An Acoustic Study of the Stress and Intonational System in Lakhota: A Preliminary Report*

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ABSTRACT

This paper reports a preliminary result of an acoustic study on the stress and intonational system in Lakhota, a native American language. It investigates how the stress and intonation in Lakhota are phonetically manifested; and how the stress interacts with other prosodic factors. The results preliminarily obtained from one native Lakhota speaker suggest that the primary cue of the stress is relatively high F0 which is often accompanied by higher intensity (for the vowel) and longer VOT (for aspirated stops). The results also indicate that stress is not reliably marked by duration. The stress system, however, interacts with the intonational pattern, such that, for example, intonational peak falls on the stressed syllable with a general pattern of L+H* and that it interacts with the boundary tone L%, resulting in mid tone utterance-finally. This paper can be viewed largely as a qualitative study on an understudied native American language, Lakhota and as forming a basis for further development of its stress and intonation system whose acoustic properties of its prosodic system have not been investigated before.

Keywords: Lakhota, stress, intonation, prosody, acoustic study

1. Introduction

Stress and its acoustic correlates have been well described for languages such as English and Japanese (e.g., Beckman, 1986). In general, pitch, duration, and amplitude are known to be primary acoustic cues for stress (e.g., Fry, 1955; 1958; Lehiste, 1970; Umeda, 1975; Crystal and

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* Reviewers pointed out that the arguments and implications of this paper are not fully corroborated by the data due to its small-scale scope and this point is well taken. I take it that the results and their interpretations presented in this paper should be considered tentative. Nevertheless, I believe that the present study has its merit as a qualitative preliminary research: it documents some acoustic properties of an understudied American Indian language, Lakhota, though with data obtained from one speaker, and hopefully serves as a kernel from which understanding of American Indian Languages can be further developed. This work was supported by the research fund of Hanyang University (HY-2005-N).

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House, 1988). Understanding acoustic manifestation of stress, however, requires a simultaneous examination of stress and intonation because it is known cross-linguistically that these factors significantly interact with each other. For example, in English, pitch accent (e.g., H* or L*), which is one of the primary constituents of the intonation system, falls on lexically determined stressed syllables (e.g., Pierrehumbert, 1980; Beckman and Pierrehumbert, 1986); similarly, in Japanese, lexical stress draws the intonational peak (e.g., Beckman and Pierrehumbert, 1986). Moreover, the acoustic manifestation of such prosodic factors is language-specific in that prosodic prominence which comes from overlay between lexical stress and intonational structure is marked primarily by pitch in Japanese but by combination of pitch, duration and amplitude in English (cf. Beckman, 1986). In order to understand the phonetic and phonological aspects of the prosodic structure of a given language, it is therefore important to investigate how the stress and intonation systems interact, how they are phonetically manifested, and how the phonetic manifestations of prosodic structure mark the language in question in a way that may differentiate it from other languages.[1)]

This paper investigates some phonological and phonetic aspects of stress and intonation in Lakhota, a native American Indian (Siouan) language of the Great Plains, spoken in the north-central US and southern Canada. Lakhota researchers (e.g., Boas and Deloria, 1941; Shaw 1980) suggest that the most salient acoustic cue of stress in Lakhota is pitch, which is similar to Japanese. However, to my best knowledge there is no acoustic study of Lakhota stress available in the literature. Thus, this paper examines acoustic manifestation of stress in Lakhota preliminarily by looking at one Lakhota speaker's acoustic data with respect to acoustic parameters such as pitch, duration, and amplitude. This paper also investigates the intonational structure of Lakhota in a preliminary effort to establish how the intonational system of Lakhota can be phonologically defined and how it interacts with the stress system. In what follows, I will first review some phonological aspects in Lakhota stress which are based on the Lakhota literature as well as on the elicitation data obtained by this author's consultation with a native Lakhota speaker (section 2); report some preliminary results of a small-scaled acoustic experiment which examines the acoustic properties of stress (section 3); and outline the intonational system of Lakhota and its interaction with stress based on a qualitative observation of acoustic patterns (section 4).

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1) This introductory paragraph includes some general discussion about stress and intonation. One reviewer suggested that the introduction should focus more on matters that are directly relevant to the research questions of the paper. While it is a reasonable suggestion that may streamline the introduction, I, as an author, took the liberty to keep it as I believe that the current form will certainly enhance readers' understanding of the interplay of stress and intonation systems, an essential element for the present study.

2. Some Phonological Aspects of Stress

It has been agreed that stress plays an important role in Lakhota (Boas and Deloria, 1941; Carter, 1974; Shaw, 1980). Boas and Deloria (1941) note that stressed ('accented' in their term) syllable is not lexically determined, but rather occurs by rules. They claim that the stress is fixed on the second syllable. A simple case is given in (1):

(1) a. *Lowán-yelo.* b. *Wa-lówan-yelo*
sing -M 1st.sbj-'sing'-M
'He is singing' 'I am singing'
(-yeló (-M) = a male speech particle.)

However, despite the regularities as given in (1), there are a number of examples which seem to deviate from the generalization that stress falls on the second syllable of a word. Some of examples that were collected from a consultation with a native Lakhota speaker are given in (2):

(2) a. *shúnka* 'dog' b. *thísto* 'ruminant's foreleg"
c. *wóte* 'to eat something' d. *wóshkate* 'toys'

The exceptions to the generalization (i.e., stress falls on the second syllable) as given in (2) can be accounted for largely by Shaw (1980)'s observations. One such apparently exceptional case involves unsuffixed noun and verb stems that end with a consonant. Words such as *shúnka* (2a) has a consonant-final stem *shunk*. Then the final vowel [a] is inserted by a 'stem formation' rule which surfaces disyllabic words. Since the stress assignment rule (i.e., stress falls on the second syllable of the polysyllabic word but on the first syllable on the monosyllabic word) applies before the stem formation ([a]-insertion) rule, the stress still remains on the first syllable.

Second, the stress assignment rule applies before vowel deletion, which results in surface opacity where the first, rather than second syllable in polysyllabic words gets stressed. For example, [a] deletes before another vowel inside a word ('A-Drop') such that, for example, *thísto* (2b) derives from /tha-isto/ in which stress is originally assigned on the second syllable. Another similar example that creates an initial stress is found in coalescence cases. The word *wóte* in (2c) derives from /wa-yúte/ in which /-ayú-/ has simplified as /ó/, a process known as coalescence, which again gives rises to surface opacity.

While the three exceptional cases given in (2a-c) can be successfully accounted for by phonological processes such as [a]-insertion, 'A-Drop' and coalescence, as suggested by Shaw

(1980), the final example *wóshkate* (2d) constitutes a genuine exception to the general stress pattern as it cannot be explained by any other morphophonemic processes. This undermines Shaw's generalization on the predictability of stress that is stipulated in the stress assignment rule. A consultation with a native speaker of Lakhota has indeed revealed that there are so many cases of such an exception, which leads to the postulation that stress is lexically specified such that some words receive stress on the first syllable and some on the second syllable, regardless of the number of syllables in a word. Throughout this paper, therefore, it will be assumed that the stress system in Lakhota is lexically determined, rather than rule-based.

3. Acoustic Correlates of Stress

As discussed at the outset of the paper, one of the primary purposes of this paper is to determine how the stress system in Lakhota is phonetically marked. It should be noted, however, that the data were obtained by consulting just one native speaker of Lakhota due to difficulties in finding Lakhota speakers. The results presented in this section, therefore, must be taken to be preliminary and are subject to further modifications when the on-going study is finalized.

3.1. Method

The word list in (3) was constructed by consulting a native speaker of Lakhota, which was designed in order to examine the stressed vs. unstressed syllables in the initial position of words in isolation:

(3) stressed initial syllable

a. *pápa*	'dried meat'	b. *pháte*	'to operate'
c. *phákakse*	'to behead'	d. *phámahel*	'the head covered as by a shawl'

unstressed initial syllable

e. *pahá*	'to separate'	f. *phahán*	'porcupine'
g. *phasá*	'nose'	h. *phaxtá*	'forehead'

(Note: 'ph, th, kh' = aspirated stops; 'x' = a voiceless velar fricative)

Note that the test vowel /a/ occurred in the first syllable which is either stressed or unstressed, and the word onset consonant was always bilabial. The words in (3) were examined for a statistical analysis of the acoustic phonetic characteristics of stress. In addition, some words as given in (4) were examined further for qualitative observations of the stress.

(4)	a. *lakhóta*	'Lakhota'	b. *glágla*	'shore/edge'
	c. *thaspán*	'apple'	d. *thánka*	'big/large'
	e. *máza*	'metal/iron'	f. *maghá*	'duck'
	g. *magháju*	'rain'	h. *kháte*	'hot/warm'
	i. *kháte*	'wind'	j. *washté*	'good'
	k. *washéshte*	'good(pl.)'		

Each word was recorded with 4 repetitions in a sound-treated booth at the UCLA phonetics lab by the Lakhota consultant Ms. Mary Iron Teeth. The recorded materials were then digitized at 12800 Hz sampling rate and analyzed using PitchWorks. Vowel duration, peak intensity during the vowel and Voice Onset Time (VOT) were measured from the first syllable of the words in (3) where the first syllable is stressed or unstressed. The results for these phonetic parameters were then analyzed statistically, whereas pitch was examined qualitatively for all of the listed words in (3) and (4).

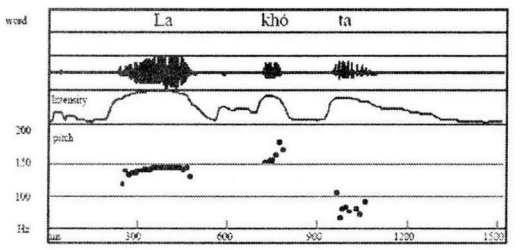

Figure 1. Pitch track and intensity contour of the word *Lakhóta*

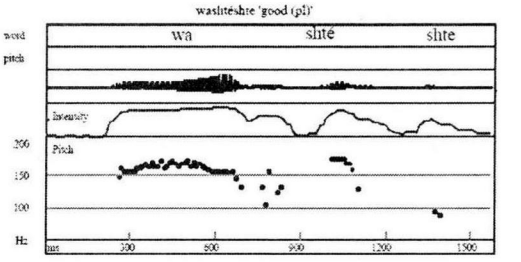

Figure 2. Pitch track and intensity contour of the word *washtéshte* 'good(pl.)'

3.2 Results and discussion

3.2.1 An observation

Let us first examine the acoustic correlates associated with the three syllable words. An example is given in Figure 1. This particular example shows an interesting durational pattern: the stressed vowel has the shortest duration. The overall intensity is also lower than the first syllable and not necessarily greater than the last syllable. Conversely, however, the stressed syllable is associated with the highest pitch peak. Figure 2 shows a similar pattern where the stressed syllable *shté* is associated with a high pitch, but not with higher intensity. Thus, from the examples in both Figure 1 and 2, we can infer that the prominence associated with a stressed syllable is realized mainly through high pitch, but not necessarily by either duration or amplitude.

However, there are some other cases in which stressed syllables are associated with longer

duration and greater intensity as well as high pitch. An example is given in Figure 3 in which the stressed syllable *ghá* is associated with not only high pitch but also relatively longer duration and greater intensity. A similar case is found in Figure 4 in which the stressed syllable *lá* is associated with longer duration, greater intensity, and high pitch. But it should be borne in mind that the observed greater intensity and longer duration, compared to cases in Figures 1 and 2, may be at least in part due to the intrinsic properties of a low vowel /a/.

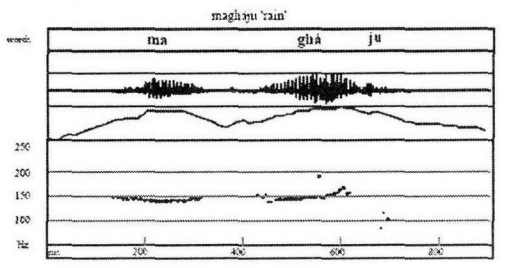

Figure 3. Pitch track and intensity contour of *maghá'ju* 'rain'

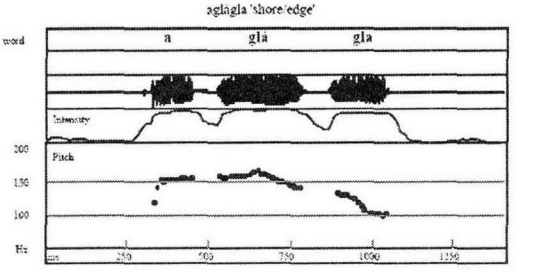

Figure 4. Pitch track and intensity contour of *aglágla* 'shore/edge'

Now let us turn to disyllabic words. Examples are given in Figures 5 and 6. The most striking fact here is that the first syllable, which is supposed to be unstressed, has longer duration, higher pitch, and greater intensity. This is true in both figures. This is probably the reason why many linguists recording Lakhota are not sure about where stress occurs in words like this.

Then the question is how a Lakhota speaker knows whether words like *washté* 'good' and *thaspán* 'apple' have stress on the second syllable. This can be answered by comparing examples in Figures 5 and 6 with the example in Figure 7, where the first syllable is stressed and the second syllable is not. As can be seen in Figure 7, the unstressed second syllable is associated with low pitch, resulting in a sharp fall. Speakers seem to make contrast between words with the stressed second syllable and words with the stressed first syllable by employing such a drastic fall in pitch from the stressed syllable to the unstressed second syllable in the former case. Put differently, even if the stressed second syllable does not have higher pitch than the first unstressed syllable, as we saw in Figure 5 and 6, speakers may still perceive it stressed as long as there is no sharp falling for the second syllable. Figure 8 shows such distinctions for a minimal pair, *kháte* 'hot' and *khaté* 'wind.'

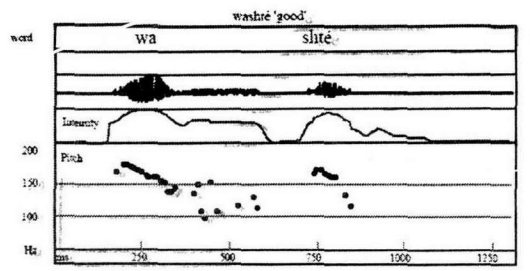

Figure 5. Pitch track and intensity contour in *washté* ('good')

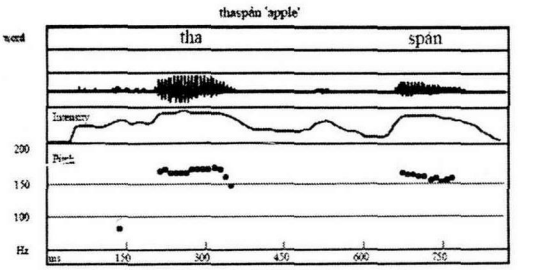

Figure 6. Pitch track and intensity contour in *thaspán* ('apple')

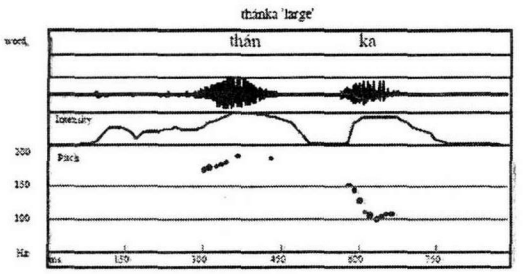

Figure 7. Pitch track and intensity contour of the word *thánka* 'large'

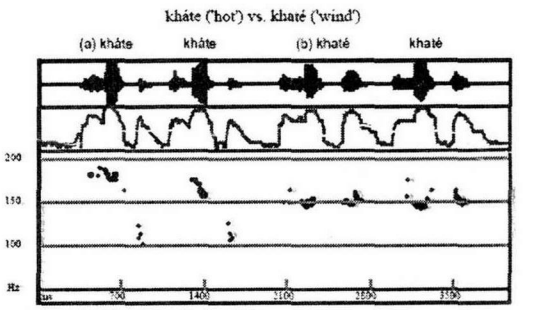

Figure 8. Comparison for the minimal pair, *kháte* ('hot') vs. *khaté* ('wind')

3.2.2 Voice Onset Time (VOT)

VOTs were measured for aspirated and unaspirated labial stops ('ph' and 'p') in word initial position before stressed and unstressed vowels. (See (3) for a complete word list.) Results of a two-way ANOVA with Stress and Consonant Type factors showed that there is a significant effect of stress on VOT ($F(1, 28) = 12.40$, $p < 0.05$) for the aspirated stop 'ph' but not for the unaspirated stop 'p' ($F(1, 28) < 1$, $p > 0.1$), with a significant interaction between Stress and Consonant Type ($F(1,28)=7.21$, $p<0.05$).

For the aspirated stop, the VOT is longer for stressed syllables than for unstressed syllables as shown in Figure 9. The greater VOT for the stressed syllable suggests that the prominence of stressed syllables is realized in part through a greater articulatory magnitude in glottal opening, because a greater opening of the glottis usually results in greater VOT (cf. Cooper, 1991; Pierrehumbert & Talkin, 1992; Jun, 1993). From this finding, we could also infer that the feature [spread glottis] that may be associated with the aspirated stop is enhanced under stress. Note, however, that this effect holds only for syllables with aspirated stops for which [spread glottis] may be a primary feature.

For the unaspirated stop, no effect of stress on VOT can be presumably accounted for by the phoneme inventory of Lakhota. If the VOT for unaspirated stops are lengthened due to stress, it might blur the phonemic contrast between aspirated and unaspirated stops. To the extent that the data hold, this is also compatible with findings in Korean and Dutch. Cho & McQueen (2006) have shown that when both unaspirated and aspirated stops occur in a language (e.g., Dutch), unaspirated stops tend not to undergo lengthenign of VOT in prosodically strong position (e.g., stressed syllables or domain-initial syllables), presumably in order to maintain the phonemic contrast between the unaspirated and the aspirated stops. Similarly, Cho & Jun (2000) have also shown that the fortis stops (with virtually no aspiration) in Korean do not undergo VOT lengthening in domain-initial position.

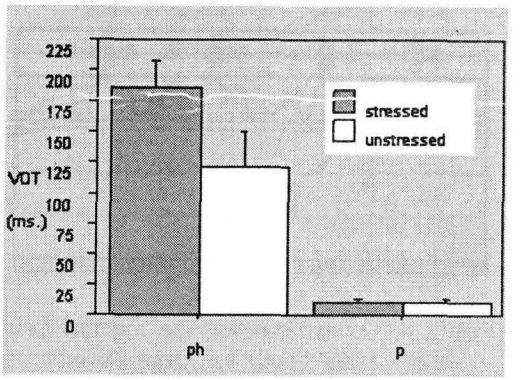

Figure 9. Voice Onset Time (VOT) in Lakhota for aspirated and unaspirated stops conditioned by stress. Error bars indicate standard deviations.

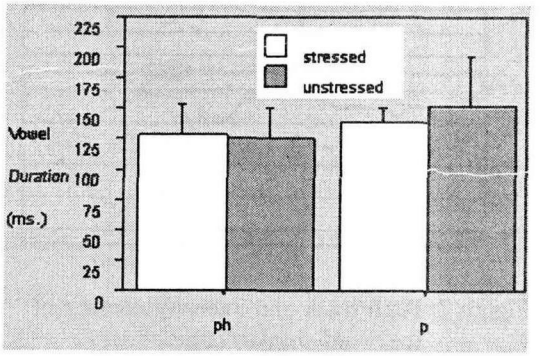

Figure 10. Vowel duration after aspirated and unaspirated stops in Lakhota. Error bars indicate standard deviations.

3.2.3 Vowel Duration

Vowel duration was measured for the vowels preceded by aspirated and unaspirated bilabial stops. The results of one way ANOVAs show that there is no effect of stress on vowel duration, as can be seen in Figure 10.

3.2.4 Change in intensity (dB) from the target syllable to the following syllable

In order to examine the intensity of stressed and unstressed vowels in the first syllables relative to following syllables, the difference in peak intensity of vowels between the first and second syllables was measured with aspirated and unaspirated bilabial stops separated. As shown in Figure 11 (the left panel), after 'ph,' there is no difference between the case when the first syllable is stressed and the case when the second syllable is stressed. On the other hand,

for the unaspirated stop 'p,' there is a substantial difference between the two cases—there is a greater change in intensity from the stressed syllable to the unstressed syllable than from the unstressed syllable to the stressed syllable.

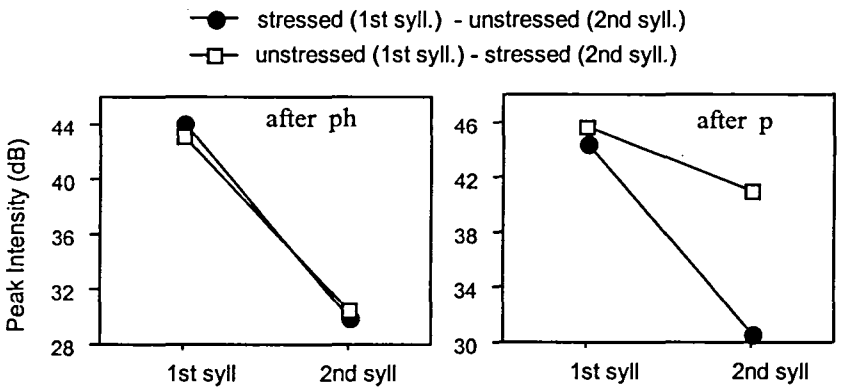

Figure 11. Change in intensity from the 1st syllable to the second syllable in Lakhota. The left panel is when the aspirated stop ph occurs word initially and the right panel is when the unaspirated stop p occurs word initially.

Thus far, we have observed several factors which contribute to marking the prominence associated with stress in Lakhota. First, pitch appears to be one of the most invariable factors, as discussed in section 3.2.1. Second, while there is a significant effect of stress on VOT for aspirated stops, no such effect was found for unaspirated stops (section 3.2.2). In addition, stress does not induce difference in the duration of vowels (section 3.2.3). Finally, no absolute difference in intensity was found between stressed and unstressed syllables, which is compatible with acoustic characteristics of Japanese pitch accent (cf. Beckman, 1986). Instead, the change in intensity from the first syllable to the second syllable showed that there is a greater falling in intensity when the first syllable is stressed than when the first syllable is unstressed (section 3.2.3), which can be interpreted as showing that the relatively greater amplitude change from stressed to unstressed syllables is an additional cue to mark the stress system. This effect, however, was observed only for words with initial unaspirated stops.

Though we have examined only limited data in this study, our preliminary data suggest that the speaker employs different strategies in marking stress for different segmental environments in addition to making pitch difference. For a syllable with an aspirated stop as an onset, the speaker makes the VOT longer presumably to make the syllable prominent. On the other hand, for a syllable with an unaspirated stop as an onset, VOT does not seem to serve as a cue to stress, but instead the speaker seems to employ change in intensity for enhancing the relative prominence.

3.3 Factors interacting with stress

In this section, I argue that there are some other factors that must be considered in interpreting any acoustic patterns associated with stress.

3.3.1 Initial strengthening

An interesting point that emerges from the previous sections is that the first syllable is almost always associated with greater intensity compared with the second syllable, regardless of the stress. Such higher intensity seems to be one of the factors that make judgment of stress difficult. The greater intensity may be accounted for by the hypothesis that the utterance-initial syllable has more strong acoustic events than the utterance-medial or final syllables (Fougeron & Keating, 1997; Cho & Keating, 2001; Keating, Cho, Fougeron and Hsu, 2003). Keating, et al (2003), for example, showed that utterance initial segments have stronger articulation compared to the utterance-medial ones, which is generally true cross-linguistically. In order to examine whether such initial strengthening effect is applicable to Lakhota in a systematic way, the intensity peaks of the first and second syllables of the words in (3) were compared. As shown in Figure 12, the intensity is always greater for the word-initial syllable than the following syllable. This effect holds regardless of whether the first syllable is stressed or not. Thus, Lakhota seems to exhibit initial strengthening in the domain of acoustic intensity. Note that the word-initial syllable in our data is also utterance-initial, since the test words were uttered in isolation. So, the comparison was in fact between utterance-initial and utterance-medial positions.

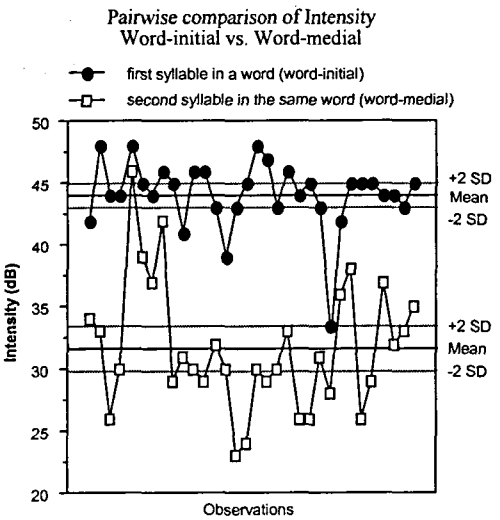

Figure 12. Pairwise comparison of Intensity between the first and second syllables in words in (3).

Another point worth mentioning is that there is less variation in intensity for the initial syllable compared with the non-initial one, as can be seen in Figure 12. The standard deviation, as marked by dotted lines in the figure, is smaller for the initial syllable and greater for the non-initial syllable. The greater variation found for the second syllable can be accounted for by stress difference. When the second syllable is stressed, the intensity is closer to that of the first syllable. On the other hand, when the second syllable is unstressed, the intensity is further away from that of the first syllable. Such difference, however, seem to be small for the first syllable presumably due to initial strengthening. This may also explain why the intensity difference for the stress-unstressed syllables with unaspirated initial stops is not attributable to the intensity change in the initial syllable but in large part to the intensity change in the second syllable.

It has been also known that VOT is another important phonetic correlate of domain-initial strengthening (Keating, et al., 2003). In order to see if initial strengthening can be extended to VOT, a small corpus was designed as in (5):

(5) a. Sentence initial / Word initial (=Si/Wi)
phámahel wanjila omna yelo
covered head just one smell M as by shawl
'Just one of them smelled the head covered as by shawl'

b. Sentence initial / Word medial (=Si/Wm)
ma phásu wanjila omna yelo
1sg.Poss nose just one smell M
'Just one of them smelled my nose'

c. Sentence medial / Word initial (=Sm/Wi)
wanjila phámahel omna yelo
just one head covered smell M
'Just one of them smelled the covered head'

d. Sentence medial / Word medial (=Sm/Wm)
wanjila ma phásu omna yelo
just one 1sg.Poss nose smell M
'Just one of them smelled my nose'

In (5), the stressed syllable *phá* with the bilaibal aspirated stop 'ph' occurs in four different prosodic positions (e.g., Sentence initial/Word initial, Sentence initial/ Word medial, Sentence medial/Word initial and Sentence medial/Word medial). (Note that the Sentence-initial vs. Sentence-medial conditions were defined according to whether the target-bearing word (not the target itself) occurred sentence-initially or sentence-medially, such that in the

Sentence-initial/Word-medial condition the target syllable *phá* in *ma phásu* is not strictly in the sentence-initial position.) Each sentence was repeated four times. The result is shown in Figure 13. There is a main effect of Word Position, showing that VOT for aspirated stop 'ph' in the word initial syllable is greater than that in the word medial syllable ($F[1,15]$, $p < .05$), regardless of the position in sentence. The effect seems to be cumulative, in that VOT is longer for the word initial and at the same time sentence initial syllable, intermediate for the word-initial but sentence-medial syllable, and shorter for the word medial syllable. This suggests that initial strengthening may be quite a robust phenomenon in Lakhota.

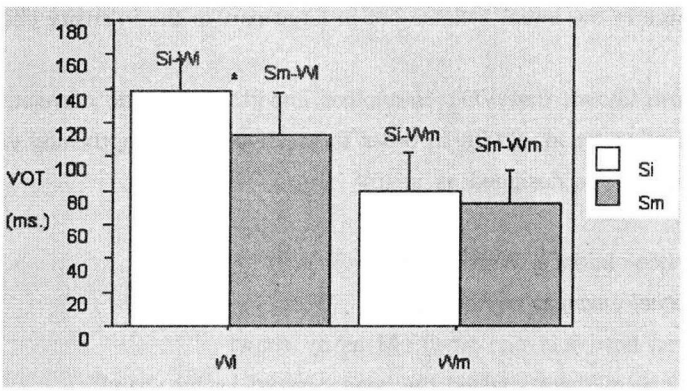

Figure 13. Variation in VOT for aspirated stop 'ph' as a function of prosodic position. Error bars indicate standard deviations.

Another interesting point is that there is also a significant interaction between Sentence Position and Word Position ($F[1,15]$, $p<.05$) due to the fact that VOT is longer Sentence-initially than Sentence-medially, but only when the target occurs word-initially. In other words, when the target occurs word-medially, VOT does not vary with Sentence Position — whether the target-bearing word occurs Sentence-initially verus Sentence-medially. This suggests that the initial strengthening effect is primarily local to initial position of words in Lakhota as in other languages (cf. Keating, et al., 2003).

3.3.2 Utterance final boundary tone

Another factor to consider is the boundary tone. It is generally agreed that certain type of tones (high, low) can characterize the edges of certain prosodic domains (e.g., Pierrehumbert, 1980; Beckman and Pierrehumbert, 1986; Pierrehumbert and Beckman, 1988; Jun, 1993; Fougeron and Jun, 1997; Gordon, 1999). For example, in English the end of a statement is usually marked by a low boundary tone (L%) at the end, although such tonal marking of boundaries may differ from language to language. (Note that '%' refers to a boundary tone that occurs at edges of

phrases.) Gordon (1999) shows that in Chickasaw statements are characteristically marked by a H% final boundary tone, whereas both Wh and yes/no questions are realized with a L% final boundary tone. In any event, what emerges from boundary tone phenomena across languages is that a tonal marking is generally used cross linguistically in order to signal the end of phases.

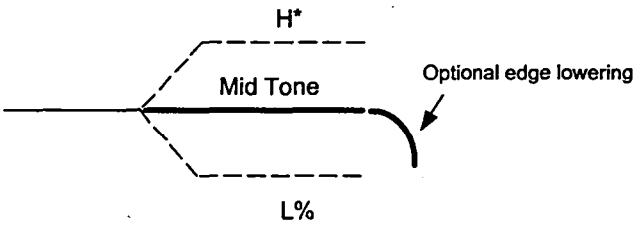

Figure 14. Interaction between high tone (H*) associated with a stressed syllable and boundary low tone (L%).

In the figure, '*' and '%' refer to the tones associated with stress and boundary tone, respectively. The dashed lines are assumed underlying tonal contours of the high tone of the stressed syllable and the low tone of the boundary. I suggest that the interaction between the opposite tones results in mid tone on the surface as marked by a thick line in the figure. The final fall in the figure, labeled as optional edge lowering, indicates that the boundary L% is optionally realized when the final syllable is long enough for it. Our data show that the speaker usually makes such a fall with creaky voice. Figure 15a shows the realization of L% with no interaction with high tone for stress. On the other hand, Figure 15b shows a surface mid tone for the most part of the final syllable due to the interaction between the two tones. This example also includes the optional edge falling toward the end of the final syllable. Note that the sharp fall was made by creaky voice.

Another evidence of the interaction between H* and L% can be found when a word with a stressed final syllable occurs in the middle of the utterance. Figure 16 shows such a case in which the word final stressed syllable is associated with a local intonational peak as marked by a circle. Note that the same syllable, *ghá*, occurring utterance finally as in Figure 15b, does not form a peak, due to the boundary L% tone. This effect is roughly equivalent to the realization of a stable rather than rising ending in English when the phrasal tone H is suppressed by L% (e.g., Pierrehumbert and Beckman, 1988).

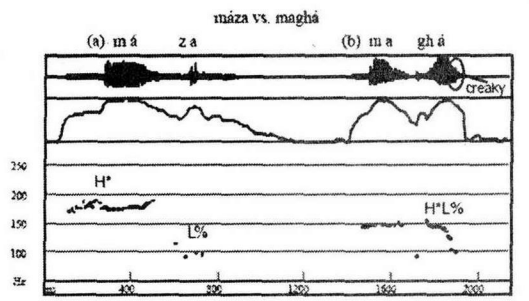

Figure 15. Interaction between high tone (H*) associated with a stressed syllable and boundary low tone (L%). (a) *máza* 'metal' and (b) *maghá* 'duck'

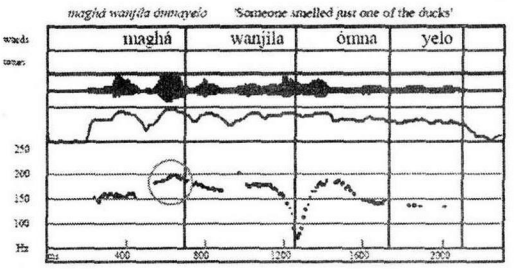

Figure 16. Pitch track of a neutral declarative sentence where the stressed syllable in *maghá* is associated with high peak as marked by a circle.

3.4 Summary

In this section, I have attempted to provide some acoustic correlates of stress, in part in connection with other prosodic factors such as domain initial strengthening and utterance final tonal phenomenon. A careful observation of the recorded tokens (using Pitchworks) suggests that the primary cue of the stress in Lakhota is relatively high pitch. Some of the data also suggested that higher intensity and greater VOT (for aspirated stops) together with higher pitch seem to enhance the prominence. However, the realization of these acoustic cues for stress often seems to be blurred due to several factors such as initial strengthening and the boundary tone phenomenon, which are prosodically conditioned. Certainly much work with systematic phonetic experiments is needed in order to better understand the stress system in Lakhota.

4. A Preliminary Look at Intonational Structure

In this section, I present a preliminary look at some intonational structure in Lakhota that might interact with stress system in Lakhota..

4.1 Method

The intonational structure was examined qualitatively with various short sentences recorded with four repetitions each. Sample sentences that are to be discussed in this section is given in (6):

(6) a. *yámni míla ómnap* 'Three of them smelled the knife.'
b. *yámni ógle ómnap* 'Three of them smelled the shirt.'

c. *yámni mázayajopi yuháp*	'Three of them have the brass instrument.'
d. *wanjí míla ómna*	'One of them smelled the knife.'
e. *wanjí míla ómna*	'One of them smelled the knife'
f. *wanjí ógle yuhá*	'One of them has the shirt.'
g. *yámnila míla ómnanp*	'Just three of them smelled the knife.'
h. *yámnila ógle ómnanp*	'Just three of them smelled the shirt.'

The recorded materials were digitized at 12800 Hz sampling rate and were analyzed qualitatively on a sentence-by-sentence basis using PitchWorks.

4.2 Pitch accent

4.2.1 Basic pitch accent L+H*

The intonational peak with high pitch seems to fall on the stressed syllable in Lakhota. Figure 17 shows that the local intonational peak falls on the stressed syllable in each word. Following Beckman (1986) and Beckman and Pierrehumbert (1986), I refer to these peaks as pitch accents with the diacritic '*' and the syllable with pitch accent as pitch accented syllable. As can be seen in the figure, the type of pitch accent is L+H* since it is made by rising tone and its peak is realized within the stressed syllable, which is true for all three pitch accents in the figure. A similar pattern is found in Figure 18. The only difference between Figures 17 and 18 is that there is a glottal stop at the beginning of the second word *ógle* in Figure 18. This glottal stop seems to make the end of the first word *yámni* and the beginning of the second word *ógle* extremely lowered in pitch. Compare this with the pitch track in Figure 17 where the second word *míla* does not have such an effect. This extra lowering effect was also found for the beginning of the final word *ónmap* in both figures.

4.2.2 F0 Declination

It is well known that F0 (pitch) tends to decline over the course of an utterance (e.g., Pierrehumbert, 1980). Pierrehumbert hypothesizes that F0 declination is attributable to downstepping of subsequent pitch events. This downstepping phenomenon seem to be robust in Lakhota, too, as shown in Figures 17 and 18. The lines superimposed on the pitch track in Figure 18 capture F0 declination over the course of the utterance. All the tokens examined in this study showed that the intonational peak is always highest in the first pitch accented syllable and lowest in the last pitch accented syllable in the utterance. Such a lowered peak is marked by !H*.

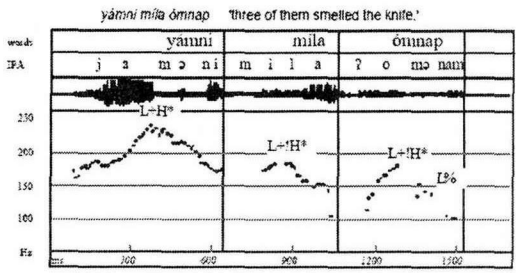

Figure 17. Pitch track of a neutral declarative sentence, *yámni míla ómnap* 'three of them smelled the knife.'

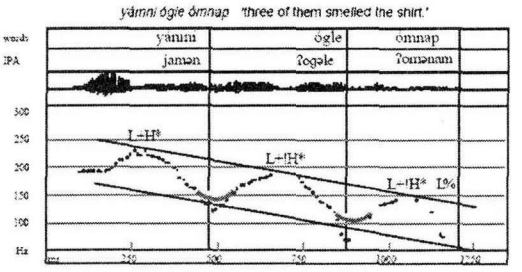

Figure 18. Pitch track of a neutral declarative sentence, *yámni ógle ómnap* 'three of them smelled the shirt.'

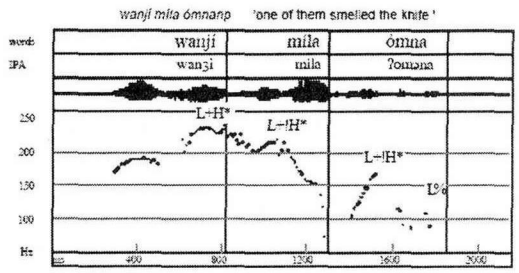

Figure 19. Pitch track of a neutral declarative sentence, *wanjí* ('just one') *míla* ('knife') *ómna* ('smell') 'One of them smelled the knife.'

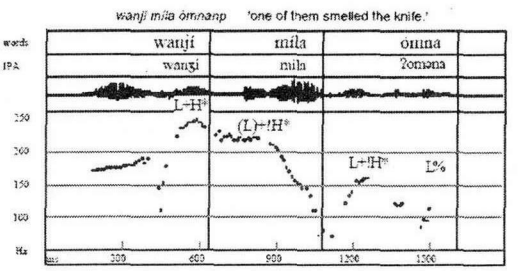

Figure 20. Pitch track of a neutral declarative sentence, *wanjí míla ómna* 'One of them smelled the knife' with L tone undershot. (L) refers to L tone undershot.

4.2.3 Undershoot of L tone in L+H

Figure 19 shows the pitch track of another neutral declarative sentence where the first word *wanjí* has stress on the final syllable on which the pitch accent falls. Since there is not enough time during the last syllable *ji* for both L+H* and falling in preparation of the following pitch accent L+H* for *míla*, the falling preparation was made in the beginning of *míla*. Note that such a falling preparation is usually made at the end of the preceding word if the last syllable of the preceding word is not stressed. Such falling in preparation for rising L+H* is another evidence that L+H* pitch accent exists in Lakhota — if there were no L tone, we would not expect lowering in pitch before the following H*. However, in many of such cases in which pitch accented syllables are adjacent to each other, the L tone seems to be undershot, or not realized on the surface, as shown in Figure 20, the same utterance as in Figure 19, but with L tone undershot for *míla*.

4.2.4 Interaction between pitch accent and boundary tone on a sentence level

In section 3.3.2., I discussed the interaction between pitch accent H* and boundary tone L% for words in isolation. Figure 21 shows the interaction on the sentence level. Note that the first part of the last syllable *há* is not associated with high pitch nor with low pitch, showing the interaction between the two opposite tones H* and L%. However, since the final syllable is relatively long (presumably because the syllable is open and has the vowel [a], which is usually intrinsically longer than other vowels), the speaker makes the L% tone at the end of the syllable with creaky voice.

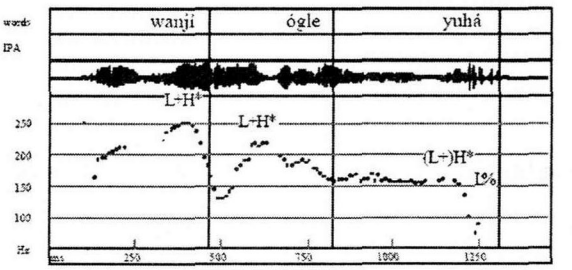

Figure 21. Pitch track of a neutral declarative sentence, wanjí ógle yuhá 'One of them has the shirt.'

4.3 Realization of Secondary stress

It has not yet known to us whether Lakhota has secondary stress or not. We sometimes observed that long words tend to have a secondary stress alternating from the main stressed syllable. In this section, I further explore such possibility based on several observations, and argue that secondary stress indeed exists in Lakhota.

Let us examine Figures 22 and 23 where the polysyllabic word *yámnila* 'just three' occurs. As can be seen in the figures, the final syllable *la* is associated with relatively longer duration and intensity, and a local bump in pitch (as marked by !H in the figure). Especially, the local bump in pitch resembles the L+!H* in which the L tone was presumably not realized as was the case with Figure 20. If there were no prominence at all associated with the final syllable la in *yámnila*, there should be no such local pitch bump in the course of the tonal falling from H* to the following L. This tonal phenomenon seems to suggest that the secondary stress alternates after the primary stress.

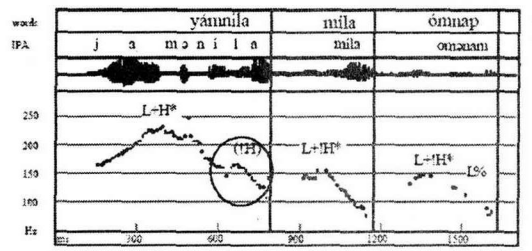

Figure 22. Pitch track of a neutral declarative sentence, *yámnila míla ómnanp* 'Just three of them smelled the knife.' The circled part indicates there is secondary stress.

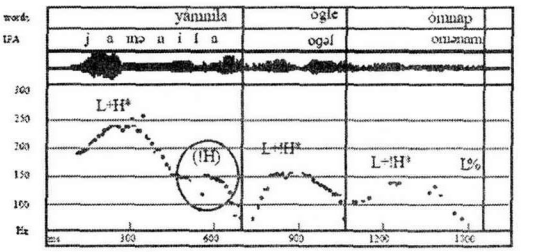

Figure 23. Pitch track of a neutral declarative sentence, *yámnila ógle ómnanp* 'Just three of them smelled the shirt.' The circled part indicates that there is secondary stress.

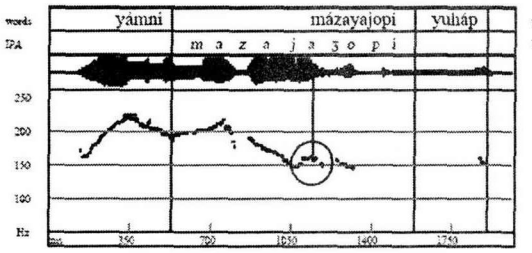

Figure 24. Pitch track of a declarative sentence, *yámni mázayajopi yuháp* 'three of them have the brass instrument.' The circle intonational event indicates the secondary stress.

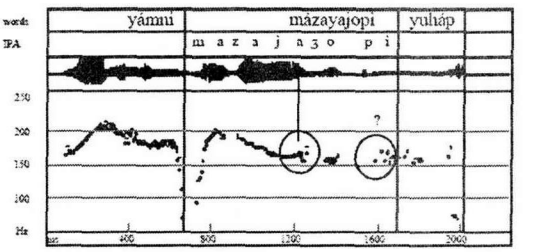

Figure 25. Pitch track of a declarative sentence, *yámni mázayajopi yuháp* 'three of them have the brass instrument.' The circled intonational events indicate the secondary stress.

However, words which seem to show apparent secondary stress are in fact morphologically complex words. For example, we know that *yámnila* is composed of *yámni+la,* and it seems that the separate morpheme la receives some prominence as just seen. Now the question is whether the stress simply alternates after the primary stressed syllable or whether it marks the stress on the second constituent of the morphologically complex words. While this question cannot be resolved here, we can tentatively test this by examining words with five syllables like *mázayajopi* (*máza* + *yajópi*) 'brass instrument' where the primary stress occurs in the first syllable followed by four syllables. If the secondary stress falls on the third syllable *yá,* we could say that the secondary stress occurs alternately after the primary stress. On the other hand, if the secondary stress falls on the fourth syllable *jo* which is the stressed syllable for *yajópi* in isolation, we could assume that the stress is maintained paradigmatically. Figures 24 and 25 indicate that the secondary stress occurs as a result of alternating the stress after the primary stressed syllable, rather than as a result of preserving the stress paradigmatically. Note that the secondary stress peaks in Figures 24 and 25 are aligned with the syllable *ya* [ja].

So far, I have attempted to present a preliminary look at some basic intonational structures in Lakhota. Though much remains to be further explored, the intonation data suggest several points. First, intonational peak in Lakhota falls on the stressed syllable with a pattern of L+H*. When two pitch accented syllables are adjacent to each other, the L tone in L+H* tends not to be realized. Second, there is interaction between pitch accent H* and boundary tone L%, resulting in mid tone at the end of utterance. Last, for the polysyllabic words, secondary stress seems to be reliably present in Lakhota. The reason why it is not acoustically and perceptually salient is perhaps because the speaker distinguishes the syllable with secondary stress from that with primary stress, which is at the same time pitch accented syllable. Pitch accent appears to be the most perceptually salient event which marks stress and intonation at the same time.

5. Conclusion

This paper has examined some phonological and phonetic properties of stress, basic intonational structures, and interaction between stress and intonation of Lakhota, contributing preliminary acoustic data on stress and intonation to the literature on Lakhota. The preliminary results showed that there are quite a few prosodically conditioned factors such as intonation, initial strengthening, and final weakening which interact with the stress system of Lakhota. These results suggest that a full understanding of suprasegmental system of a language requires a holistic analysis of various factors. Much work with systematic phonetic experiments is needed to better understand the prosodic structure of Lakhota, but it is hoped that this will serve as a basis for further development of stress and intonation system in Lakhota.

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