Voiceless Tone Depressors in Nambya and Botswana Kalang'a*

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0. Introduction

It is well known (Beach 1924, Hombert 1978, etc.) that voiced obstruents can act as tonal depressors, lowering the phonologically expected tone of a following vowel. For example, Hyman & Mathangwane (1998) and Mathangwane (1999) show that in Botswana Kalang'a (BK), word-final High tones normally double onto the toneless initial syllable of a following word. However, an intervening voiced obstruent blocks high tone doubling (Mathangwane 1999:173, Fig. (2)):

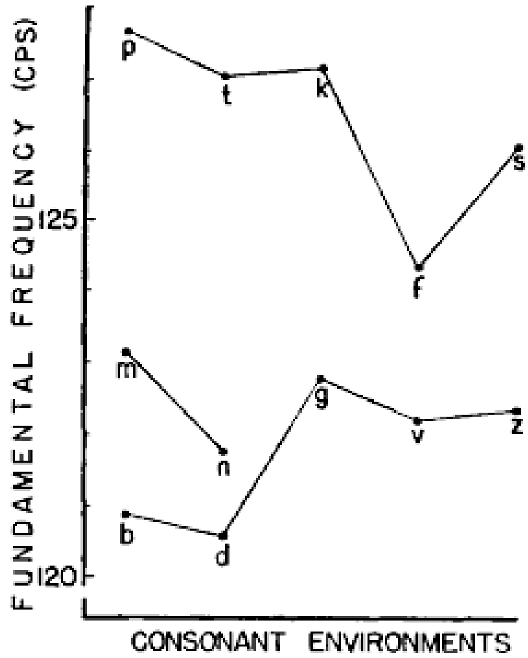
(1) Botswana Kalang'a High tone spread
  a. /tʃi-pó tʃi-tʃó/ → [tʃi-pó tʃ**í**-tʃó] 'your gift'

  BUT depressor blocks high tone spread (depressor is underlined):
  b. /<u>z</u>^{w}i-pó <u>z</u>^{w}i-zó/ → [<u>z</u>^{w}i-pó <u>z</u>^{w}**i**-zó] 'your (pl.) gifts'

Phonetic studies (House & Fairbanks 1953, Hombert et al. 1979) provide an explanation for tonal depression: voiced consonants lower the F0 of a following vowel even in non-tonal languages like English, as shown in (2). On the basis of this phonetic interaction between tone and voice, some recent theories of phonological feature representation (Bradshaw 1999, Halle 1995) argue that voicing and low tone should be designated with a single feature.

* This research was supported in part by NSF POWRE grant #SBR-9806180, and an International Research supplement to this grant, awarded to Laura Downing. The International Grant allowed her to spend May-July 2000 at the University of Zimbabwe, Harare, where the Nambya data cited in this paper was collected. Thanks to the Departments of Linguistics and of African Languages at the University of Zimbabwe, and in particular to Francis Matambirofa and Carolyn Harford, for their hospitality during this stay. Special thanks are due to Theodora Ncube, an undergraduate student at the University of Zimbabwe and native speaker of Nambya from Hwange, Zimbabwe, for her patience and insight in working on her language. Phonetic analysis was conducted at the UBC Interdisciplinary Speech Research Laboratory. Any errors of fact or interpretation in this paper are our responsibility.

(2) Effect of consonant on F0 of following vowel
(House & Fairbanks 1953, Fig. 2)



In this paper, we present phonetic evidence from both BK and Nambya (closely related Southern Bantu languages) that is problematic for the view that tone lowering is necessarily linked to [+voice], since it shows that both languages contain phonetically and phonologically voiceless depressors. The paper is organized as follows. In section 1, we show that contrastively voiced obstruents are tonal depressors, in both BK and Nambya, while other consonants are not. Then we show that both languages have apparently voiceless obstruents which pattern with the voiced obstruents in triggering tonal depression. In section 2, we present a phonetic study of the voiceless depressors showing first that they are phonetically voiceless, second that the voiceless depressors are phonetically distinct from the voiceless non-depressors, and third that this phonetic property is shared across both languages. Links with observations from other languages are discussed as well. Finally, in section 3, we discuss the implications of these findings for both phonological theories of tone-voice interaction and a phonetic understanding of the influence of consonantal properties on F0.

1. Depressor Effects in BK and Nambya

In both BK and Nambya, as in other Southern Bantu languages, voiced obstruents "interfere" with productive tone processes, lowering the tone of a following vowel in some phonological contexts.[1] In BK, as Hyman & Mathangwane (1998) and Mathangwane (1999) demonstrate, contrastively voiced obstruents act as High tone blockers. As shown in (3), word-final High tones productively double onto a following (toneless) syllable if the intervening consonant is voiceless (or not contrastively voiced, so sonorants and implosives pattern with voiceless obstruents for this process):[2]

(3) BK tone doubling (HTS3) – not blocked by voiceless obstruents

a. /ʧi-pó ʧi-ʧé/ → [ʧi-pó ʧ**í**-ʧé] 'his/her gift'
b. /ku- ʧá βu-sîkú/ → [ku- ʧá β**ú**-sîkú] 'to fear at night'
c. /ku- túmá βu-sîkú/ → [ku- túmá β**ú**-sîkú] 'to send at night'

However, as shown in (4), this tone doubling process is blocked if a contrastively voiced consonant (depressor consonant) intervenes:

(4) BK tone doubling (HTS3) – blocked by depressor consonants

a. /<u>z</u>ʷi-pó <u>z</u>ʷi-zé/ → [<u>z</u>ʷi-pó <u>z</u>ʷ**i**-zé] 'his/her gifts'
b. /ku- ʧá <u>z</u>ʷi-pó/ → [ku- ʧá <u>z</u>ʷ**i**-pó] 'to fear gifts'
c. /ku- túmá <u>z</u>ʷi-pó/ → [ku- túmá <u>z</u>ʷ**i**-pó] 'to send gifts'

A further depressor effect in BK is revealed by comparing the data in (5a) with that in (5b). As Hyman & Mathangwane show, while tone doubling is not blocked word internally by depressor consonants, the vowels following these consonants surface with a Low tone in contexts where we find High tones in comparable words that lack depressor consonants.[3] Note that there is only one underlying High tone in verb stems, which is arguably contrastively associated with the stem-initial vowel; other High-toned syllables within the stem are the result of tone doubling:

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[1] Both Nambya and BK are linguistically and geographically neighboring Southern Bantu languages. All the Nambya data cited in this paper is from Downing (field notes). All the Botswana Kalang'a data is from Hyman & Mathangwane (1998) and Mathangwane (1999), and is based on the dialect of Joyce Mathangwane, a native speaker linguist of BK. Thanks to Joyce for helpful discussion of the BK data. See Bradshaw (1999) for a comprehensive survey of languages exhibiting depressor effects.

[2] Hyman & Mathangwane (1998) refer to this process as HTS3, to distinguish it from two other processes of High tone doubling (spread) which they show are not affected by the presence of voiced obstruents. In (2), (3) the representations to the left of the arrow are inputs to HTS3, not necessarily the underlying representations. In all the data cited, acute accent indicates High tone; lack of accent indicates Low tone.

[3] It is beyond the scope of this paper to account for why depressor consonants have different effects in different phonological domains in BK. The interested reader can consult Hyman & Mathangwane (1998) for detailed discussion. For our purposes, the point to be drawn from these data is that generally only contrastively voiced obstruents lower the tone of a following vowel.

(5) BK word medial High tone realization in High-toned verb stems

a. Stems without depressors

[ku-túmá βú-sîîkú]	'to send at night'
[ku-fúmíká βu-sîîkú]	'to cover at night'

b. Stems with depressors
(underlined; unexpected Low-toned vowels are bold)

[ku-dz**i**má βú-sîîkú]	'to extinguish at night'
[ku-pédz**a** βú-sîîkú]	'to finish at night'
[ku-dz**i**múlá βu-sîîkú]	'to reduce heat at night'
[ku-bíg**a**nyá βu-sîîkú]	'to bury at night'
[ku-mílídz**a** βu-sîîkú]	'to lift at night'

Research on Nambya tone so far reveals a similar depressor effect. As shown by the data in (6), the stem-initial High tone of a verb stem regularly doubles on to a following vowel.

(6) Nambya realization of High tone on stems without depressors

[ku-tálá]	'to measure'	[ku-táná]	'to delay'
[ku-pátúka]	'to burst'	[ku-písá]	'to burn'
[ku-kwómá]	'to dry (intrans.)	[ku-kángá]	'to fry'
[ku-ʃóɓá]	'to call'	[ku-ʃótóka]	'to jump'

However, as shown by the data in (7), if the High-toned stem contains a depressor consonant, the vowel following the depressor is Low-toned in contexts where we find High tones in comparable words in (6) that lack depressor consonants:

(7) Nambya realization of High tone on stems with depressors
(underlined; unexpected Low-toned vowels are bolded)

[ku-b**o**ɓóla]	'to pierce'	[ku-zʷ**i**mbá]	'to swell; to miss'
[ku-dʒ**e**lúla]	'to tear'	[ku-ʒ**i**lílíka]	'to sweat'
[ku-g**o**tʃá]	'to roast'	[ku-b**e**.úka]	'to turn over (intrans.)'
[ku-dʒ**i**má]	'to extinguish'	[ku-v**u**ná]	'to harvest; to break'

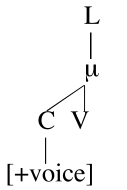
The data so far shows that in BK and Nambya contrastively voiced consonants trigger tonal depression. Again, as shown in (2) above, this well-known pattern is consistent with data from previous studies.

Because the correlation between voicing and pitch lowering is uncontroversially both phonetically grounded and phonologically active, several recent feature theories propose to formally encode this relationship. Peng (1992), for example, argues that the tone/voice correlation is best formalized in terms of grounding constraints (Archangeli & Pulleyblank 1994), like those in (8a). As shown in (8b), in languages where tone/voice is phonologically active, these constraints would evaluate a tautomoraic CV sequence as phonetically grounded if the consonant is [+voice] and the vowel is Low toned. However, since the representation in (8c), with the consonant [-voice] and the vowel Low toned, is ungrounded, no language should have active alternations requiring this output.

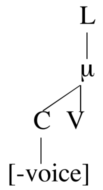
(8) Peng (1992) tone/voice grounding theory

a. (Some) Grounded Constraints:
IF [+voice] THEN Low tone.
IF [-voice] THEN NOT Low tone.

b. Grounded representation



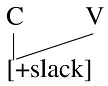
c. Ungrounded representation



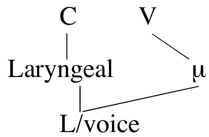
Other recent theories, Halle (1995; originally proposed in Halle & Stevens 1971) and Bradshaw (1999), formalize the correlation by defining Low tone and [+voice] as different phonetic realizations of the same phonological feature, either [+slack vocal cords] (Halle & Stevens 1971; Halle 1995) or [L/voice] (Bradshaw 1999). As shown in (9a, b), both of these theories straightforwardly predict that a contrastively voiced consonant will lower the pitch of a following vowel if [+slack] or [L/voice] is associated both with the voiced consonant and a following vowel. In contrast to Peng's grounding approach, a relation between [–voice] and Low tone is simply inexpressible in both of these theories.[4]

(9) Low tone = [+voice]

a. Halle (1995)



b. Bradshaw (1999)



[4] For Bradshaw (1999), in fact, [voice] is a privative feature, so only a correlation between [+voice] and Low tone can be formalized. For Halle (1995), voicing is not privative; [+stiff] designates both [-voice] and High tone. It is not clear to us how either of these theories accounts for the fact that [+voice] is the marked feature for voicing in these frameworks while High tone is arguably (Pulleyblank 1986) the marked feature for tone. It is beyond the scope of this paper to pursue this problem. However, see Anderson (1978) for a detailed discussion of why it is problematic to designate tone and voicing with the same feature.

All three theories make the strong prediction that only voiced consonants should lower the tone of following vowels.

It is extremely surprising, then, to find that both BK and Nambya have a set of voiceless obstruents which pattern with the contrastively voiced obstruents in acting as tonal depressors. As Mathangwane (1999) shows, in BK there is a contrast between 'non-depressor' aspirated voiceless stops and 'depressor' aspirated stops (P^h, T^h).[5] As shown in (10a), the non-depressors, as expected with voiceless obstruents, do not block HTS3 and can in general be followed by High tones. The 'depressor' aspirated stops, in contrast, pattern with other depressor consonants in blocking HTS3 and in being necessarily followed by a Low tone on the surface. This is shown in (10b).[6]

(10) Botswana Kalang'a depressor vs. non-depressor voiceless aspirates (depressors are underlined; compare the tone of the bolded vowels in the depressor vs. non-depressor sets)

a.	*Non-depressor aspirates and non-aspirates*			
(i)	/ku-ʃímá p^{h}ilé/	→	[ku-ʃímá p^h**í**lé]	'to hate a bad singer'
(ii)	/ɲóká N-lefú/	→	[ɲóká nd**é**fú]	'long snake(s)'
(iii)	/p^{h}óko jáŋgu/	→	[p^h**ó**kó jáŋgu]	'my (castrated) billygoat'
(iv)	/-t^{h}ánt^{h}anula/	→	[-t^{h}ánt^h**á**núla]	'unstitch; unbraid'
b.	*Depressor aspirates*			
(i)	/ku-ʃímá P^{h}ené/	→	[ku-ʃímá P^h**e**né]	'to hate a steenbuck'
(ii)	/ɲóká N-tatú/	→	[ɲóká T^h**a**tú]	'three snakes'
(iii)	/T^{h}éko jáŋgu/	→	[T^h**e**kó jáŋgu]	'my hiccup'
(iv)	/kúT^{h}uβula/	→	[kúT^h**u**βúla]	'pluck off, of leaves'

In Nambya, there is a contrast between two 'f's, a 'depressor f' and a non-depressor.[7] As shown in (11a), High-toned verb stems that begin with the non-

[5] Mathangwane (1999) transcribes these depressor aspirates as having a breathy voiced release. We are adopting a different transcription here, for reasons to be explained in section 2.3.

[6] In BK, as in many Bantu languages, /l/ regularly alternates with [d] after a homorganic nasal. /N/ is the class 9/10 prefix required on adjectives and other modifiers of nouns in this class (which often themselves have this prefix). 'Depressor' aspirates are the synchronic as well as the diachronic output of N+voiceless stop sequences. (See section 3.1., below, for more examples and discussion.)

[7] The distinction between the two 'f's is recognized in the orthography, with the depressor written 'fh' to distinguish it from the non-depressor 'f'. (An 'h' following a letter is a Southern Bantu convention for indicating a sound which is breathy voiced and/or a tonal depressor.) However, Theodora Ncube did not pronounce all the words the dictionary spells 'fh' with the depressor 'f', so the pronunciations here are not likely to be spelling pronunciations. In fact, it was not clear to me how widely known Nambya orthography is among native speakers, since Theodora felt that 'to sew' and 'to become rich', for example, are to be spelled and pronounced identically, even though the dictionary spells them differently and there is a clear tonal difference in the pronunciation. It is also not clear to me whether the differences between Theodora's pronunciation and that suggested

depressor have a High tone on the first two syllables (cf. (6)). In contrast, stems that begin with 'depressor f' (F) pattern with the other depressor consonant-initial stems (cf. (7)) in having a Low tone on the first syllable and a High tone on the second, as shown in (11b).

(11) Nambya, realization of High tone in stems with non-depressor 'f' vs. depressor 'F'

a. *Non-depressor 'f'*

[ku-f**ú**má]	'to become rich'	[ku-f**ú**písa]	'to shorten'
[ku-f**ú**ndá]	'to learn'	[ku-f**ú**lá]	'to blow s.t. out of s.o.'s eye'
[ku-f**á**]	'to die'	[ku-f**í**lá]	'to die for'

b. *Depressor 'F' (underlined)*

[ku-F**u**má]	'to sew'	[ku-F**i**lá]	'to spit'
[ku-F**u**líla]	'to thatch'	[ku-F**u**lá]	'to work metal'

The voiceless depressors raise research questions which we pursued by undertaking a phonetic analysis of recordings of the Nambya data in (11). First, are the 'voiceless' depressors in (11b) actually phonetically voiceless or does some measurable degree of (breathy) voicing distinguish them from the non-depressors in (11a)? If it does turn out that the voiceless depressors are truly voiceless, is there another phonetic property which distinguishes the depressors and non-depressors? Finally, do the voiceless depressors of Nambya share any common phonetic property with the voiceless depressors of BK? The results of our phonetic study are presented in the next section.

2. Phonetics of Voiceless Depressors in Nambya and BK

An acoustic analysis was conducted to test for phonetic differences between the two types of 'f' (depressor and non-depressor) in Nambya. In section 2.3, these results are compared to findings from Mathangwane's (1999) study of BK aspirated stops.

2.1. Methods

Field recordings were collected on standard cassette tapes from a single female native speaker of Nambya, who produced a variety of words in isolation. Recordings were digitized at 44.1kHz onto an Apple PowerBook G3 using SoundEdit™ 16 v2 audio editing software. 16 tokens of /f/ and 13 tokens of /F/ were chosen from a single recording session. In all examples the target segment occurs word-internally, in the context #Cu_uCV..., with the first syllable of the word unstressed. Acoustic analysis of these tokens was conducted using Scicon's

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by the dictionary spelling reveals a dialect difference or a difference in the pronunciation of younger compared to older speakers.

MacQuirer v4.9.7. Standard two-way analyses of variance (ANOVAs) calculated using StatView v5.0 were used to compare the two types of ‘f’.

As was evident both from the spectrograms and from FFTs calculated on the midpoint of frication, two distinct spectral peaks were identified for both types of ‘f’: One longer, more prominent band with a maximum amplitude averaging around 5.5kHz, and the other with a maximum amplitude averaging around 14.5kHz. Since this two-peak pattern is typical of [f], and since the very high frequency band may be perceptually relevant in distinguishing fricatives (Tabain 1998), both were analyzed in this study. Thus, nine different measurements were taken to compare the two types of ‘f’:

- Spectral (FFT) measures:
  1. Bandwidth (Hz) of high freq. band at midpoint of frication (cf. Tabain 1998)
  2. Bandwidth (Hz) of low frequency band at midpoint of frication
  3. Frequency (Hz) at peak of high frequency band at midpoint of frication
  4. Frequency (Hz) at peak of low frequency band at midpoint of frication
  5. Peak amplitude (dB) of high frequency band at midpoint of frication
  6. Peak amplitude (dB) of low frequency band at midpoint of frication

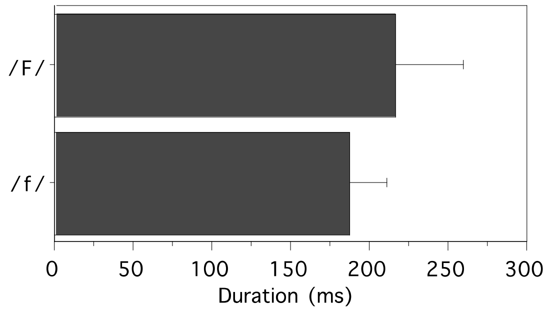
- Temporal measures:
  7. Duration (ms) of high frequency band
  8. Duration (ms) of low frequency band
  9. Total duration (ms) of frication

2.2. Results

First, no difference was found between Nambya /f/ and /F/ in terms of periodicity during frication; except for miniscule sporadic spillover of voicing from the preceding vowel into the onset of frication (up to three periods) appearing in both types, both types of ‘f’ were completely voiceless throughout.

According to ANOVA results, both types of ‘f’ were found to be the same for all six of the spectral measures. However, the total duration of frication noise (and, proportionally, the durations of each of the two component bands) was found to be significantly greater ($p < .05$) for depressor /F/ than for non-depressor /f/ (mean 217ms vs. 187ms, respectively, as shown in (12)).

(12) Mean duration of frication noise in Nambya depressor /F/ vs. non-depressor /f/ (error bars = standard deviation)



2.3. Comparison of Nambya Results with BK

The above results show that there is indeed a phonetic difference between Nambya depressor /F/ and non-depressor /f/, with the depressor showing significantly greater frication duration than the non-depressor. In this section, we compare these results to the aspirated series reported for BK by Mathangwane (1999).

First, Mathangwane refers to the tone-depressor aspirated stops /P^h, T^h/ in BK as the "breathy aspirates", identifying them as being phonetically distinct from the non-depressor aspirate series. It is important to note that she uses the term "breathy" here "for ease of identification," and does not claim that these stops are actually voiced or breathy-voiced stops (she has since further verified their voiceless status in personal communication). She does, however, describe the differences between the two types of aspirated stop in some detail. The main difference she cites (aside from the pitch effect on the following vowel) is that the tone-depressor aspirates "have a longer duration of noise in the high frequencies than the regular aspirates after the vowel onset...," citing a difference of 32 ms between the mean durations. This difference in duration is almost identical to the 30-ms difference between frication duration in the two types of 'f' observed above for Nambya.

Unfortunately, as the data from Mathangwane's study is no longer available, we are unable to support our interpretation of her results. In particular, questions remain as to what is meant by "noise in the high frequencies," and "after the vowel onset." Both of these will have to be addressed (perhaps using new data) before the connection between the Nambya and BK stops can be finally confirmed. However, we believe that the existence of this phonetic connection linking the frication duration of the Nambya f's and of the BK aspirate release bursts further supports the view that voicelessness and tone depression may be compatible for certain classes of voiceless segments.

This possibility is further supported by F0 lowering effects found in previous phonetic studies of aspiration and frication. While unaspirated voiceless stops have generally been viewed as uncontroversially raising vowel F0 relative to voiced stops, the reults for aspirated stops and fricatives have been much less clear.

Zee (1980:90) cites a number of cases where, contrary to the typical pattern, aspirated stops have been observed to have a lowering effect on the F0 of the following vowel, as compared with the effect of the unaspirated equivalent. In a study of Thai stops (Erickson 1975), while 8 of 11 subjects showed a higher F0 onset for vowels following an aspirated stop than for those following an unaspirated stop, the remaining three subjects showed the opposite effect. This F0 lowering effect in Thai was also oberved by Gandour (1974). Kagaya & Hirose (1975) observed a similar F0 lowering effect following aspirated stops for a speaker of Hindi. Particularly interesting for the case of aspirated stops is that of Madurese (Cohn 1993, Cohn & Lockwood 1994). Cohn & Lockwood (1994) measured both closure duration and VOT of nasal, voiced, voiceless unaspirated, and voiceless aspirated stops, as well as F0 of following vowels, of two speakers of Madurese. Their study found that aspirated stops not only lowered the F0 of the following vowel (by 10Hz for their first subject and 40Hz for the second), but that the aspirated stops were 23-40ms longer in total duration (closure plus VOT) than the voiced and voiceless unaspirated stops, respectively. This finding further supports the connection between duration of voiceless aspirates/fricatives and F0 lowering.

Likewise for /f/, House & Fairbanks (1953) observed that the F0 of vowels following voiceless consonants was uniformly significantly higher than those following voiced consonants, with the single exception of /f/, which grouped statistically with /m/ and /g/ in its effect on following vowel F0 (see graph in (1) above). Beyond this, other studies in this literature tended not to include /f/, leaving little comparative data.

These studies lend additional support to the notion that distinct mechanisms are employed across different languages, and even different speakers of the same language, for producing aspiration/frication, and that these production mechanisms affect the F0 of following vowels in distinct ways, which in turn may become phonologized in some tone systems.

3. Implications for the Phonology and Phonetics of Tonal Depression

3.1. Problems with Adapting Current Theories of Tone-Voice Interaction

These phonetic results are clearly problematic for the phonological theories illustrated in (8) and (9) which tie Low tone to [+voice]. While it has been observed before (Zulu (Traill et al. 1998), Musey (Shryock 1995), Swati (Schachter 1976)) that voiceless segments can trigger depressor effects on a following vowel, the BK and Nambya voiceless depressors are fundamentally different from these cases. In the Nguni languages (Zulu and Swati) and in Musey (Shryock 1995), pitch lowering is motivated diachronically, as the synchronically voiceless consonants triggering tonal depression were historically voiced. Even though the voicing has been lost on the consonant, it is, in a sense, preserved in the tone of the following vowel, as we might predict could happen if voice and Low tone are defined by a single feature. As shown in (13), it is plausible to propose the historically voiced consonants are also synchronically voiced in the input, even though, in the output, the L/voice feature is associated only with the following vowel, since this simply involves reassociation of a single input feature ([L/voice], as shown here, or [+slack]):

(13)
a. Input (historically motivated) b. Output (synchronically accurate)

As Bradshaw argues, further evidence that Nguni depressor consonants are best represented as synchronically voiced in the input comes from that fact that they productively alternate with phonetically voiced consonants for other phonological processes like labial palatalization.[8] As shown in (14), the depressor labial stop of Swati (phonetically voiceless, unaspirated [p]) alternates with the phonetically voiced affricate [dʒ] in a palatalizing context:

(14) Swati palatalization: [p] ~ [dʒ] (Bradshaw 1999, p. 158, fig. (20a)); [p] is a depressor)

[sigupu]	'calabash'
[sigudʒini]	'in the calabash'
[sigudʒana]	'little calabash'

If the depressor [p] were voiceless in the input, it would be difficult to explain why it should acquire voicing in this context. For reasons like these, Bradshaw argues that the strong correlation between voicing and pitch lowering predicted by having a single Low/voice feature is well motivated at an abstract level in languages like Swati, even though it is contradicted by the surface phonetics.

However, it is not plausible to argue that the phonetically voiceless depressors of BK and Nambya are phonologically voiced. As shown in (15), the voiceless depressors of Nambya and BK are historically as well as synchronically voiceless.[9]

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[8] See Downing (1999) and Sibanda (1999) and references cited in both these works for analyses and further discussion of labial palatalization in Nguni languages.

[9] The BK data is from Mathangwane (1999; p. 162, Fig. (32)); the Nambya data is from Downing (field notes). The source of the Proto-Bantu cognates is the Tervuren Proto-Bantu database (Coupez, et al. 1998).

(15) Proto-Bantu cognates (ụ is the Proto-Bantu close high back vowel)

<u>Proto-Bantu</u>	<u>Botswana Kalang'a</u>	<u>Nambya</u>	<u>Gloss</u>
-**tụ́**ma	-t^{h}úmá	-<u>**F**</u>umá	'sew'
-**tụ́**ija; -**tu**a-	-t^{hw}á	-<u>**F**</u>ilá	'to spit'
-**tụ́**da	-t^{h}úlá	-<u>**F**</u>ulá	'to work metal'
-to**nt**a	-do<u>**T^{h}**</u>a	-dona	'drip'
-ta**nt**a ('cross')	-ta<u>**T^{h}**</u>a	-tana	'climb'
-**pó**bida	-<u>**P^{h}**</u>obéla	?	'sink, as in mud'

In Nambya, the source of the 'depressor f' in Proto-Bantu is a voiceless coronal stop followed by the close high back vowel. In BK, as Mathangwane (1999) shows, the source of the depressor voiceless aspirates is (typically) a nasal-voiceless stop sequence. Further, there is no evidence that the voiceless depressor consonants pattern with voiced consonants in the synchronic phonology. On the contrary, in BK there are also a few synchronic alternations showing that voiceless aspirates are the surface output of an input nasal-voiceless stop sequence. As we saw in (10b), above, the class 9/10 agreement prefix is /N-/ (a nasal that surfaces homorganic with a following consonant). Adjectives and other stems that begin with voiceless stops when preceded by other class prefixes regularly surface with a voiceless aspirated depressor in class 9/10.[10] More examples of this are given in (16):

(16) BK alternations between voiceless stop and depressor aspirate in Class 9/10 (alternating segments are underlined for ease of comparison)

a.	/ku-<u>t</u>énga/	'to buy'	/<u>T</u>^{h}éngo/	'purchase price (cl. 9)'
b.	/βa-<u>t</u>atú/	'three (cl. 2)'	/<u>T</u>^{h}atú/	'three (cl. 9/10)'
c.	/tʃi-<u>p</u>aβí/	'broad; wide (cl. 7)'	/<u>P</u>^{h}aβí/	'broad; wide (cl. 9/10)'
d.	/m-<u>p</u>úzu/	'wild sour raisin tree (cl.3)'	/<u>P</u>^{h}úzu/	'sour wild raisins (cl. 10)'

There is, then, no phonological motivation independent of tonal depression for proposing that the phonetically voiceless depressors of BK and Nambya are phonologically voiced.

Another alternative analysis that would also allow the L/voice correlation to be maintained is to propose that the vowels following the voiceless depressors of BK and Nambya are lexically associated with a Low tone. Bradshaw argues persuasively that this approach is necessary to explain some grammatical depressor effects in Swati described by Rycroft (1980). As illustrated by the data in (17), in constructions like the imperative, the (long) penult vowel of a toneless verb stem must have a rising tone (this is the usual realization of a High tone on a penult vowel preceded by a depressor consonant), no matter what consonant

[10] The nasal class 9/10 prefix does not surface before voiceless consonants. However, it does surface in other contexts: m-bili 'two (cl. 10)', n-dedu 'beard (cl.9)', etc.

precedes the vowel. (The consonant beginning the penult syllable in all these cases is both phonologically and phonetically voiceless):[11]

(17) Swati grammatical depression (unexpectedly 'depressed' penult is bolded) (Bradshaw 1999, p 100, Figs. (41), from Rycroft (1980))

[kho.ts**àá**.ma]	'bend down!'
[pha.ph**àá**.ma]	'wake up!'
[tʃa.ph**àá**.ta]	'mock!'

Since pitch lowering here is predicted by the morphological context, not the phonological context, it can best be accounted for by stipulating that a Low tone is lexically associated with the penult in this construction.

This approach could also be made to work for Nambya and BK. As shown for the Nambya examples in (18), if a vowel preceded by a voiceless depressor consonant is lexically associated with a Low tone, it will correctly block association of a stem High tone to that syllable:

(18) Nambya, lexical Low tone on vowel accounts for 'depressor f' vs. 'non-depressor f'

a. Lexical Low tone vs. b. No lexical Low tone

```
  H                                H
   \                               |\
-F u m a    'to sew'           -f u m a    'to become rich'
   |
   L
```

However, lexically associating a Low tone with these vowels fails to explain why the lexical Low tone only occurs with particular consonants. More importantly, it fails to explain why these consonants share a phonetic property.[12]

[11] As Rycroft (1980) notes, the rising tone on the penult is only found on toneless verb stems with no depressor consonant elsewhere in the stem. See Bradshaw (1999) for an analysis of this restriction. While it is worth noting that a study by Traill (1990) shows that the Swati "depressorless" rising tones are phonetically distinct from the rising tones following depressor consonants, the results of this study do not clearly affect the phonological analysis sketched here.

[12] A further problem with this approach is that it is unclear how the stem High tone could spread beyond the lexically associated Low tone in BK words like those cited in (5b), e.g.,

```
bí ga nyá.
|  |
H  L
```

3.2. A New Phonetic Correlate of Lowered F0?

Based on the results of this study, as well as those of previous studies such as the ones cited in section 2.3 above, we believe that there exists evidence of at least two distinct mechanisms for producing voiceless frication, one of which produces the well-known pitch-raising effects on a following vowel, and the other of which has a lowering effect. We believe that it is this latter effect that is responsible for the tone depressor effects in Nambya and BK.

The exact properties of these mechanisms remain to be elucidated in future work.

4. Conclusion

In this paper we have shown that both BK and Nambya contain a set of consonants which are phonetically voiceless yet have a depressor effect on the pitch of the following vowel. This finding is problematic for phonological theories which posit that only contrastively voiced segments can induce tone lowering, since the depressor segments are neither historically nor synchronically voiced. It is also phonetically unexpected, since most phonetic studies of the effect of consonants on F0 show that voiceless consonants raise rather than lower the pitch of the following vowel. However, we have also shown that these results correspond with conflicting results in the phonetics literature with respect to vowel F0 specifically following voiceless aspirated stops and the voiceless fricative /f/; we hope that this study will help to clarify these phonetic issues. While more phonetic work on these languages clearly needs to be done, this study suggests that voicing is not the only consonantal property which can lower the pitch of a following vowel.

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