms, voiced stops differed significantly from voiceless and devoiced stops, which did not differ from each other (Scheffe, $p<.05$). It is worth noting that the f0 curves for low tones resemble those reported for Yoruba and American English (Hombert et al., 1979), that is, the f0 time course of vowels following voiced and voiceless/devoiced stops differ from each other in direction of f0 change (rising vs falling/level) and average relative values. In contrast, the duration of the pitch perturbation caused by voicing in the consonant is restricted in time in Shekgalagari and Yoruba (20–40 ms) vis-à-vis non-tonal languages such as American English (> 100 ms).

The results for high tones are slightly more difficult to interpret. The unexpected high f0 values of high tones after voiced obstruents (vis-à-vis after devoiced and voiceless obstruents) may reflect an asymmetry in the data. The words [m.**b**ɔ́hɛ́], [m.**b**ɔ́hɛ́lɛ], [man**d**óndó], [ɲ.ɟábétsa], which represent high tones after a voiced stop, all have a sequence of two high tones after the segment of interest, whereas the words with the devoiced and voiceless obstruents only have H+H in 6 out of 16 tokens. However, we cannot provide an explanation of how the tone confound may result in higher f0 values,[15] therefore it is possible that some other factor may be at play. Nonetheless, note that the difference in frequency between the points in time 0 and 20 ms is significantly larger for voiced (average 7.3 Hz) than for voiceless and devoiced consonants, as shown by a one-factor ANOVA [$F(2, 95)=5.67$; $p<.01$]. Pairwise comparisons similarly showed a larger difference for voiced stops than for voiceless and devoiced stops, which did not differ from each other. These results suggest that the perturbation caused by a voiced consonant on a following high tone is greater (that is, the f0 lowering effect is relatively larger) than the effect of a voiceless or devoiced consonant. It cannot be discarded, however, that the larger difference for voiced obstruents is due to the higher f0 in the vowel in this context. The tone confound on the voiced stop data with high tones means we cannot really say whether the voiced stops behave similarly or differently from the other stops. However, we can still say the voiceless and devoiced stops are no different from one another. In other words, the data show that devoiced stops perturb the time course of f0 variation on a following low and high tone in the same way as voiceless stops.

Taken together, these results indicate that for this speaker post-nasal devoicing is a categorical process, that is, devoiced obstruents did not differ from underlying voiceless obstruents in any of the variables analyzed: VOT, duration of the fricative interval (in the case of affricates), voicing into closure, closure duration, duration of preceding nasal (and VN sequence), and effects on the f0 of following vowels.[16] Voiced obstruents differed

[14] A difference in the closure duration post-nasally and post-vocalically may result in a difference in the percent of the closure that is realized with voicing in these two contexts, even if the absolute value of the voiced portions do not differ. However, no consistent differences in closure duration in the two contexts were found that could be argued to be at the basis of post-nasal voicing. The mean closure duration for post-nasal (135.20 ms) and post-vocalic (136.7 6 ms) voiceless stops did not differ significantly. The greater closure duration for post-nasal (98.63 ms) vs post-vocalic (84.05 ms) voiceless affricates would result in a smaller percent of voicing in the post-nasal context. Voiced stops also differ in closure duration (93.15 ms post-nasally vs 103.94 ms post-vocalically) but of course they have voicing throughout the closure. Devoiced stops and affricates only occur post-nasally (closure duration: 133.54 and 93.80 ms, respectively), and voiced fricatives (151.86 ms closure duration) only occur after a vowel.

[15] One could speculate that two consecutive high tones may start at and reach higher values than a sequence of H+L, which could account for the higher starting frequency of the voiced tokens. However, prior studies have shown that in H+H vs H+L sequences, the first H tends to be lower in the first case than in the second (Beckman & Pierrehumbert, 1986). This is obviously an area that would greatly profit from further investigation.

[16] A potential problem with the present interpretation of the statistical results is to take the lack of evidence of significant differences as supporting the neutralization of the voicing contrasts post-nasally. We feel confident in accepting the absence of a difference in the six parameters analyzed in stops and fricatives as evidence for contrast neutralization because an indication was found in the same data set that this amount of data (n) would have revealed a difference had there been one (as was the case for differences between voiced and devoiced/voiceless segments). While it is theoretically possible that our tests may not have sufficient power to detect small differences between devoiced and voiceless stops at this n, we consider it highly unlikely.

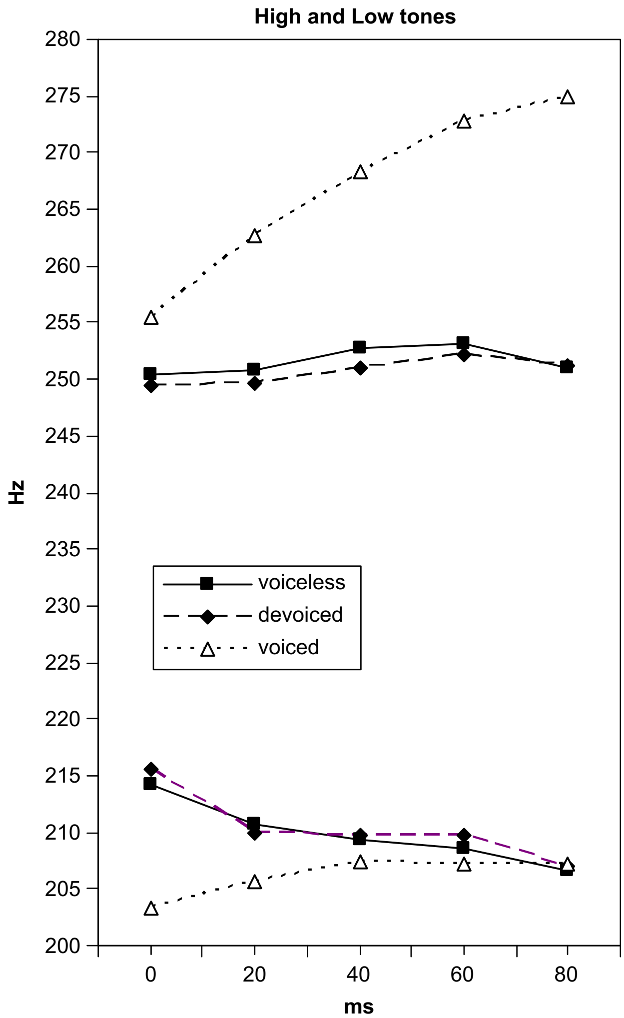

Fig. 6. Average fundamental frequency of vowels with high (top) and low tones (bottom) following post-nasal voiceless, devoiced and voiced stops and affricates (the values for the 'voiced' category correspond to the voiced stops exclusively as voiced affricates – or fricatives – do not occur after a nasal). The values have been pooled across place of articulation within each voicing category. The zero point on the abscissa represents the first glottal pulse after stop release; this occurs slightly later in time in voiceless and devoiced stops than in voiced stops. Each data point represents the mean of the following number of observations: *Low tone*, $N_{\text{voiced}}=25$; $N_{\text{devoiced}}=30$; $N_{\text{voiceless}}=40$ and *High tone*, $N_{\text{voiced}}=20$; $N_{\text{devoiced}}=40$; $N_{\text{voiceless}}=45$.

from devoiced and voiceless obstruents in all these parameters. In addition, voiceless stops did not show longer voicing into the closure post-nasally than post-vocalically, in contrast with the findings for most languages.

4. Discussion

The results presented in Section 3 show no evidence of phonetic differences between devoiced stops and lexical voiceless stops which indicates that the post-nasal devoicing process in Shekgalagari is categorical, that is, voiced stops have merged with voiceless stops post-nasally. Coetzee et al. found similar results for Tswana, as well as a productive behavior of post-nasal devoicing (i.e., it was applied to non-words), which led them to conclude that this language contains a rule of post-nasal devoicing, in line with Hyman (2001). However, this is not the only possible interpretation. The categorical nature of post-nasal devoicing suggests that this is a historical process and that the phonological form has changed from voiced to voiceless post-nasally, with the voiceless form being then extended to cases of reduplication. In other words, that speakers store /m+p/ forms in their lexicons. This interpretation is not at odds with Coetzee et al.'s findings that post-nasal devoicing was a productive process for some Tswana speakers. It is possible that these speakers have learned that words beginning with [b] (or any voiced obstruent) are pronounced with [p] post-nasally, that they store both forms and know they are related (similar to how English speakers store 'a' and 'an'), and that they form novel words analogically.

An intriguing issue is how this phonetically problematic process of post-nasal devoicing may have originated in these languages. We suggest a possible explanation. First, the experimental results provide a crucial finding: there is no appreciable difference in passive voicing of voiceless stops/affricates after nasals vis-à-vis after oral segments (Figs. 4 and 5) in contrast to what has been reported for other languages. Since greater phonetic voicing in post-nasal position stems from the gradual raising of the velum at the end of the nasal, which allows air to continue to escape through the nose during the initial part of the stop closure (thus prolonging vocal fold vibration), the absence of such greater passive voicing suggests an early closure of the velum and no nasal leakage into the stop closure. Second, these languages show what has been termed 'post-nasal' fortition,[17] that is, the emergence of an epenthetic stop in N+fricative sequences (e.g., [xʊ**z**ʊ́mɛla] 'to hunt for' vs [n.**ts**ʊ́mɛ́la] 'hunt for me!') (as we indicated earlier, post-nasal devoicing has long been considered a further instance of post-nasal fortition). Phonetically, such epenthetic stops in the transition from a nasal to a fricative arise due to an early raising of the velum relative to the oral constriction. That is, the velum is raised before the oral closure for the nasal stop is released, oral pressure rises, and when the oral constriction is released it causes a burst and an obstruent is created (Ohala, 1997; Ohala & Solé, 2010). Such early velum raising allows the build-up of oral pressure to create strong frication for the following fricative.

These two facts taken together, lack of greater passive voicing of voiceless stops post-nasally and 'intrusive' stops, suggest that speakers of these languages inhibit nasal leakage into the stop closure by an early raising of the velum relative to the oral constriction. In other words, given that the velum is a sluggish articulator, in Shekgalagari the velum has to start raising early to ensure that the raising is completed by the time that the oral constriction for the nasal is released. One may expect that, in N+voiced stop sequences, such early velic raising during the oral closure for the nasal will result in a long stop closure (with the nasal and oral valves closed) which, in the absence of articulatory adjustments, is likely to devoice (due to the difficulty of sustaining vocal fold vibration as oral pressure rises over time, and the pressure differential drops below the threshold for vocal fold vibration; Ohala, 1983). Similarly, in N+voiced fricative sequences, anticipatory velic closure will result in an intervening stop (velum closed during the nasal stop closure) and oral

[17] Terms such as 'strengthening' and 'fortition' have been used as cover terms to refer to such disparate phenomena as devoicing, aspiration, ejectivization, intrusive stops, (post-nasal) occlusivization, and frication amongst others. What these cases have in common is that they involve a higher-than-normal oral pressure build-up which results in an increased intensity of frication (or a noisy release burst), which may be auditorily associated to 'strength'. Such increased pressure build-up, however, may arise from distinct articulatory mechanisms, for example, larynx raising, differences in the timing of articulatory gestures (e.g., early closure of the nasal valve), or narrowing of the articulatory constriction. Given that 'strenghthening' and 'fortition' do not have a unique articulatory/acoustic correlate, it is best to refer to the physical phonetic correlates responsible for such auditory effect.

pressure rise during the stop and fricative constriction leading to passive devoicing. The devoiced obstruent, having a strong release burst due to the high pressure accumulated in the oral cavity during the long constriction, may have been reinterpreted as voiceless.

To summarize, the sequence of articulatory and perceptual stages would be as follows: early closure of the velum, oral pressure rise during the resulting long obstruent, passive devoicing and strong release burst reinterpreted as a (unaspirated) voiceless segment. Of course, further instrumental research on Shekgalagari and Tswana is needed to confirm this explanation. However, the observed effects of early velum raising in N+obstruent sequences allows a unified explanation of the emergence of epenthetic stops in N+fricative sequences and post-nasal devoicing in these languages.

Our suggestion that post-nasal devoicing is not necessarily a phonetically unnatural process differs from the historical explanation of Hyman (2001) for Tswana, also endorsed by Coetzee and Pretorius (2010). Hyman argues that phonetically unnatural phonological processes – such as post-nasal devoicing – may result from historical restructuring, i.e., the confluence of specific and unique historical circumstances.[18] The availability of instrumental evidence on the realization of post-nasal and post-vocalic stops and fricatives allows us to offer a new perspective on the phonetic grounding of post-nasal devoicing. While there will be many cases of restructuring which result in rather un-phonetic-looking synchronic phonologies our present study suggests that one such case, post-nasal devoicing, now has a competing phonetic account that should be evaluated against the more complex historical restructuring account.

5. Conclusions

In summary, the results indicate there is no phonetic difference between [mp] from /m+b/ ("devoiced") vs. /m+p/ ("voiceless") in any of the parameters analyzed. Thus post-nasal devoicing appears to be a discrete change that may be analyzed as a phonological rule or as a lexicalized process. The existence of post-nasal devoicing, in addition to the almost total lack of ND within morphemes, as opposed to NT, clearly establishes that there is a preference for NT in this language.

Another finding is that the results undercut the claim that the phonetic tendency toward post-nasal obstruent voicing (i.e., passive voicing continuation into the stop closure) is present in all languages that have nasal+voiceless obstruent clusters (Hayes, 1999; Hayes & Stivers, 2000). In fact, Shekgalagari (and Tswana, cf. Coetzee et al., 2007; Coetzee and Pretorius, 2010) speakers show early raising of the velum, which allows them to preserve the distinction between NT and (the rather limited cases of) ND. We have argued that such early raising of the velum is at the basis of the devoicing of the obstruent and the affrication of N+fricative sequences, e.g. /nz/→[nts]. This interpretation, based on variations in interarticulatory timing and associated aerodynamic consequences on voicing, differs from Zsiga et al.'s claim that post-nasal devoicing and affrication are cases of strengthening.

[18] In this case: (i) spirantization of voiced stops except after nasals; (ii) subsequent devoicing of voiced stops, which happen just coincidentally to occur after nasals. At this stage this produced alternations between [β] and [p], and [l]/[r] and [t]. Finally, (iii) [β] and [r] become [b] and [d], respectively. The general bias against voiced stops in (i) and (ii) is taken as evidence for the *D constraint. However, in Shekgalagari, where stops also devoice after nasals, voiced stops exist not only initially and post-vocalically, but also in some newly created ND sequences, thus providing surface exceptions not only to *D but also to *ND.

The results suggest that the two patterns, post-nasal voicing and devoicing, may not be as antagonistic as it has been assumed, but rather that both may be derived from a common source, variations in the timing of velopharyngeal closure. We have argued that different languages may vary in the quantitative values used along specific phonetic dimensions, e.g., timing of velic raising, with different phonetic and phonological consequences. Thus, late velic raising in NT sequences promotes voicing – and impairs obstruency – and may result in post-nasal voicing (or nasal assimilation, NT, ND > nn) whereas early velic raising favors devoicing and obstruency, and may result in post-nasal devoicing (or denasalization, NN > ND, as in Kikongo and Kiyaka).[19] This is in line with detailed phonetic studies (e.g., Busà, 2007; Browman & Goldstein, 1995; Ohala and Solé, 2010; Recasens & Espinosa, 2005) which have shown that small differences in the timing, temporal extent, or magnitude of articulatory or acoustic variation may give rise to qualitatively different results, in part due to the quantal nature of speech (Stevens, 1989). Thus, small variations in the articulatory or acoustic domains may result in categorically different patterns. Hence one of the conclusions of this study is that apparently opposite constraints such as *NT and *ND may derive from variations in articulatory timing in the relevant languages.

Finally, it is now generally agreed that sound change is phonetically natural. The question is whether phonetic naturalness plays a role in synchronic phonology. Hyman (2001) proposes that while phonetic naturalness is relevant in diachrony, it need not be a property of synchronic phonologies; when a sound change is phonologized, it takes on a synchronic life of its own. While this is in part true, it is also true that synchronic phonologies (i) are partly the result of phonologization (e.g., a devoicing rule) of these phonetic effects, which may then undergo phonemicization (as the post-nasal devoicing process is neutralizing), and that (ii) phonological categories, in turn, exhibit variation in certain phonetically predictable ways. So there seems to be a mutual interaction – or feedback – between 'natural' phonetics and phonology. Possibly, whereas the division between phonetics and phonology, and synchrony and diachrony, has allowed us to advance in our understanding of the structure of speech and language, it has also obscured the sometimes inextricable links between these approaches.

Acknowledgements

This work was partly supported by the Ministry of Science and Innovation, Spain, Grant no. FFI2010-19206. The authors are grateful to Andries Coetzee and Maria Gouskova for their comments on an earlier version of this article.

Appendix A

Tokens elicited for acoustic analysis. Tokens are written in broad transcription alongside the English gloss. The tones shown are the tones that occur when the form is said in the carrier sentence *Re ___ gatshi* (for example, the imperative [ɟabúɛla] in isolation is pronounced [ɟabúɛ́la], with the high tone spreading to the next syllable, when said in the carrier sentence) (see Table A1).

[19] See Hyman (2001: section E) for a list of processes and counter-processes which may be explained in terms of differences in interarticulatory timing (including early velic raising relative to the lowering of the tongue sides in n+l > nd).

Table A1

STOPS				
	/b/-initial		**/p/-initial**	
(1)	**b**alɛ́la	'count for!'	**p**alɛ́la	'refuse!'
	m**p**alɛ́la	'count for me!'	m**p**alɛ́la	'refuse me!'
	m**b**alɛ́lɛ	'count for him/her!' (< mʊbalɛlɛ)	–	
	χʊ**b**alɛla	'to count for'	χʊ**p**alɛla	'to refuse'
(2)	**b**ɔ́ha	'tie!'	**p**ɔ́ca	'go round!'
	m**p**ɔ́ha	'tie me!'	m**p**ɔ́ca	'go round me!'
	m**b**ɔ́hɛ́	'tie him!' (< mʊbɔ́hɛ)	–	
	χʊ**b**ɔ́ha	'to tie'	χʊ**p**ɔ́ca	'to go round'
(3)	**b**ɔ́hɛ́la	'tie for!'	**p**ɔ́cɛ́la	'go around for!'
	m**p**ɔ́hɛ́la	'tie for me!'	m**p**ɔ́cɛ́la	'go around for me!'
	m**b**ɔ́hɛ́lɛ	'tie for him/her!' (< mʊ**b**ɔ́hɛ́lɛ)	–	
	χʊ**b**ɔ́hɛ́la	'to tie for'	χʊ**p**ɔ́cɛ́la	'to go around for'
	/d/-initial		**/t/-initial**	
(1)	**d**ʊshá	'remove!'	**t**ʊbá	'pluck!'
	n**t**ʊshá	'remove me!'	n**t**ʊbá	'pluck me!'
	ń**de**	'perfective morpheme'	–	
	χʊ**d**ʊsha	'to remove'	χʊ**t**ʊba	'to pluck'
(2)	**d**ʊdɛ́la	'respect for!'	**t**ʊbɛ́la	'pluck feathers for!'
	n**t**ʊdɛ́la	'respect for me!'	n**t**ʊbɛ́la	'pluck feathers for me!'
	man**d**óndó	'plentiful'	–	
	χʊ**d**ʊdɛla	'to respect for'	χʊ**t**ʊbɛla	'to pluck feathers for'
(3)	**d**álɛla	'be full for!' (also **d**álɛ́la)	**t**álɛ́la	'despise!'
	n**t**álɛla	'be full for me!' (also n**t**álɛ́la)	n**t**álɛ́la	'despise me!'
	man**d**óndó	'plentiful'	–	
	χʊ**d**álɛla	'to be full for someone'	χʊ**t**álɛ́la	'to despise'
	/ɟ/-initial		**/c/-initial**	
(1)	ɟísa	'feed!'	**c**íla	'stare at in anger!'
	ɲ**c**ísa	'feed me!'	ɲ**c**íla	'stare at me in anger!'
	χʊɟísa	'to feed'	χʊ**c**îla	'to stare at in anger'
(2)	ɟabúɛ́la	'fetch water for!'	**c**abʊ́lɛ́la	'take out a portion for!'
	ɲɟabúɛ́la	'fetch water for me!'	ɲ**c**abʊ́lɛ́la	'take out a portion for me!'
	χʊɟabúɛla	'to fetch water for'	χʊ**c**abʊlɛla	'to take out a portion for'
(3)	ɟábétsa	'cheat someone!'	**c**ámúla	'squeeze!'
	ɲɟábétsa	'cheat me!'	ɲ**c**ámúla	'squeeze me!'
	χʊɟábétsa	'to cheat someone'	χʊ**c**ámúla	'to squeeze someone'
	/ɡ/**-initial**		**/k/-initial**	
(1)	ɡabá	'carry on the shoulder!'	**k**abá	'sow seeds!'
	ŋɡabá	'carry me on the shoulder!'	ŋ**k**abá	'sow me!'
	χʊɡaba	'to carry on the shoulder'	χʊ**k**aba	'to sow seeds'
(2)	ɡaɡɛ́la	'speak on behalf of!'	**k**aɛ́la	'show to!'
	ŋɡaɡɛ́la	'speak on behalf of me!'	ŋ**k**aɛ́la	'show to me!'
	χʊɡaɡɛla	'to speak on behalf of'	χʊ**k**aɛla	'to show to'
AFFRICATES				
	/z/-initial		**/ts/-initial**	
(1)	**z**ʊ́mɛ́la	'hunt for! '	**ts**ʊnɛ́na	'filter for!'
	n**ts**ʊ́mɛ́la	'hunt for me!'	n**ts**ʊnɛ́na	'filter for me! '
	xʊ**z**ʊ́mɛla	'to hunt for'	χʊ**ts**ʊnɛna	'to filter for'
(2)	**z**ípa	'zip up!'	**ts**íca	'cover with a diaper!'
	n**ts**ípa	'zip up for me!'	n**ts**íca	'cover with a diaper for me!'
	χʊ**z**ípa	'to zip up'	χʊ**ts**íca	'to cover with a diaper'
(3)	**z**ʊ́**m**ɛ́la	'hunt for!'	**ts**ʊ́háʒa	'cause to age!'
	n**ts**ʊ́mɛ́la	'hunt for me!'	n**ts**ʊ́háʒa	'cause to age for me!'
	χʊ**z**ʊ́mɛ́la	'to hunt for '	χʊ**ts**ʊ́haʒa	'to cause to age'
	/ʒ/-initial		**/tʃ/-initial**	
(1)	ʒuwɛ́la	'skin for!'	**tʃ**úwɛ́la	'make a whistling noise!'
	n**tʃ**uwɛ́la	'skin for me!'	n**tʃ**úwɛ́la	'make a whistling noise for me!'
	χʊʒuwɛla	'to skin for'	xʊ**tʃ**úwɛla	'to make a whistling noise for'

Table A1. (*continued*)

(2)	ʒuwέla	'skin for!'	**tʃ**ukúta	'rinse your mouth!'
	n**tʃ**uwέla	'skin for me!'	n**tʃ**ukúta	'rinse your mouth for me!"
	χʊʒuwɛla	'to skin for'	χʊ**tʃ**ukuta	'to rinse one's mouth!'
(3)	ʒuwá	'skin!'	**tʃ**úa	'make a whistling noise!'
	n**tʃ**uwá	'skin for me!'	n**tʃ**úa	'make a whistling noise for me!'
	χʊʒuwa	'to skin'	χʊ**tʃ**úa	'to make a whistling noise for'

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