ACOUSTIC CORRELATES AND CONTRAST MAINTENANCE IN BURMESE VOICELESS SONORANTS

Chiara Repetti-Ludlow

New York University
ChiaraRepettiLudlow@nyu.edu

ABSTRACT

This study examines acoustic correlates to the Burmese sonorant voicing contrast. In Burmese, voiceless sonorants are identified largely by preaspiration, and previous literature has found other correlates are important to the contrast as well. However, no study has yet examined how these acoustic correlates vary in different phrasal positions. To address this topic, a production study was carried out with participants reading minimal pairs in three phrasal positions. Results show that preaspiration and F0 on the sonorant are important correlates in all three phrasal positions. In initial and medial position, SoE on the following vowel also significantly differentiated voiced and voiceless sonorants. However, in final position, vowel devoicing causes SoE information to be lost, which results in HNR becoming a more important correlate. Thus, there seems to be a trading relationship.

Keywords: acoustic correlates, Burmese, voiceless sonorants, vowel devoicing, prosody

1. INTRODUCTION

Voiceless sonorant consonants are typologically rare segments, occurring in only 2% of the world's languages [1]. Burmese is one such language, with 6 phonemic voiceless sonorant consonants: [m̥, n̥, ɲ̊, ŋ̊, l̥, w̥] [2, 3], with previous literature typically describing these segments as voiced sonorants with a preceding voiceless period, similar to preaspiration [4, 5, 6]. Previous work on these segments has focused on correlates such as fundamental frequency (F0) [7], duration [4, 6], electroglottography [8], and oral and nasal airflow [6, 8]. Although this research has furthered our understanding of Burmese voiceless sonorants, the focus has been on aerodynamic and temporal aspects of the sonorants, rather than correlates related to voicing and aspiration. Given the salience of aspiration as an acoustic correlate and the effects it can have on adjacent segments due to coarticulation [9], a more thorough examination of the acoustic correlates to the Burmese sonorant voicing contrast is warranted, with a focus on preaspiration.

Another question addressed in this study is how phrasal position and acoustic correlates interact. Acoustic correlates often re-weight due to prosodic constraints, such that a given correlate is fully or partially neutralized in a certain prosodic environment. For example, in languages like German [10], cues to the voicing contrast, such as voice onset time (VOT), are lost in word-final position. To compensate for this loss of acoustic information, other cues receive a higher relative weight, thereby allowing listeners to recover the contrast. In the case of German, when VOT information is lost, the duration of the preceding vowel receives a higher weight and allows for the contrast to be maintained. Phrase-final loss of acoustic information has been observed for other languages and types of contrasts as well. For example, in Mandarin, F0 is a primary cue to tonal contrasts, but in phrase-final position, the F0 cue weakens due to devoicing [11]. This results in correlates like HNR becoming more important to compensate for the neutralization. Similarly, in Newcastle English, /t/ has preaspiration in phrase-final position, which reinforces the segment that would otherwise be partially neutralized due to the absence of release burst information [12]. Put generally, in cases where a correlate of a contrast becomes unavailable in some prosodic environments, other correlates may be sufficient to compensate for lost acoustic information.

In order to construct a full picture of the Burmese sonorant voicing contrast, it is necessary to consider the relative importance of acoustic correlates and the ways in which correlates re-weight based on prosodic constraints. This work therefore sets out to answer three primary research questions:

1. What are the main acoustic correlates to the Burmese sonorant voicing contrast?
2. Are there any prosodic neutralization processes and do they result in re-weighting?
3. Does the presence of preaspiration change the central correlates to the voicing contrast?

2. METHODS

To examine the acoustic realization of voiced and voiceless sonorants in Burmese, a production study was conducted in which participants read target words in one of three phrasal positions. Target words were monosyllabic minimal pairs consisting of every combination of 8 onset consonants ([w, w̥, l, l̥, ŋ, ŋ̊, m, m̥]), 2 tones (high and low), and the nucleus vowel, [a]. Each target word appeared in 9 different carrier phrases, 3 for each phrasal position (phrase-initial, phrase-medial, and phrase-final). Each phrase targeting a given prosodic position had the same number of syllables, the same preceding consonant, and no adjacent aspirated stop. All stimuli were checked by a native speaker of Burmese and target phrases were sorted into three randomized lists for a total of three participants per list. Altogether, these combinations resulted in 144 target phrases, such as [ŋa **la** hãʊ̃] 'my old mule.' Further sonorants, tones, and vowels were not included and no filler sentences were used in order to keep the experiment under an hour. Phrases were presented to participants in Burmese orthography one at a time in a slideshow and participants were given a break after every 10 phrases.

Nine native speakers of Burmese were recorded: six women and three men, ranging in age from 19-42. All participants were living in New York at the time of the study and had been living in the United States between 1-20 years. Participants were contacted primarily through personal channels and Facebook groups and were reimbursed $25 for participating in the hour-long study. No participants were excluded. Participants were recorded in a sound-attenuated booth using a Zoom H4n Pro recorder and a head-mounted Shure WH20 microphone. The recordings were done with a bit depth of 16-bit for a sampling rate of 44.1 kHz. After collecting the data, target words were labeled in Praat [13], with the preceding vowel, preaspiration (when relevant), sonorant, and following vowel individually labeled in a TextGrid, as shown in Figure 1. Aspiration was segmented according to the beginning and end of clear frication in the spectrogram and waveform, and the sonorant and vowels were segmented based on the beginning and end of the second formant in order to reliably attain voice quality measures.

The measures considered in the analysis were duration, H1-H2, strength of excitation (SoE), harmonics-to-noise ratio 0-3500 Hz (HNR), and F0, in line with recent work on phonation and sonorants [14, 15]. A summary of these measures can be found in Table 1. Average measures taken over the sonorant and adjacent vowels were obtained using VoiceSauce [16]. A linear discriminant analysis (LDA) was run in R using the MASS package lda() function to determine the acoustic correlates that were best able to predict the voicing category of the sonorant [17]. Linear mixed-effects regressions were then carried out using the lme4 package lmer() function to verify that the values of these acoustic correlates were significantly different between voiced and voiceless sonorants [18].

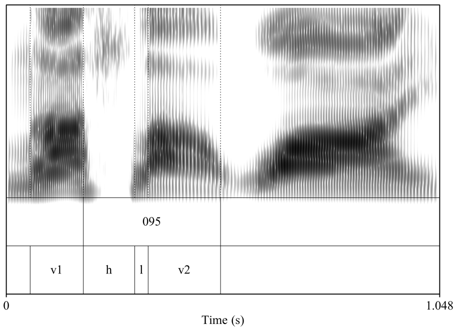

Figure 1: Labeling of [ŋa l̥a wãĩ] 'my round sword' with preaspiration.

Acoustic measure	Correlate
Duration (ms)	Segment length
H1-H2 (dB)	Breathiness/Creak
SoE	Degree of voicing
HNR (dB)	Asp./Non-modal phonation
F0 (Hz)	Aspiration/Voicing

Table 1: Acoustic measures and their correlates.

3. RESULTS

In order to determine the most important correlates to the contrast, three LDAs were carried out, one for each phrasal position. Duration, H1-H2, SoE, HNR, and F0 measures taken over the sonorant and adjacent vowels were used in the analysis, as was the duration of preaspiration (0 if absent). The phrase-initial LDA predicted voicing category with 84% accuracy, and the phrase-medial and phrase-final LDAs predicted voicing category with 87% accuracy. In all phrasal positions, the most important correlate of the contrast was the duration of preaspiration (LDs: initial = 0.99, medial = 1.07, final = 1.17). Preaspiration was present in 79% of voiceless sonorants, with no significant differences based on phrasal position. The second most important correlate in all phrasal positions was F0 of the sonorant (LDs: initial = 0.87, medial =

0.38, final = 0.50). In initial and medial position, SoE of the following vowel was the third most important correlate (LDs: initial = -0.42, medial = -0.23), but in final position HNR of the sonorant was the third most important (LD: final = -0.42). Linear mixed-effects regressions were carried out on these correlates and the results, shown in Table 2, confirm that the top three LDA correlates for each phrasal position are significantly different between voiced and voiceless sonorants. Of particular interest is the third most important cue, which is different in phrase-final position compared to the other positions, as illustrated in Figure 2.

Initial	β	z	p value
Aspiration duration	58.65	6.73	**<0.01***
F0 of sonorant	36.06	10.99	**<0.01***
HNR of sonorant	-0.28	-0.29	0.77
SoE of vowel	-0.0017	-6.54	**<0.01***

Medial	β	z	p value
Aspiration duration	84.96	11.27	**<0.01***
F0 of sonorant	21.18	6.30	**<0.01***
HNR of sonorant	-2.31	-2.10	0.06
SoE of vowel	-0.0009	-2.53	**0.02***

Final	β	z	p value
Aspiration duration	78.97	13.70	**<0.01***
F0 of sonorant	21.61	4.26	**<0.01***
HNR of sonorant	-3.67	-2.58	**0.02***
SoE of vowel	-0.0004	-0.75	0.46

Table 2: Results of linear mixed-effects models for the relevant LDA correlates in all phrasal positions.

One interpretation of the finding that SoE does not differentiate voiced vs. voiceless sonorants in phrase-final position is that Burmese undergoes phrase-final vowel devoicing, as indicated by a lower SoE. A linear mixed-effects model was run with the vowel's SoE as the dependent variable, and the interaction between sonorant voicing and phrasal position as a fixed effect. The results of this model, shown in Table 3, indicate that vowel devoicing occurs phrase-finally regardless of whether the preceding sonorant is voiced or voiceless, as shown in Figure 3. This suggests that there is a neutralizing process in phrase-final position that impacts one of the correlates that is used for the sonorant voicing contrast: SoE. This results in sonorant HNR receiving a higher weight.

Finally, given that there are two possible realizations of voiceless sonorants: one with a period of preaspiration and one without it, an analysis was carried out to determine whether the

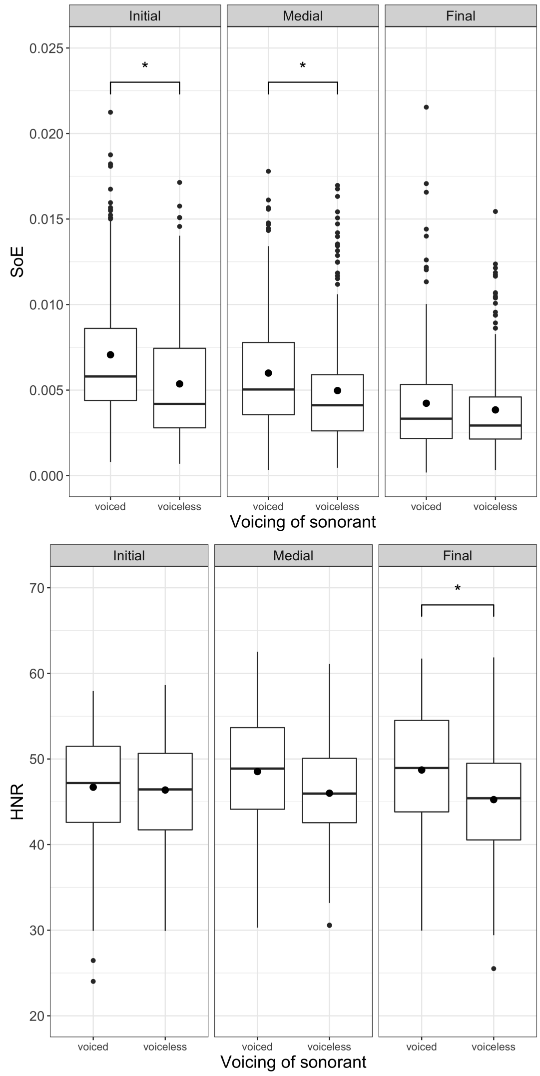

Figure 2: SoE on the vowel (top) and HNR on the sonorant (bottom) faceted by phrasal position. Stars represent significant differences and dots in the box plots represent mean values.

Difference	Son.	β	z	p value
Initial-Med.	voiced	0.0004	2.20	0.06
Initial-Final	voiced	0.003	13.74	**<0.01***
Med.-Final	voiced	0.002	8.48	**<0.01***
Initial-Med.	vless	0.0003	1.51	0.39
Initial-Final	vless	0.002	7.36	**<0.01***
Med.-Final	vless	0.001	5.83	**<0.01***

Table 3: Results of the linear mixed-effects model examining vowel SoE, phrasal position, and voicing of the preceding sonorant.

same correlates significantly differentiated voiced vs. voiceless preaspirated and voiced vs. voiceless unaspirated sonorants. Linear mixed-effects models

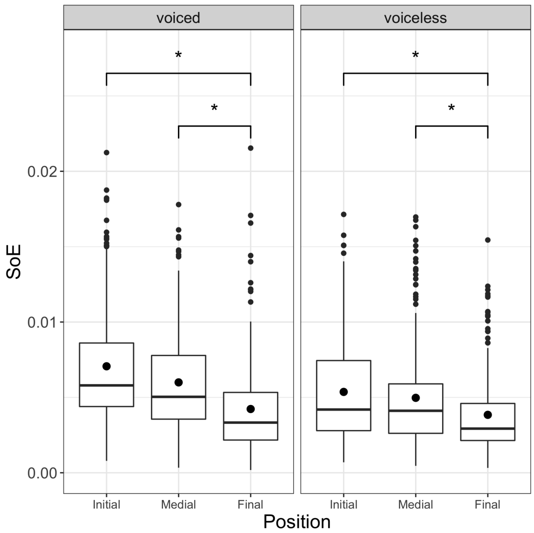

Figure 3: SoE on the vowel faceted by sonorant voicing. Stars represent significant differences and dots in the box plots represent mean values.

were carried out for the three relevant correlates (F0 of sonorant, HNR of sonorant, SoE of vowel) in each phrasal position, and results are shown in Table 4. F0 on the sonorant significantly differentiated sonorant voicing in all three phrasal positions regardless of aspiration. HNR on the sonorant was significantly different for voiced vs. voiceless preaspirated sonorants only in medial and final positions. SoE on the following vowel significantly differentiated voiced and voiceless sonorants in initial and medial position regardless of aspiration, but not in final position.

Initial	Asp.	β	z	p value
F0 son	preasp	39.39	12.99	**<0.01***
HNR son	preasp	-1.05	-1.13	0.28
SoE vowel	preasp	-0.0003	-6.30	**<0.01***
F0 son	unasp	29.13	8.30	**<0.01***
HNR son	unasp	1.31	1.30	0.21
SoE vowel	unasp	-0.0013	-3.42	**<0.01***

Medial	Asp.	β	z	p value
F0 son	preasp	24.12	7.68	**<0.01***
HNR son	preasp	-2.81	-2.62	**0.02***
SoE vowel	preasp	-0.0008	-2.33	**0.03***
F0 son	unasp	11.08	2.82	**<0.01***
HNR son	unasp	-0.62	-0.52	0.61
SoE vowel	unasp	-0.0011	-2.54	**0.02***

Final	Asp.	β	z	p value
F0 son	preasp	25.19	5.22	**<0.01***
HNR son	preasp	-3.90	-2.74	**0.02***
SoE vowel	preasp	-0.0005	-0.93	0.37
F0 son	unasp	10.33	1.88	**0.05***
HNR son	unasp	-2.93	-1.94	0.07
SoE vowel	unasp	-0.0001	-0.12	0.91

Table 4: Results of linear mixed-effects models for voiced vs. voiceless preaspirated sonorants and voiced vs. voiceless unaspirated sonorants.

4. DISCUSSION

First, the results of this study suggest that preaspiration is the primary correlate of the Burmese sonorant voicing contrast in all three phrasal positions, but it is not the only correlate that is important to the contrast. Correlates such as F0 and HNR on the sonorant, and SoE on the following vowel all provide important acoustic information, demonstrating that both correlates related to complex phonation (preaspiration, HNR) and correlates traditionally associated with voicing contrasts (F0, SoE) are used. Second, this study found that Burmese undergoes phrase-final vowel devoicing, similar to what has been observed in languages like French [19] and Bulgarian [20]. This is reflected by a lower SoE on final vowels compared to vowels in other phrasal positions. Given that SoE on the vowel following the sonorant is an important correlate to the voicing contrast in initial and medial positions, this means that important acoustic information is lost in final position. However, HNR measured over the sonorant becomes more important in this phrasal position, potentially to compensate for the lost acoustic information. Since the LDA's predictive power is equally strong in medial and final position, this means that the model isn't performing worse despite lost SoE information. Thus, the voicing contrast is not neutralized in phrase-final position, but rather, correlates re-weight to preserve the contrast. Third, the presence or absence of preaspiration did not seem to impact F0 on the sonorant or SoE on the following vowel, but it did impact HNR on the sonorant. While HNR was never a significant correlate phrase-initially, in medial and final position, it was only significantly lower for voiceless sonorants when preaspiration was present. This suggests that HNR is tied to the period of preaspiration.

These findings demonstrate that in Burmese, the neutralization of acoustic correlates can lead to re-weighting in certain prosodic positions, similar to what has been observed in German [10]. However, this is contingent on other factors, such as the presence of preaspiration, as some correlates are interdependent.

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