The Phonetic Basis of a Phonological Pattern: Depressor Effects of Prenasalized Consonants

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1. Introduction

Phonetically-based patterns of the interaction between consonantal features and the realization of pitch on a following vowel have formed the basis of classic theories of tonogenesis. However, not all phonological patterns which exhibit consonant-tone interaction are predictable from basic segmental information. In such cases where phonological patterns seem opaque, contradictory, or inexplicably divergent, two things are needed: representational accounts which can reliably derive environments in which patterns and their deviations will arise, and acoustic analyses which clarify the nature of the phonetic motivators underlying the patterns in question.

The current study addresses the latter need by providing acoustic analyses that speak to a curious pattern in the literature: the phonologized interaction between prenasalized consonants and tone in certain tonal languages. An acoustic analysis of F_0 data demonstrating the phonetic effects of prenasalized consonants on pitch will provide a basis to distinguish between a number of possible representational accounts which could account for the cross-linguistic data.

2. Consonant-F_0 interaction and the prenasalized consonant dichotomy

2.1. The interaction of consonant and pitch

It has long been recognized that the realization of pitch on a given vowel segment is influenced by adjacent consonant segments. It is generally believed that the identity of preceding consonants are more influential on a following vowel than those consonants which follow the vowel (Hombert 1978), although models based on Haudricourt (1954) have also argued while that onset consonants determine the height of the pitch realization, syllable-final segments can influence the shape of the pitch contour (Thurgood 2002).

Classic acoustic studies (House and Fairbanks 1953, Lehiste & Peterson 1961, Hombert et al. 1979) have demonstrated the link between obstruent identity and the realization of pitch on a following vowel. Broadly, it has been found that voiced segments lower F_0, while voiceless segments raise it. Physiological accounts for this phenomenon include the relative tenseness or slackness of the vocal cords in voiceless as opposed to voiced consonants (Hombert et al. 1979), the impact of laryngeal height (Honda 2004), and the influence of the cricothyroid muscle in voicing (ibid). In his dissertation, Lee (2008) points out that several laryngeal features, not just voicing, are involved in this phenomenon - suggesting that voicing, phonation, aspiration, and glottalization should all have an effect on the realization of F_0.

From the listener's perspective, the interaction of consonant type and pitch is useful information. A change in pitch as a function of consonant type is an extra cue about what segment was articulated – thus, F_0 can help emphasize contrasts which might otherwise be challenging to hear. In many languages, these cues – often exaggerated beyond the minimum needed for contrast enhancement – develop into phonemic distinctions on the basis of pitch, leading to tonogenesis (Haudricourt 1972, Tang 2008).

2.2. The pattern of prenasalized depressor effects

Hyman (2008) recognizes an interesting pattern in the cross-linguistic literature on consonant-tone interaction regarding the status of prenasalized consonants as depressors (segments which reliably lower pitch on a following vowel). Many languages have phonologized the depressor effects of prenasalized segments into predictable tone patterns. As Hyman points out, it is reasonable to expect such a process to take place in languages where there is a phonological contrast between voiced prenasalized and voiceless prenasalized segments. In such a case, F_0 would be an important cue to an otherwise difficult-to-hear contrast between voiced and voiceless segments because of the potential carryover of nasal voicing onto the oral part of the segment, which would minimize the voicing distinction. Indeed, Hyman's survey of African languages (Table 1) with phonologized depressor effects finds that when voiced and voiceless prenasalized stops (hereafter referred to as ND and NT, respectively) contrast in a language, ND does reliably act as a depressor.

More surprising is the fact that when ND does *not* contrast with NT, ND may still act as a depressor, even there is no contrastive imperative in the voicing dimension for it to do so. This is not always the case; there is a split in the African language data between languages without the ND/NT contrast which do and do not have ND as a depressor consonant.

Table 1. Hyman's (2008) survey of African languages with phonologized depressor effects.

	ND / NT contrast	**No ND / NT contrast**
ND acts as a depressor	Nguni (Swati, Zulu, Ndebele, Xhosa)	Lamang, Musey, Ngizim, Ouldeme, Podoko Shona
ND does not act as a depressor	[none]	Bole, Geji, Miya, Zar; Yulu, Suma, Ikalanga, Mijikenda (Giryama, Digo, Kauma, Rihe)

Hyman recognizes a number of potential factors which could condition this pattern. Historical motivators could give rise to a distinction if all depressor ND segments in languages without the ND/NT contrast were derived from plain voiced stops, and all non-depressor ND languages derived their ND from plain nasal segments. Alternately, the effects of voiced stops on F_0 could have been analogized to ND at some point in some languages' history. Representationally, ND segments could be represented as obstruents or sonorants, leading them to pattern with the segment type that they are specified as. Alternately, there could be a hierarchical level of features (Dresher 2009, Mackenzie 2008) which requires specification of [+voice] on depressor ND, but underspecifies voicing for non-depressor ND.

One challenge in adjudicating between these proposals is a lack of a solid understanding of the intrinsic phonetic effects of prenasalized consonants on $F_{0.}$ It is conceivable that NT segments could pattern with voiceless stops (particularly if NT is aspirated, which is common cross-linguistically) and raise F_0, but it is also possible that NT could pattern with nasal segments and have a relatively neutral effect. ND segments could pattern with voiceless stops and lower F_0, or could pattern with nasals as well and have a neutral effect. Either or both segments could also fall as intermediaries between these positions, contributing an effect that is more extreme than a pure nasal, but less influential than a plain voiceless or voiced stop.

Acoustic analyses of ND-F_0 interactions in languages which have not yet phonologized depressor consonant effects will provide a phonetic baseline by which to understand phonological patterns in the data. To that end, the current study looks at consonant-F_0 interaction in Chichewa, a language which has contrastive ND and NT, as well as high and low tone, and lacks phonologized depressor consonant effects.

3. About Chichewa

Chichewa is a Bantu language spoken primarily in Malawi, with significant language populations also found in Mozambique and Zambia (where the language is known as Chinyanja). The phonological inventory of Chichewa is as follows (from Mchombo 2004):

Figure 1: The phonological inventory of Chichewa.

	Bilabial	Labiodental	Alveolar	Palatal	Velar
Plosives (aspirated)	pʰ		tʰ		kʰ
Plosives	p b		t d		k g
Plosives (prenasalized)	mpʰ mb		ntʰ nd	nʧʰ nʤ	ŋkʰ ŋg
Nasals	m		n	ɲ	ŋ
Fricatives		f v	s z	ʃ ʒ	
Affricates			ʦ ʣ	ʧ ʤ	
Laterals			l		
Trills			r		
Semi-consonants	w			y	
Vowels	i ɛ a ɔ u				

3.1. Chichewa Tone

The tone system of Chichewa consists of two basic level tones: high and low. Contour tones are attested as well, but are present only as combinations of the basic level tones (Mtenje 1987). For the purposes of the present study, only level tones will be considered.

Myers (1998) presents evidence that the tonal system of Chichewa is asymmetric: only high tone is phonologically active. Low tone is inert and unspecified in the grammar. Evidence for this comes from the restriction on permissible positions of high tone as compared to the unrestricted distribution of low tone, as well as from acoustic analyses showing that F_0 realizations of low tone are predictable from adjacent high tone realizations. There is no tonal target for the low tone, so it is produced as a transition between high tones in words where both tones appear. In addition, F_0 troughs - unlike F_0 peaks - are not aligned in a regular way to syllable boundaries, indicating that only high tone is represented phonologically.

3.2. Examining depressor effects in Chichewa

The phonological system of Chichewa makes it an ideal candidate for the examination of the intrinsic phonetic effects of prenasalized consonants on F_0. Because it is a tone language, it provides the environment for phonetic consonant-tone interaction; however, because low tone is phonologically unspecified, words with exclusively low tones also provide a baseline measure that mimics the interaction effects in a language that has no phonemic tone. The consonant inventory is rich enough to provide a wealth of contrasts – in addition to a set of contrastive voiced and voiceless prenasalized segments, the language also contrasts plain voiced stops, voiceless aspirated stops, and voiceless unaspirated stops. These segments, together with plain nasals, provide a wide variety of consonantal contexts in which to study the phenomenon of interest[1].

4. Current study – methods and analysis

4.1. Stimuli

Stimuli were selected from an electronic dictionary of Chichewa organized and searchable at the phonological level (Mtenje 2001). All forms used in the study can be found in the appendix of this paper. Stimuli were chosen with consideration for the segments in the penultimate syllable of the word, which is lengthened in Chichewa (see Kanerva 1989). While the realization of tone has been found cross-linguistically to often be delayed until early in the following syllable, stress-lengthened syllables show a reduced delay, and peak F_0 for high tone penultimate syllables in Chichewa falls well within the duration of the syllable (Myers 1999). This means that investigation of penultimate stressed syllables will provide more local (and therefore easier-to-measure) effects than unstressed, unlengthened syllables, which may have their peak tonal targets shifted onto the following syllable.

Six consonant types at three places of articulation were combined with two vowels and two tones to generate a set of 72 stimuli forms. The two vowels used were [a] and [u], to provide context of both a high and low vowel. The six consonant types were nasals (hereafter referred to as a natural class as "N"), voiced stops ("D"), voiced prenasalized stops ("ND"), voiceless unaspirated stops ("T"), voiceless aspirated stops ("TH"), and prenasalized voiceless (aspirated) stops ("NT"). (Note that prenasalization collapses the contrast between aspirated and unaspirated voiceless stops, even though this may or may not be represented in the

[1] To the author's knowledge, only one study to date has examined depressor effects in Chichewa: Trithart (1976). The study used a segmental-level analysis to examine the possibility of a link between two distinct phonological contexts with depressor effects, but does not measure their phonetic effects.

orthography of a given form.) Each consonant type was represented by a bilabial, coronal, and velar consonant, for a total of 18 unique consonant forms.

Because low tone is phonologically inert and has variable realizations which are dependent on the tonal context surrounding it (Myers 1998), forms where low tone was analyzed were selected only if they had low tones throughout the syllable. This prevented forms from being included if low tone would be raised as a function of adjacent high tones. Uniformly high tone forms were difficult to find; however, an environment of adjacent low tones should not affect the realization of high tones in the same way that high tones affect low tones. Therefore, a mixture of high and low tones in a form was not considered problematic if the critical syllable being analyzed had high tone.

A total of 207 tokens from 69[2] unique word forms were analyzed in the present study.

4.2. Recordings

The stimuli for this experiment were recorded by a native speaker of the standard dialect of Chichewa. The speaker was born in Malawi but had been living in the San Francisco Bay Area for seven years at the time of recording. Stimuli were recorded with a head-mounted condenser microphone and a pre-amplifier in a sound booth at the Phonology Laboratory in the UC Berkeley Department of Linguistics.

The speaker was given the list of stimuli in random order and was asked to say each stimulus three times. He was instructed that each repetition should be clear and consistent with other repetitions, in order to minimize the effects of list intonation on the realization of pitch on different repetitions of the same form. Each recorded token was preceded by a letter corresponding to the repetition of the stimulus. For example, when the form *tambala* appeared on the stimuli list, the speaker would record the following: “A: tambala. B: tambala. C: tambala.” Stimuli were recorded in short blocks of approximately fourteen forms per block, with a small break occurring between each block.

4.3. Analysis

Several pieces of information were measured manually from each critical syllable. Measurements were made of the duration of the vowel, the mean F_0 over the duration of the vowel, and a series of pitch measurements made every 10 ms over the duration of the vowel. These incremental pitch measurements were then condensed to a series of 10 roughly-evenly spaced measurements over the course of the vowel, which effectively normalized all vowel durations so that individual tokens could be compared at uniform points regardless of duration. Information about the onset consonant was collected as well: VOT length, length of the oral segment (if present), and length of the nasal segment (if present) were also measured, to determine if other aspects of the consonants had an effect on F_0. All acoustic measurements were made in Praat (Boersma and Weenink 2012).

[2] See Appendix for discussion of the reduction of unique CV combinations from 72 to 69.

5. Results

5.1. Aggregate F_0 data

A general linear model was fit to the mean F_0 data to determine which factors significantly influenced the realization of pitch over the vowel as a whole. The model ($F (27, 279) = 13.53$, $p < 0.001$) found significant effects of the following predictors: token repetition (A, B, or C), syllable onset consonant type (N, D, ND, T, TH, or NT, hereafter referred to as “consonant type”), vowel height, final consonant (in all cases, the onset of the next syllable), length of the nasal portion of the consonant preceding the vowel (hereafter “nasal length”), length of the oral portion of the consonant preceding the vowel (hereafter “oral length”), and tone. Vowel duration and VOT were not significant predictors of pitch in the mean data. Table 2 provides mean values for VOT, F_0, nasal length, and oral length for each consonant type, averaged over all tokens in the class.

Table 2. Mean F_0, VOT, nasal and oral length values for penultimate syllables by consonant type.

	TH	T	NT	N	ND	D
F0	147.389	145.266	135.337	137.899	135.422	135.236
VOT	0.106	0.015	0.058	NA	-0.024	-0.050
Nasal length	NA	NA	0.097	0.163	0.141	NA
Oral length	0.26	0.119	0.106	NA	0.014	0.098

The following analysis will focus primarily on the contribution of consonant type and consonant attributes (VOT, nasal length, oral length) to the realization of F_0, with consideration for tone later in this section[3].

Pairwise comparisons of consonant type on mean F_0 with Tukey's HSD test found these significant contrasts (all significance levels corrected for multiple comparisons): T-D ($p = 0.036$), TH-D ($p = 0.005$), T-ND ($p = 0.042$), TH-ND ($p = 0.006$), and TH-NT (0.009). Two comparisons were marginally significant: TH-N ($p = 0.066$) and T-NT ($p = 0.057$).

In addition to separating out the plain voiceless stops from their voiced and prenasalized counterparts, the pairwise comparisons show that TH has a significantly different effect than NT, even though both segments contain some aspiration. Conversely, T and TH do not dissociate at all in this view of the data ($p = 0.988$). As the model did not find VOT to be a significant predictor of F_0 in the aggregate, neither of these comparisons is particularly surprising. However, the pattern suggests that prenasalization has a significant impact above and beyond that of voicing.

[3] The other predictors are relevant to the ultimate realization of F_0 on a given syllable, but do not directly speak to the question of prenasalization effects. However, they may be phonetic variables whose specific realizations in a language contribute to the ultimate determination of whether depressor effects are phonologized (see section 6).

However, the aggregate data is not sophisticated enough to show true consonant-F_0 interaction effects, as these effects are strongest at vowel onset and weaken considerably over the duration of the vowel. To get a more accurate sense of the data, it is necessary to look at the contribution of consonant types at different points in the vowel.

5.2. The effect at vowel onset, midpoint, and offset

Figure 2 shows pitch traces over the duration of the vowel by consonant type. It is clear that while differences between the effects of consonant types are largely neutralized to a voiceless-voiced/nasal distinction by the midpoint of the vowel (time 5-6), there are more nuanced contrasts at the vowel onset (time 1).

A linear model fit to the realization of F_0 at vowel onset ($F (27, 178) = 16.26$, $p < 0.001$) finds the same significant predictors of F_0 as the model fit to the aggregate data: token repetition, consonant type, vowel height, final consonant, tone, nasal length, and oral length.

Pairwise comparisons reveal that at vowel onset, several contrasts are significant: NT-D ($p < 0.001$), T-D ($p < 0.001$), TH-D ($p < 0.001$), T-N ($p = 0.012$), TH-N ($p < 0.001$), NT-ND ($p = 0.019$), T-ND ($p < 0.001$), TH-ND ($p < 0.001$), TH-NT ($p < 0.001$), and TH-T ($p = 0.005$).

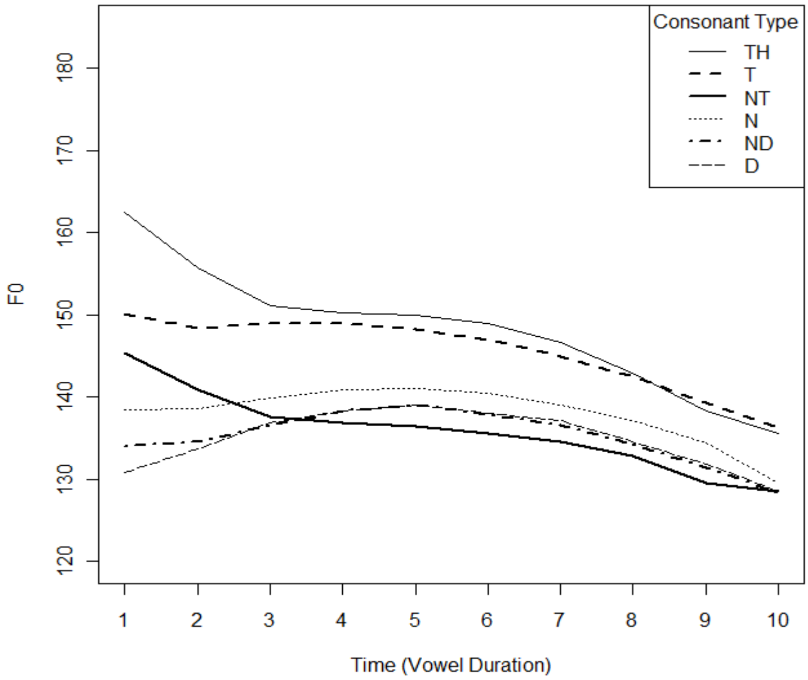
These results clearly indicate that prenasalized consonants are not a unified class of depressors, as NT and ND have significantly different effects. NT is also significantly different from its plain counterpart, TH (but does not differ from T), clearly demonstrating that the nasal portion of the consonant contributes to the realization of F_0 on the following vowel. However, NT does not contrast significantly with N ($p = 0.424$), and so its effect cannot be concretely dissociated from the effect of plain nasals. N, ND, and D do not significantly contrast with one another at vowel onset.

Table 3. Average F_0 at time 1 (vowel onset), by consonant type.
Nasal and oral length values from Table 2 are also reproduced here.

	TH	T	NT	N	ND	D
F_0	162.4899	150.181	145.329	138.519	133.980	130.830
Nasal length	NA	NA	0.097	0.163	0.141	NA
Oral length	0.26	0.119	0.106	NA	0.014	0.098

Again, nasal and oral length were significant predictors of F_0 at vowel onset. Table 3 shows that while N and ND have significant nasal segments, NT realizations in the data have very short nasal durations. This may have contributed, along with the voicing distinction, to the varied effects of NT and ND. However, nasal length values for N and ND are very similar, making it hard to accurately estimate the effect of prenasalization (as opposed to the presence of nasalization more generally). Oral length is strongly correlated with F_0 ($p < 0.001$, $\rho = 0.380$); however, the significance of this correlation should be interpreted with caution. Some penultimate syllables in the current data set were also initial syllables, and as several were plain voiceless segments, measurement of oral length for such syllables are not exact for all tokens.

Figure 2: Pitch contours over the duration of the vowel by consonant type.



By the midpoint of the vowel, onset consonant is still a significant predictor ($F(27, 179) = 14.12$, $p < 0.001$), but the significant pairwise contrasts between consonant type are not informative beyond those seen in the aggregate data. By the vowel offset (time 10), all significant pairwise contrasts have been neutralized.

Table 4: Mean F_0 values at time 5 (vowel midpoint), by consonant type.

TH	T	NT	N	ND	D
149.950	148.233	136.427	141.003	139.086	139.020

Table 5: Mean F_0 values at time 10 (vowel offset), by consonant type.

TH	T	NT	N	ND	D
135.598	136.259	128.539	129.611	128.455	128.520

So far, Chichewa provides no evidence that nasals act differently than other voiced segments. If N and D do not exhibit significantly different effects, then the potentially unique effect of ND cannot be reliably distinguished either. However, there is another place to look to learn something: the differing contribution of consonants to F_0 in high tone vs. low tone syllables.

Since Chichewa has a phonologically inert low tone (Myers 1998), the contrast between high and low tone may be analyzable as a contrast between tone on the one hand and a baseline context on the other.

5.3. The contribution of tone to consonant type contrasts

Separate linear models were conducted for F_0 realizations on subsets of the data with high tone ($F(21, 77) = 14.91$, $p < 0.001$) and low tone ($F(16, 91) = 12.01$, $p < 0.001$) tokens. The high tone model found the same significant predictors as those in the aggregate data, with the addition of VOT[4] and duration as relevant predictors. A Spearman's correlation test demonstrates a nearly-significant but weak negative correlation between mean F_0 and duration for high tone vowels ($p = 0.060$, $R^2 = -0.187$). This trend may indicate that there is a high tone target which is easier to reach in a longer vowel, but which gets undershot in a shorter vowel. If this interpretation is correct, it agrees nicely with the lack of correlation between duration and F_0 for low tone vowels, which have no tonal target.

The low tone model did not find a significant effect for duration, consonant type, VOT or nasal length in the aggregate data. The differences between the models of the mean data for high and low tones are suggestive of differences between syllables with specified tonal targets and those without such targets.

Turning now to the realization of F_0 at the onset of the vowel, different patterns of predictors again emerge. In high tone syllables ($F(21, 77) = 18.01$, $p < 0.001$), VOT and duration are *not* significant predictors, but the model otherwise resembles that of the model for the mean data in high tone syllables. The low tone model at vowel onset ($F(22, 84) = 12.75$, $p < 0.001$) is richer in predictors than its counterpart in the aggregate data: consonant type is significant here, as are oral length and VOT.

Table 6. Mean F_0, by consonant type at time 1 (vowel onset), as well as average VOT, nasal length, and oral length values, in high tone syllables.

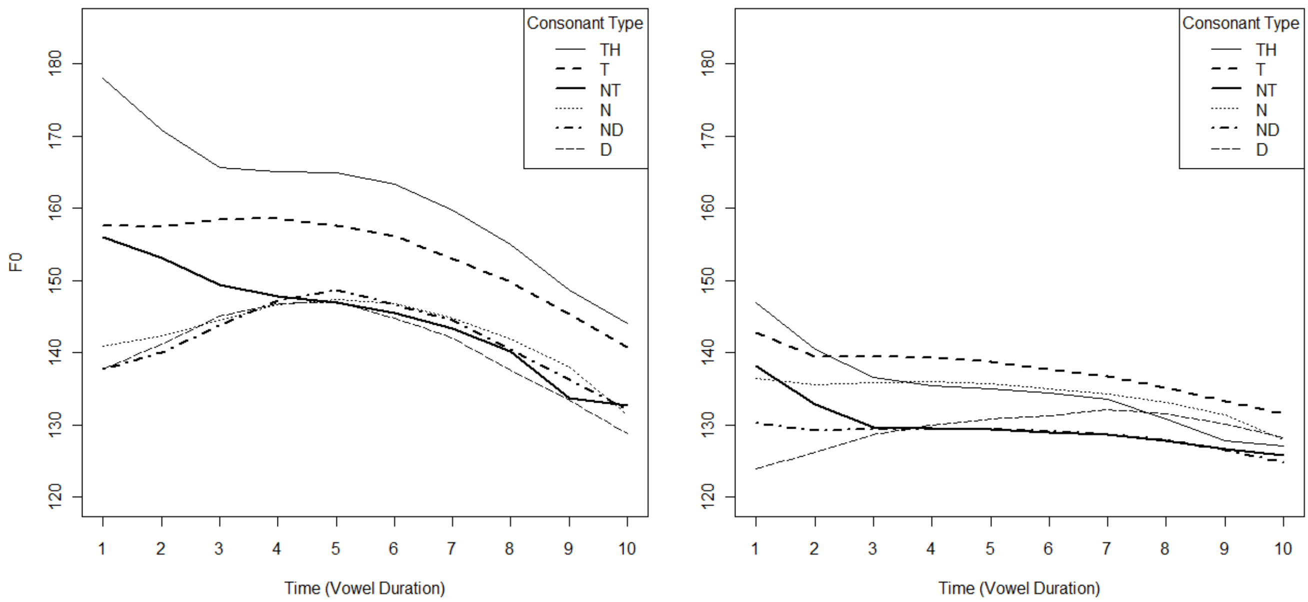
	TH	T	NT	N	ND	D
F_0	178.005	157.591	155.988	140.926	137.727	137.717
VOT	0.119	0.012	0.044	NA	-0.022	-0.062
Nasal length	NA	NA	0.100	0.114	0.163	NA
Oral length	0.289	0.097	0.114	NA	0.035	0.115

Figures 3 and 4 suggest that effects at time 1 differ in high tone and low tone syllables. Pairwise comparisons bear out this pattern. In high tone syllables (see Table 6 for mean values), the majority of significant contrasts (which include TH-D, $p < 0.001$; T-N, $p = 0.002$; TH-N, $p < 0.001$; T-ND, $p < 0.001$; TH-ND, $p < 0.001$; TH-NT, $p < 0.001$; TH-T, $p = 0.002$) are between voiceless and voiced segments. However, two contrasts of note are NT-N ($p = 0.021$) and NT-ND ($p = 0.002$). This provides evidence that NT can have a distinctly

[4] However, VOT is *not* a significant predictor in high tone syllables at vowel onset, suggesting that its relevance as a predictor should be considered with caution.

different effect than both its voiced counterpart and plain nasals. (The NT-D contrast is also significant, p = 0.001.) But crucially, ND, N, and D are all very tightly clustered.

Figures 3 and 4: Pitch contours over the duration of the vowel, by consonant type, for high tone vowels (left) and low tone vowels (right).



In low tone syllables (see Table 7), fewer contrasts emerge at vowel onset than in high tone syllables (although several voicing contrasts still reach significance). Critically, however, the contrast between N-D emerges as significant (p = 0.014). This is the first piece of evidence that plain nasals and plain voiced stops have significantly different effects on F_0 in Chichewa.

The contrast between ND and D remains insignificant in low tone syllables, although impressionistically, the raw numbers do show a much larger difference than in high tone syllables (compare the values in tables 6 and 7). A similar trend is found in the contrast between ND and N: in low tone syllables, there is a much larger raw difference than in high tone syllables (which again does not reach significance). While no reliable conclusions can be drawn from these patterns, the raw values in these low tone contrasts hint at the possibility of more contrast than high tone syllables. This suggests the potential for another difference between syllables with and without tonal targets; further work should be done to determine if a reliable contrast can be found here. The low tone data as compared to the high tone data also suggest that length of the oral closure may not be the critical factor in determining the extent of pitch depression: the effects of ND and D on F_0 are more dissimilar in low tone syllables, even though in this data set the distinction between the length of the oral closure between ND and D is much more striking in the high tone syllables.

Table 7. Mean F_0, by consonant type at time 1 (vowel onset),
as well as average VOT, nasal length, and oral length values, in low tone syllables.

	TH	T	NT	N	ND	D
F_0	146.9743	142.7704	138.2227	136.3941	130.2341	123.9418
VOT	0.093	0.017	0.068	NA	-0.027	-0.038
Nasal length	NA	NA	0.938	0.205	0.119	NA
Oral length	0.233	0.141	0.100	NA	0.039	0.080

6. Implications for cross-linguistic patterns of prenasalized depressor effects

6.1. Overall patterns

Based on averages of F_0 at vowel onset across the six consonant types, the following hierarchy of pitch raising and lowering effects in Chichewa emerges:

TH > T > NT > N > ND > D

As shown in the pairwise comparisons of each model, not all of these contrasts are robustly significant, but there are interesting trends suggested in almost every case. Voiceless stops are unambiguously distinguishable from segments with potential depressor effects. And in fact, given the strong effect of TH, voiceless aspirated stops may most accurately be termed "pitch raisers," given their enhancement at the beginning of the vowel above and beyond that which is targeted by the midpoint of the syllable.

The distinctions between voiced, nasal, and prenasalized segments are less clear. NT segments appear to have a fairly robust raising effect, not unlike that of plain voiceless segments, although this effect is tempered by the presence of the nasal portion of the consonant. In the absence of strong evidence for a depressor effect by ND segments, it is possible that in Chichewa, enhancement in the voicing distinction of prenasalized segments is a burden borne primarily by the voiceless segment, rather than its voiced counterpart. The fact that Chichewa lacks phonologized depressor effects means that a sharply-defined effect of ND is not necessary. If the effect of Chichewa is primarily one of pitch raising, rather than lowering, it is possible that the lower part of the pitch range is simply too compressed to yield significant contrasts. Data from other languages would be instrumental in demonstrating whether Chichewa is an exception in with respect to pitch raising, or whether this directional tendency occurs in other languages – and to what extent the asymmetry of the tonal system might play a part in this distinction.

As it currently stands, the mean phonetic effect of ND, which sits squarely between that of N and D, seems well-positioned to pattern with either segment. This provides some phonetic evidence for the phonological intuition that ND sits between N and D on the depressor hierarchy. It also provides a means by which languages with and without ND depressor effects could arise – all that may be needed is some language-specific feature or environment that pushes prenasalized voiced stops to pattern with either nasals or with plain voiced stops.

6.2. The contribution of tone

Despite a lack of significant contrasts, low tone syllables in Chichewa appear to be likelier candidates for contrasts to appear between ND segments, plain nasals, and plain voiced segments. A study with a larger set of tokens may provide the statistical power necessary to determine whether such trends are spurious, or whether they reflect a true contrast.

Low tone syllables did show a significant contrast between the effect of plain nasals (N) and plain voiced stops (D). If the effect of nasals is considered a baseline (as nasals have no need to enhance a voicing distinction), then this result is definitive proof of the phonetic depressor effect of plain voiced stops in low tone syllables in Chichewa. As suggested earlier, it may be the case that the primary burden of voicing contrast enhancement falls to voiceless segments; nevertheless, it is clear from this result that voiced segments contribute to the distinction as well. Since low tone is phonologically inert in Chichewa, this result is unlikely to be related to enhancement of tone. However, it may be a reflection of durational differences between the two classes of segments. Since voiced stops appear to have shorter durations than nasals in Chichewa (see Table 3), the depressor effect of D can be attributed to an extra cue to the voicing of the segment – again, a circumstance that is not applicable in the case of nasals.

The contrast between low and high tone patterns is an interesting result, and it begs the question of whether the asymmetry in the Chichewa tonal system is responsible. One possible explanation for the pattern is that the low – or inert – tone data represents a more intrinsic phonetic effect, while the high tone data distorts and masks contrasts in the pursuit of a tonal target. It would be worthwhile to collect data from other languages with and without multiple tonal targets, in order to determine if such a pattern is replicated. One particularly fruitful investigation would be a study of a language with high and low tonal targets, with an inert mid tone which was the default for syllables unspecified for tone. A language with such a contrast would also provide more tonal "strata" targets, which could potentially provide clearer depressor effects and help clarify how the phonetic effects of ND should be classified.

6.3. Representational accounts

While the data on ND segments do not clearly dissociate the effects of these segments from either plain nasals or plain voiced stops, the data on NT segments suggests that prenasalization is relevant to F_0 realization. NT segments did not have effects identical to those of voiceless stops, but neither did their effects overlap entirely with those of nasal segments. This suggests that a representational model of prenasalized segments should not ignore either the oral or the nasal portion of a segment – both should be present in a featural account. The fact that NT and ND contrasted significantly in high tone syllable suggests that [+/- voice] is also an important part of the featural representation of prenasalized segments.

This data speaks to a broader discussion in the recent literature regarding those segments which are capable of affecting pitch. Recent arguments have been made (Lee 2008, Tang 2008) that [+/-voice] should not be the only laryngeal feature considered in representational accounts of consonant-tone interaction. One other laryngeal feature is relevant to the present data set – aspiration. Somewhat surprisingly, VOT was rarely a significant predictor of F_0 – it appeared to play some part in the aggregate high tone data, and had a significant role at the onset of low tone syllables, but its contribution was not consistent, even though TH and T seemed to be making different contributions to the realization of F_0. This may be partly attributable to the fact that NT segments were affected by the nasal portion of the consonant, and thus did not raise pitch in the same way as plain aspirated stops.

Lai et al. (2008) have noted the contradictory nature of results in the literature regarding the effect of aspiration on F_0, and suggest that factors such as place of articulation, tone height, and gender of the speaker may interact with the effect of aspiration. Another alternative, pertinent to the present study, is that VOT may have a consistent effect, but its magnitude may be masked by more relevant correlates to pitch raising and lowering, and thus may only appear as significant in instances where the effects of these other factors are not as strong.

6.4. Other factors contributing to the realization of F_0

As indicated by the linear model constructed in section 5.1, several factors not related to the identity of the onset consonant contributed to the realization of F_0 on the vowel of the critical syllables. Consonant duration (and the comparative length of oral and nasal segments in prenasalized consonants), vowel height, vowel duration, and the identity of the following syllable all acted as significant predictors in at least some tokens of the current study. Since the current data does not provide an unequivocal explanation for the effect of ND segments on F_0, it is plausible that these factors may play a part in explaining why some languages have predictable phonologized depressor effects, and others do not. These factors could provide the conditioning environment that leads to a stronger or weaker depressor effect, particularly if any of them correlated with the distribution of ND segments in a given language. In addition to potential representational and historical accounts of the split, future work should consider whether these factors are correlated in any meaningful way with the distinction between ND-as-depressor and ND-as-non-depressor languages.

7. Conclusions

This study has aimed to provide phonetic evidence to speak to the question of the intrinsic effects of prenasalized segments on F_0. The data presented here is only a preliminary step and should be significantly supplemented with data from other speakers and other languages. However, there is promising evidence that the intuition regarding ND segments sitting between N and D on the depressor scale has a basis in phonetic reality.

In addition to gathering more data on this specific question of prenasalized consonant-pitch interaction – from Chichewa, from other languages which have ND/NT contrasts, and from languages which do not have this contrast – there are related questions that could benefit from further acoustic analyses. In particular, if an ND-D or ND-N distinction is found to have robust support, it would be fruitful to know if there is something special about prenasalized segments that slots them into the depressor hierarchy, or whether similar effects could be achieved with fully realized nasal + stop clusters. It is clear that acoustic analyses have the potential to shed light on many aspects of this interesting phonological pattern.

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Appendix: stimuli list and notes

Table 8 presents the Chichewa words which were recorded and analyzed in this study. The first column indicates the consonant in the critical syllable (which in almost all cases was the penultimate syllable – see the notes below for exceptions regarding starred forms). The top row indicates the vowel and tone of the critical syllable. All words are presented in standard Chichewa orthographic conventions.

Table 8: Stimuli used in the present study.

	a (low)	u (low)	a (high)	u (high)
m	chisamariro*	chigumula	nsomáli	chimúna
b	bala	bulu	bála	mbúli
mb	tambala	chikumbutso	umbála	chivúmbúlú
p	chipala	chipuntho	mapása	chipúla
ph	phala	phuka	phále	phúla
mp	kampango	fwampula	N/A	N/A
n	nakanaka	nunkha	náko	linúnda
d	padugu	dula	ndále	chidúle
nd	tandala	ndula	ndála	kandúdu
t	tambala**	tula	litáli	chitúnda
th	thawa	thula	thála	thúnthu
nt	bunthama	funthula	wánthánthi	chánthúmbi
ng'	yang'ana	ng'ung'udza	ng'ála	N/A
g	chigadzo	chigulu	chigádza	chigúlu
ng	nsangala	pungula	singáno	mvungúti
k	fukata	pikula	ukáli	likúlu
kh	khala	likhula	khála	khúmi
nk	sonkhana	nkhuli	chinkána	nkúte

Orthographic conventions

Chichewa orthography uses “ng'” to refer to the velar nasal [ŋ], and “ng” to refer to the prenasalized velar stop. Plain aspirated voiceless stops are indicated in the orthography with “h” following the stop (“th”, “ph”, “kh”), to contrast with the unaspirated voiceless stop series (“t”, “p”, “k”). The exception to this is in the writing convention of prenasalized voiceless stops. The contrast between voiceless aspirated and unaspirated stops is neutralized when the stop is prenasalized; all prenasalized voiceless stops are aspirated, whether or not the orthography of a specific form represents that fact.

Prefix vs. prenasalized form

The forms *ndále* and *ndála* are more distinct than their orthographies would suggest. The former has a [d] in the onset of the penultimate syllable, preceded by a prefixed syllabic [n]. The latter, by contrast, has the prenasalized segment [nd] as its onset. While *ndále* is not an optimal form for this study, as its realization may be affected by the prefixed nasal, few forms were available with a penultimate n + á sequence, and so its inclusion was necessary.

Missing forms

Three unique forms are missing from the data set of this study: forms with penultimate 'ng + á, mp + á, and mp + ú. The former resulted from a gap in the forms present in the dictionary used to find stimuli. The latter two gaps were due to differences between the dictionary and the dialect spoken by the speaker who recorded the stimuli.

Antepenultimate syllables

Differences between the dialect of the speaker and the dictionary would have led to more gaps in the data set. Instead, two penultimate syllables were analyzed in order to avoid gaps wherever possible. The first is the starred form *chisa**ma**riro* - the antepenultimate “ma” syllable was analyzed from this form. The second is the starred form ***ta**mbala* - the antepenultimate “ta” syllable was analyzed from this form. (Note that for *tambala*, the penultimate syllable was also analyzed for the mb + a environment).

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