Situating Blackfoot within a Typology of (Mobile) Boundary Tone Grammars

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1 Introduction

Boundary tones are typically conceptualized as tones that occur at a prosodic boundary, i.e., tones anchored to syllables that are adjacent to a boundary, 'regardless of the rhythmic pattern of the phrase' (Beckman & Pierrehumbert, 1986:258). We refer to these as "static" boundary tones, and we consider a nuanced alternative. "Mobile" boundary tones are introduced by a prosodic domain but are not restricted to the boundary. Rather, their surface location is dictated by the rhythm of the phrase. This theoretical possibility follows naturally from decomposing the concept of a boundary tone into two separate principles: (i) prosodic domains may introduce tones; (ii) tones may occur at boundaries. On this decomposition, a "static" boundary tone is simply a tone that is introduced by a prosodic domain and occurs at the edge of that domain. A "mobile" boundary tone is also introduced by a prosodic domain, but surfaces elsewhere. We consider these theoretical possibilities in the context of an analysis of intonation in Blackfoot (Algonquian; Frantz 2017), providing an analysis of Blackfoot and a mini-typology that follows from the principles stated above.

Pitch contours in Blackfoot prosodic words rise to a pitch peak on the main stress, and fall at the right edge of the domain (Frantz, 2017; Taylor, 1969; Van Der Mark, 2003; Weber, 2020). We assume this contour is due to a sequence of LHL targets, where H docks to the stressed syllable and the final L is a static boundary tone (Miyashita & Weber, 2020). Figure 1 shows two pitch contours, each rising and falling over their domains.

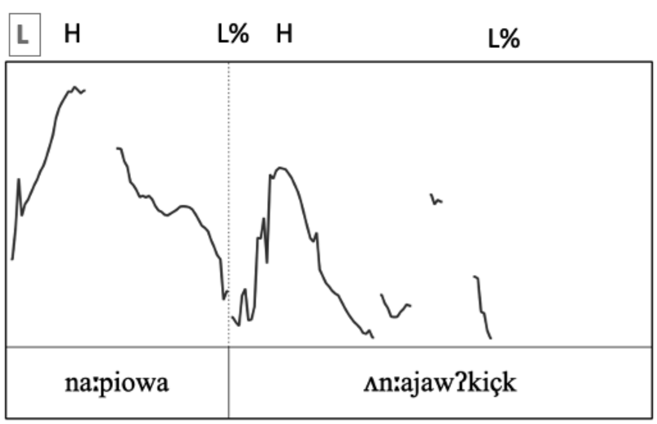

Figure 1: Two pitch contours in Blackfoot. Each has a LHL pattern.

Previous research does not address whether the domain-initial low that contributes to the rise (boxed in Figure 1) is better characterized as a low boundary tone or as part of a complex L+H pitch accent. Given a definition of "mobile" boundary tones, as above, a tone might be *introduced* by a prosodic domain but *surface* elsewhere. There are three possible hypotheses about how the initial L associates to the segmental material of the prosodic domain, schematized as grammars G1, G2, and G3 in Figure 2. Each image in the figure shows words with stress on the first, second, or third syllable; the H tone in the images is linked to this stressed

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syllable. In G1, the boundary tone %L links to the left edge syllable in all three word types and "stays" there. This grammar is equivalent to a "static" boundary tone analysis. In G2, the boundary tone links to the left edge syllable and also spreads to the stressed syllable. In G3, the boundary tone is attracted to the stressed syllable and appears to "jump" to that location. The fourth grammar, G4, is a grammar where L lexicalizes as part of an underlying, complex L+H pitch accent.

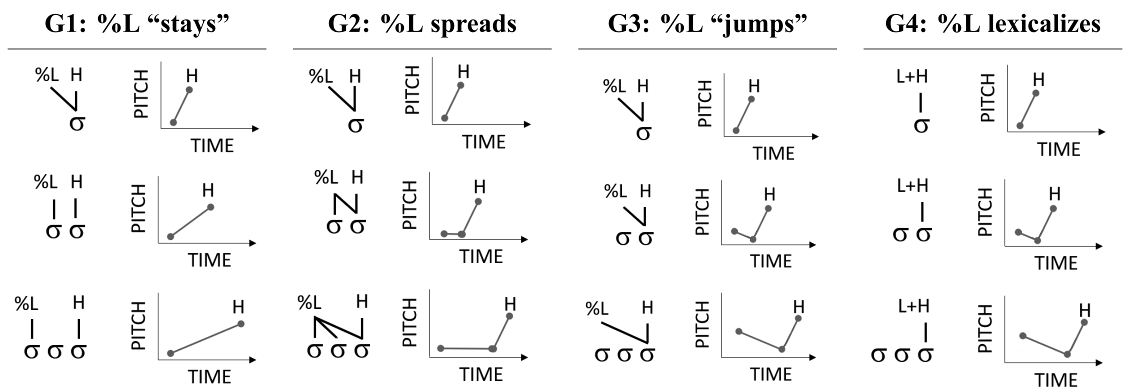


Figure 2: Four hypotheses about how the initial L in Blackfoot associates with segmental material.

These hypotheses make distinct predictions for how pitch varies across words, specifically with respect to pitch slope and L timing. Regarding pitch slope, G1 (%L "stays") is compatible with languages where the pitch slope between the L minimum and the H maximum varies with stress position—that is, pitch slope is greatest in words with first syllable stress and smaller in words with stress on a later syllable. In contrast, grammars G2, G3, and G4 are compatible with stable pitch slope across stress position. Regarding L timing, G1 (%L "stays") and G2 (%L spreads) are both compatible with languages where the timing from the left edge of the prosodic domain to the pitch minimum is consistent across stress position. In contrast, G3 (%L "jumps") and G4 (%L lexicalizes) are compatible with languages where the timing from the left edge of the prosodic domain to the pitch minimum varies with stress position—that is, the timing is earliest in words with first syllable stress and later in words with stress on a later syllable. Those predictions are summarized in Table 1.

Table 1: Predictions of G1–G4 for pitch slope and L timing

	G1	G2	G3	G4
Pitch slope stable across stress positions?	✗	✓	✓	✓
L timing varies across stress positions?	✗	✗	✓	✓

This study has three aims. Our descriptive aim is to establish the phonological status of the L pitch minimum in Blackfoot via a quantitative analysis of f0. Our typological aim is to situate Blackfoot within a typology of intonational grammars that vary in how pitch targets introduced by prosodic domains dock to segmental strings. Our theoretical aim is to argue for the existence of "mobile" boundary tones.

The remainder of this paper is organized as follows. Section 2 describes our methods for data collection. We then explain how we processed and analyzed the data in Section 3 before discussing our results in Section 4. Section 5 presents an analysis of Blackfoot in Optimality Theory (Prince & Smolensky, 1993; McCarthy & Prince, 1994). We return in Section 6 to the question of where Blackfoot is situated within the typology of boundary tones presented in Figure 2. Section 7 discusses some limitations of our analysis as well as possible extensions of the "mobile" boundary tone hypothesis to other languages, and Section 8 concludes.

2 Data Collection

Eight native speakers of Blackfoot participated in the experiment. Four participants were male and four were female, and all were between the ages of 50 and 70 at the time of recording. All participants reside on the Káínai Blackfoot reservation. Like most Blackfoot speakers (Genee & Junker, 2018), the participants in our study use English in their daily lives, and can be characterized as English-dominant bilinguals. Several participants are teachers of the Blackfoot language in a school setting.

We analyzed six words, recorded as a part of a larger project. The words consisted of three distinct stems inflected for singular and plural. The three stems differ in terms of the stress position (on the first, second, and third syllable). These items allow us to observe how the position of lexical stress influences pitch and, in particular, the key dependent variables of (1) pitch slope, and (2) L timing. Number in Blackfoot nouns is expressed via suffixes, which does not influence the position of stress from the left edge of the word. The inflected singulars and plurals for each stem are given in Table 2 below. Each speaker recorded two repetitions of each of the six words. The expected number of tokens is therefore 8 speakers $\times$ 6 words $\times$ 2 repetitions = 96 tokens.

Table 2: Target singulars and plurals

Stress (σ)	Stem	Gloss	Singular	Plural
1	/ˈmiːn-/	'berry'	[ˈmiː.ni]	[ˈmiː.ni^{s}ts]
2	/maˈminː-/	'wing'	[ma.ˈmɪn.ni]	[ma.ˈmɪn.ni^{s}ts]
3	/napaˈjin-/	'bread'	[na.pa.ˈji.ni]	[na.pa.ˈji.ni^{s}ts]

Speakers were asked to produce each word in a frame sentence. Because verbs and demonstratives in Blackfoot agree with the object in terms of number, two separate frame sentences were needed for singular and plural target words. The two suggested frame sentences were (1) for singular target words and (2) for plural target words.

(1) nitsííni'pa annî ____ matónni
I.saw.it(inan) that(inan) ____ yesterday
'I saw that ____ (inan., sg.) yesterday'

(2) nitsííni'pi anniístsi ____ matónni
I.saw.them(inan) those(inan) ____ yesterday
'I saw those ____ (inan., pl.) yesterday'

Each target word was prompted by an image, an orthographic representation of the noun, and a translation. The picture prompts for plural nouns simply doubled the image used to prompt the singular noun. Speakers exhibited multiple responses to the instructions to produce the pictured item in the frame sentence. Most speakers used the frame sentences in (1) and (2); however, some fronted the DP phrase before the verb. Others preferred to create a new frame sentence for each word. In those cases, we asked them to repeat the same sentence twice, and we ensured that the target word was not final in the sentence in order to avoid known phrase-final devoicing effects (Windsor, 2017).

There was also lexical and morphological variation in the responses which affected word duration. Some speakers produced 'wing' with an initial [o], as /**o**ˈminː-/ rather than /**ma**ˈminː-/. Some speakers produced 'bread' with a final long vowel, as /napaˈ**jiː**n-/ rather than /napaˈ**ji**n-/. Finally, some speakers produced at least some repetitions of the singular nouns without a final suffix, effectively shortening the word by one syllable. This was most common for the stem for bread, representing our third syllable stress condition.

3 Processing and Analysis

3.1 *Extracting Pitch Extrema* Pitch was tracked using the parabolic autocorrelation method in Praat (Boersma and Weenick 2020). For each token, we extracted the fundamental frequency (f0) minimum in the first 40% of the word, to represent L, and the f0 maximum that followed, to represent H. The key dependent measures (pitch slope and L timing) were calculated based on these f0 extrema, as described in Section 3.2.

Figure 3 shows an example of a token of [ˈmiː.ni] 'berry sg.'. The top panel shows the waveform. The second panel shows the spectrogram. The bottom panel shows f0. A segmental transcription is provided on the spectrogram panel. A dotted line is drawn at 40 percent of total duration. In this token, the 40 percent mark comes near the end of the long vowel in the first syllable. The pitch minimum in this token comes at the beginning of the word, during the closure for [m]. The following pitch maximum occurs during the vowel [iː].

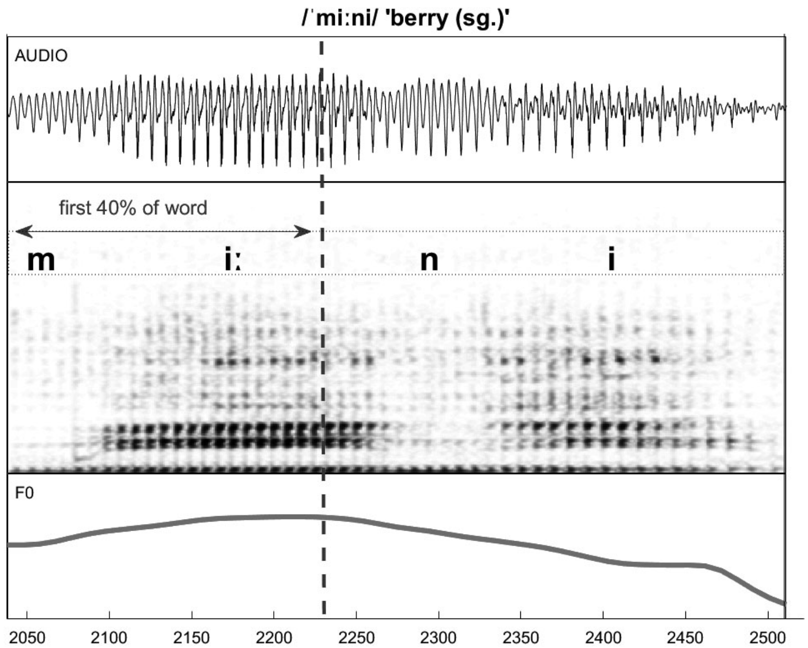


Figure 3: Illustration of measurement window.

3.2 *Dependent Measures* The key dependent variables in the analysis were pitch slope and the timing of the L tone. These were calculated based upon the pitch extrema from Section 3.1. Pitch slope (5) is the change in f0 from the L tone to H tone, i.e., the "rise magnitude" (4) divided by the the temporal interval between the L tone and the H tone, i.e., the "rise time" (3). To compare across subjects both f0 and the timing of pitch events were normalized. F0 was normalized by z-scoring within subjects (Rose, 1987). Pitch extrema greater than three standard deviation from the mean were excluded (five tokens). The timing of pitch events were normalized by dividing by the total duration of the word. Thus, rise time was calculated as a percentage of total word duration, where

- t^L is the timestamp in milliseconds of the L tone;
- t^H is the timestamp in milliseconds of the H tone;
- t^s is the timestamp of the start of the word; and
- t^e is the timestamp of the end of the word

These measurements are summarized below.

(3) Rise time: $\Delta t^{H-L} = H\_time - L\_time$, where

a. Timing of L tone: $L\_time = t^L/(t^e - t^s)$

b. Timing of H tone: $H\_time = t^H/(t^e - t^s)$

(4) Rise magnitude: $\Delta f^{H-L} = (f0^H - f0^L)$

(5) Pitch slope: $P^{\text{slope}} = \Delta f^{H-L}/\Delta t^{H-L}$

The second dependent variable of interest is the timing of the L tone relative to the the start of the word, which is a component of rise time, defined in (3a).

3.3 *Analysis* To evaluate the effect of stress position on pitch slope (5) and the timing of the L tone (3a), we fit nested linear mixed effects models to these dependent variables using the LmerTest package (Kuznetsova et al., 2017) in R (v4.0.3; R Core Team 2021). The baseline model included only a random intercept for speaker. This was the maximal random effects structure supported by the data. To this, we added the fixed effect of stress position and determined statistical significance through model comparison via a likelihood ratio test, using the *anova()* function. Stress position was treatment coded, with first syllable stress as the reference level.

4 Results

Before we look at the main results, we show a couple of checks on the data. Figure 4 shows the rise time for the L and H tones by speaker—one component of the pitch slope calculation. The y-axis shows time as a proportion of total word duration. From this we can see that there is indeed a pitch maximum following a pitch minimum in every token: all of the lines go up from L to H.

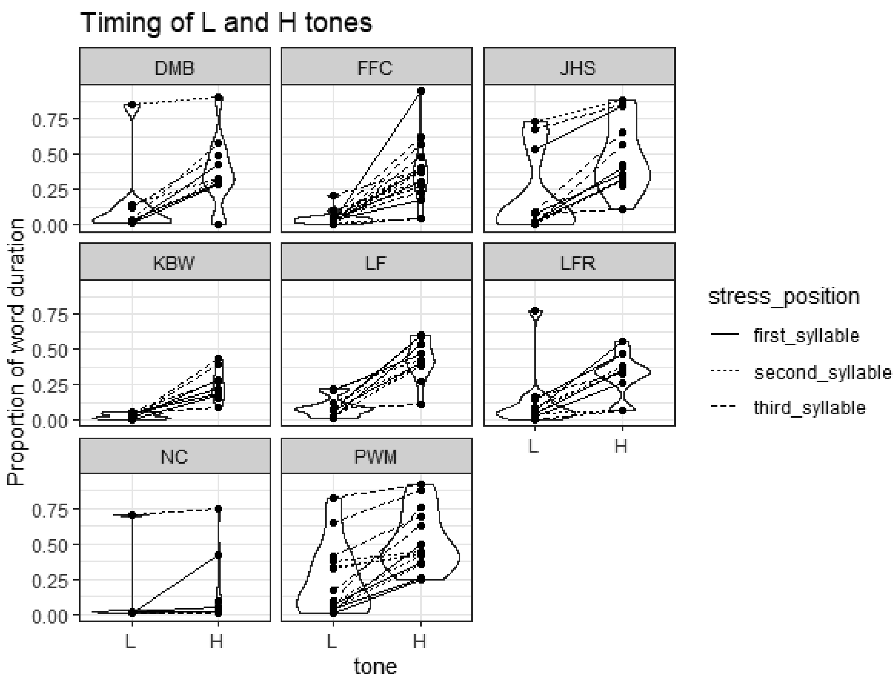


Figure 4: Rise time for L and H tones by speaker

The next data check is for rise magnitude. This is shown in Figure 5. The y-axis shows z-score normalized f0. The distributions by subject are shown in the violin plot and the change in f0 from L to H is indicated by lines coded for stress position. The key observation is that, as expected, the L is in the low pitch range (below zero) and the H is in the high pitch range (above zero).

We now turn to the main results. Our interest is in the effect that stress position has on the relation between the rise time (Figure 4) and rise magnitude (Figure 5), which is captured by the "pitch slope" dependant variable. Figure 6 shows pitch slope by stress position. We can see from the box plot that the slope did not decrease with stress position. In fact, from first syllable stress to second syllable stress there is actually an increase in slope. Adding stress position does not improve the model ($\chi^2 = 2.43$, $p = 0.30$; AIC increases from 756 to 758). This result, a null effect of stress position on pitch slope, is inconsistent with G1, the grammar in which the boundary tone %L "stays" at the boundary.

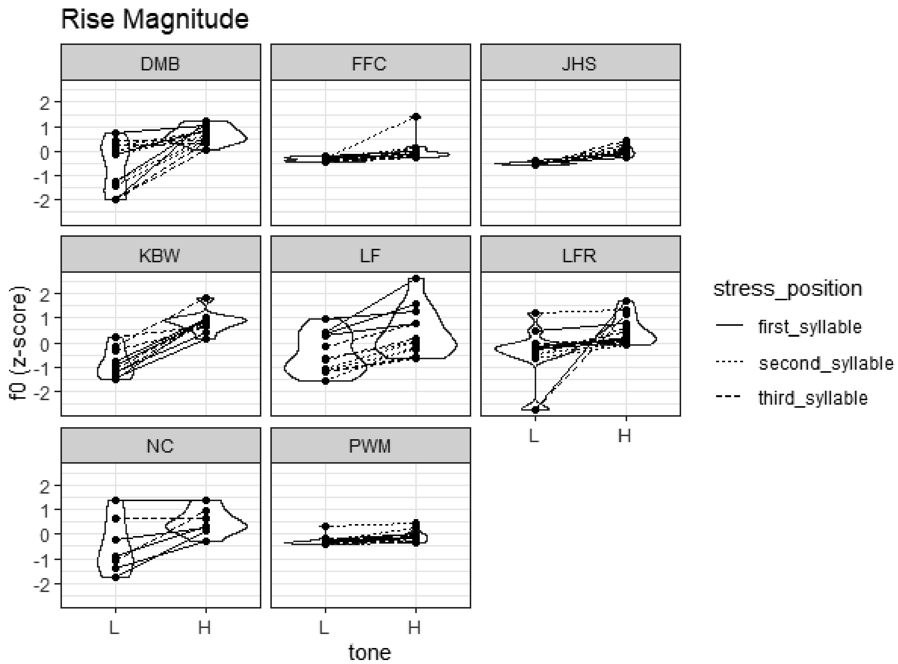


Figure 5: Rise magnitude from L to H by speaker

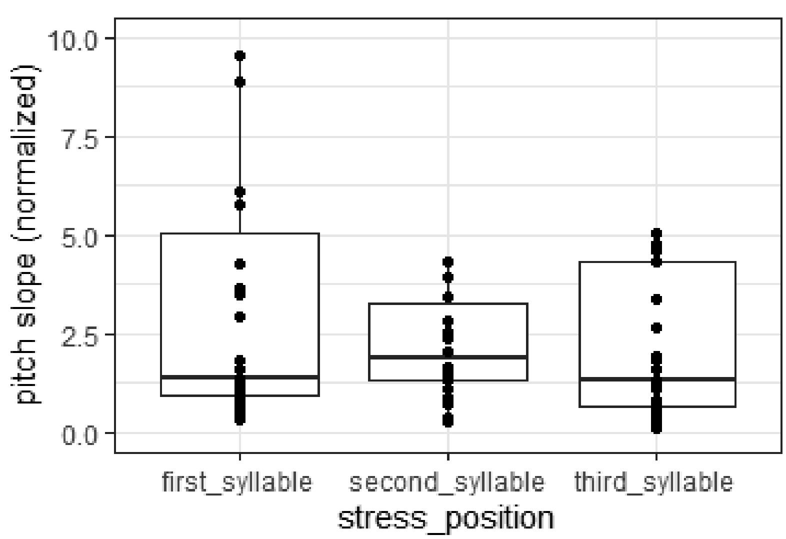


Figure 6: Pitch slope by stress position

The second main dependent variable was the timing of the L relative to the start of the word. Figure 7 shows the results. There is an increase in L tone timing from words with first syllable stress to words with second syllables stress. This indicates that when stress occurs on the second syllable, the L tone moves away from the left edge of the word towards the stressed syllable. Stress position had a significant effect on the timing of the L tone (χ^2 = 11.63, p = 0.003; AIC decreased from -132.9 to -140.5). The L tone starts later on words with later stress: second syllable (β = 0.07, p = 0.03); third syllable (β = 0.09, p = 0.0001). To assess whether the difference between second and third syllable stress is statistically significant, we re-ordered the levels of the stress position factor so that the stress on the second syllable was the intercept. In this model, only first syllable stress was significant. We conclude that there is a significant shift rightward in the timing of the L from words with stress on the first syllable to words with stress on the second syllable but not a further rightward shift to words with third (from the left) syllable stress. This result, a significant effect of stress position on %L timing, is inconsistent with G1 (where the %L boundary tone "stays" at the boundary) and G2 (where the %L tone links to a boundary syllable and spreads to the stressed syllable).

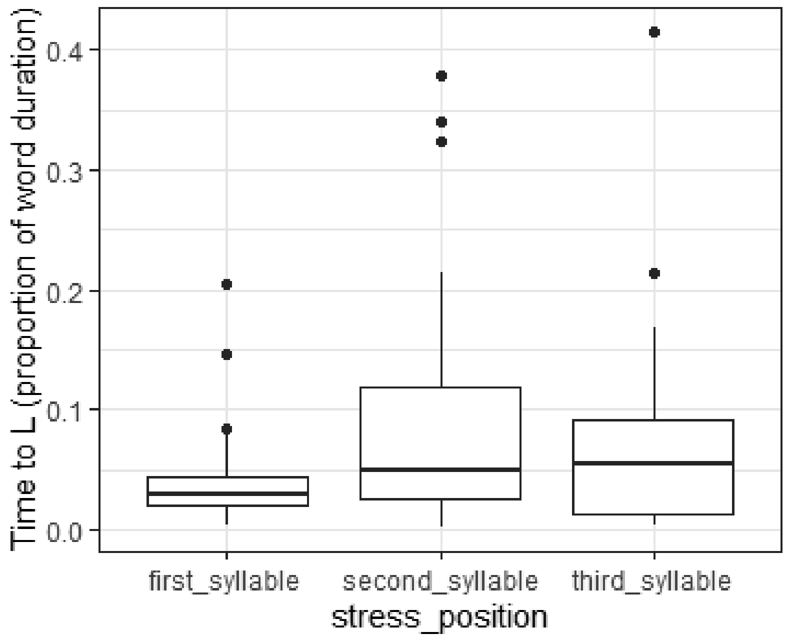


Figure 7: Time to L by stress position

The magnitude of the change in timing of the L from first syllable stress words, 0.04 (4% of total word duration), to second syllable stress words, 0.10 (10% of total word duration), is fairly small. This is in part because our materials were conservative with respect to the L shift hypothesis. The materials for our first-syllable stress condition were produced as one and two syllable words (without or with a number suffix), while the materials for our second-syllable stress condition were produced as two or three syllable words (again, without or with a number suffix). The items in the second syllable stress condition were longer in total duration than the items in the first syllable stress condition, which attenuated the shift in L timing (expressed as a percentage of total word duration). Despite this, the shift is statistically significant.

To summarize the results, we found that stress position has a significant effect on the timing of the L tone but not on pitch slope. The L tone occurred close to the left edge of the word, at around 4% of total word duration, when stress was on the first syllable. When stress was on the second syllable, the L tone moved rightward, away from the left edge, to about 10% of total word duration. This shift of the L tone is incompatible with the static boundary tone hypothesis (G1) or the tone spreading hypothesis (G2). The further rightward shift in words with third syllable stress was not statistically significant. Even as the timing of the L tone moved rightward with stress, pitch slope did not show significant differences. The non-significant numerical trend was for increased pitch slope in words with second syllable stress relative to first syllable stress. This direction is the opposite of what was predicted by the static boundary tone hypothesis (G1). We elaborate on the implications of these results in the discussion.

5 Analysis of Blackfoot

The results of our analysis of pitch events in Blackfoot allows us to rule out some of the theoretical possibilities raised in the introduction. The effect of stress position on the timing of the L tone is incompatible with G1 and G2 (from Figure 2). G1, the static boundary tone grammar, predicts that the L tone should remain close to the left edge of the prosodic domain regardless of the position of stress. G2, the tone spreading grammar, is similarly incompatible with the data, as this grammar predicts that the L should occur early in the word, regardless of stress. The observed rightward shift in the timing of the L tone remains compatible with both G3 and G4. G3, the mobile boundary tone grammar, predicts that the L should move rightward with stress and that the slope of the pitch rise should remain fairly constant across stress positions. Consistent with these predictions, we found no effect of stress position on pitch slope and a consistent shift in the timing of the L from first syllable stress to second syllable stress. These aspects of the data are also consistent with G4, the lexicalized pitch-accent grammar. As shown in Figure 2, these two grammars predict the same pitch facts, so a phonetic analysis of f0 extrema cannot decide between them.

5.1 *Deciding Between G3 and G4 for Blackfoot* There are several independent phonological arguments against G4 (the lexicalized pitch-accent analysis) and in favor of G3 (the "mobile" boundary tone analysis) for Blackfoot.

If Blackfoot is a language that instantiates G4, this is equivalent to saying that Blackfoot has undergone tonogenesis and developed a lexicalized L+H pitch accent.[1] In such a language, we would expect to see independent L and H tones, and potentially a contrast with other types of pitch accents, cf., Serbian (Inkelas & Zec, 1988) and Japanese (Kawahara, 2015). This is not the case. Instead, Blackfoot has only a privative L+H pitch movement which occurs on a stressed syllable (e.g., L+H vs. Ø) (Weber, 2020). The H tone is not independent: a higher f0 (the "H" tone) occurs only as part of the manifestation of stress, alongside other acoustic properties such as longer duration and greater intensity (Van Der Mark, 2003). Finally, L+H does not contrast with other pitch accents, such as L, L+H, or H+L. On the basis of these considerations, we conclude that L+H is not a lexicalized pitch accent in Blackfoot.

If Blackfoot is a language that instantiates G3, then the language has not undergone tonogenesis. The H is predictably located on a stressed syllable, suggesting it is not necessrily underlying, but may instead be epenthesized and then linked to the stressed syllable. Under this analysis, the %L tone is required by the prosodic word domain, but "jumps" to the stressed syllable. The prosodic word domain which co-occurs w/ %L is highly active elsewhere in Blackfoot grammar. It is the domain for phonological processes such as epenthesis, vowel coalescence, and /t/ → [ts] assibilation before high, front vocoids; it is the domain of obligatory stress; and it is the domain of a phonotactic restriction–the left edge prohibits glides (Elfner, 2006; Bliss, 2013; Weber, 2020).

In sum, we showed in the preceding sections that the phonetic data is compatible with either G3 or G4. However, there are phonological arguments for Blackfoot which strongly disfavor G4 and strongly favor G3. Having now ruled out G4, we turn in the next section to an analysis of G3 for Blackfoot.

5.2 *Optimality Theory Analysis of G3 in Blackfoot* In this section we present an Optimality Theory (Prince & Smolensky, 1993; McCarthy & Prince, 1993, 1994) analysis of Blackfoot as a mobile boundary tone language. This analysis makes use of two markedness constraints, (6)–(7), two alignment constraints, (8)–(9), and two faithfulness constraints, (10)–(11).

(6) Stress-H (Str-H)

Assign a violation for each stressed syllable in the output that is not associated with an H tone. ("All stressed syllables must be linked to an H tone.")

(7) Domain-L (Dmn-L)

Assign a violation for every prosodic word domain in the output which does not contain an L tone linked to a TBU within that domain. ("There must be an L tone for every prosodic word.")

(8) Align-T-ˈσ (Al-T-ˈσ)

Assign a violation for each tone in the output which is linked to an unstressed syllable. ("All tones should link to stressed syllables.")

[1] In fact, this analysis is presented in Stacy (2004), who argues that the pitch accent location is not predictable, and that Blackfoot is additionally developing a falling tone before glottal stops.

(9) Align-T-L (Al-T-L)

Assign a violation for each tone in the output which is not linked to the leftmost syllable within a prosodic domain. (“All tones should align with the left edge of the domain.”)

(10) Dep-Link(T)

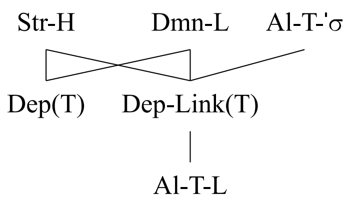
Assign a violation for each association line between a TBU and a tone in the output which does not have a corresponding association line in the input. (“No tone spreading.”)

(11) Dep(T)

Assign a violation for each tone in the output that does not have a correspondent in the input. (“Don’t epenthesize tones.”)

The ranking which derives G3 is shown in (12).

(12)



The violation profile for this ranking is illustrated in the tableau in for a schematic input with second syllable stress. The input shows the left prosodic word boundary, represented as [, and the position of stress. The optimal candidate is (e), where an L and H tone have been been epenthesized and linked to the stressed syllable, incurring two violations each of Dep-Link-T, Dep(T), and Al-T-L. Candidate (a) has no tones in the output, which violates the markedness constraints Str-H and Dmn-L. In order for (e) to be optimal, {Str-H, Dmn-L} must crucially dominate {Dep-Link-T, Dep(T), Al-T-L}. The relatively high ranking of Dmn-L also rules out candidate (b), which correctly epenthesizes an H tone and links it to a stressed syllable, but which has no L tone. Candidate (c) represents G1, where an L tone is epenthesized and linked to the leftmost syllable. This candidate violates the Al-T-'σ constraint, but satisfies Al-T-L better than the optimal candidate (e). This shows that Al-T-'σ ≫ Al-T-L. Finally, candidate (d) represents G2, where an L tone is epenthesized and spreads from the leftmost syllable to the stressed syllable. This violates Dep-Link(T) one more time than (e), but satisfies Al-T-L better than the optimal candidate (e). This shows that Dep-Link(T) ≫ Al-T-L.

(13)

/ [σ 'σ /	Str-H	Dmn-L	Al-T-'σ	Dep-Link(T)	Dep(T)	Al-T-L
a. [σ 'σ	∗!	∗!				
b. H [σ 'σ		∗!		∗	∗	∗
G1 c. L H [σ 'σ			∗!	∗∗	∗∗	∗
G2 d. L H [σ 'σ				∗∗∗!	∗∗	∗
☞G3 e. L H [σ 'σ				∗∗	∗∗	∗∗

Those three partial rankings are summarized in (14), along with which candidates are disfavored compared to (e) by each ranking.

(14) Crucial rankings in Blackfoot

a. {Str-H, Dmn-L} ≫ {Dep-Link-T, Dep(T), Al-T-L} (candidates a, b ≺ e)

b. Al-T-ˈσ ≫ Al-T-L (candidate c ≺ e)

c. Dep-Link-T ≫ Al-T-L (candidate d ≺ e)

To summarize this section, the results of the acoustic analysis of Blackfoot pitch events were compatible with either G3 (the "mobile" boundary tone analysis) or G4 (the lexicalized pitch-accent analysis). However, there are independent phonological arguments, discussed in 5.1, against G4 and in favor of G3 for Blackfoot. A small number of ranked constraints correctly predicts G3 as a possible language, compatible with the Blackfoot pitch patterns. In the next section, we show that the factorial typology of these constraints correctly predicts all four types of languages in our typology of boundary tones (Figure 2).

6 Boundary Tone Typology

A factorial typology of the constraints used above for our analysis of Blackfoot predicts the four languages types discussed in the introduction. The crucial rankings are summarized in (15). For reference, the top row shows G3, repeating the crucial rankings from Section 5.2.

(15)

Grammar	Crucial ranking			Functional grounding
G3: %L "jumps"	Al-T-ˈσ, Dep-Link(T)	>>	Al-T-L	Enhance salience of ˈσ
G1: %L "stays"	Dep-Link(T), Al-T-L	>>	Al-T-ˈσ	Mark boundary
G2: %L spreads	Al-T-ˈσ, Al-T-L	>>	Dep-Link(T)	All of the above
G4: %L lexicalizes	Faith	>>	Al-T-ˈσ, Dep-Link(T), Al-T-L	Faithful to pitch accents

G1 is the static boundary tone grammar, whereby the L tone introduced by the prosodic domain stays at the left edge. This is obtained by ranking Dep-Link(T) and Al-T-L above Al-T-ˈσ. One functional tradeoff between G1 and G3 is that while G1 makes the prosodic boundary salient with the L tone, G3 increases the salience of the stress syllable by co-locating the L and H tones, resulting in rising pitch on the stressed syllable. G2 accomplishes both functions by spreading the L tone across the domain from the left edge syllable to the stressed syllable. This grammar is achieved by ranking Al-T-ˈσ and Al-T-L above Dep-Link(T). Finally, the lexical pitch accent grammar, G4, ranks faithfulness constraints above both markedness and alignment constraints. This predicts that tones will surface according to their position and location in the underlying representation. Notably, this is the only grammar that requires lexical specification of tones and tone locations.

7 Discussion of Results

We interpreted the results of our pitch analysis as supporting G3, the "mobile" boundary tone grammar, which we fleshed out in an OT analysis. However, there are several aspects of our results that do not fit neatly with this analysis and which require further discussion.

In absolute terms, the timing of the L in words with second syllable stress, at around 10% of total word duration, places the L later than the word onset but well before the stressed syllable. That is, the pitch rise starting with the L begins earlier in the first syllable when stress is on the first syllable and later in the first syllable when stress in on the second syllable. This suggests that the mobile boundary tone need not link to the stressed syllable. It may be sufficient to precede the H of the stressed syllable, as in a L+H tone combination. A possible alternative to our mobile boundary tone analysis is that the boundary tone is constrained to occur within the first syllable. This alternative picks up on the fact that the L tone begins during the first syllable in both words with first syllable stress and words with second syllable stress. The key difference across conditions is *when* within the first syllable that the L occurs. On this view there may be a "bend not break" principle at play, where the L tone can shift towards the stressed syllable gradiently, as long as it still starts during the first syllable. Fleshing out this alternative would require gradient definitions of key constraints in the analysis.

The difference in the timing of the L between words with second and third syllable stress was not statistically significant, which is consistent with this alternative analysis. However, there may be other reasons for the exceptional behavior of words with third syllable stress. There may be pressure from the right-edge prosodic boundary tone to keep tones associated with the stressed syllable away from the right edge, i.e., avoiding tonal crowding Ladd (2008). This pressure could have been stronger for our third syllable stress words than our second syllable stress words, in part because of variation in vowel length and final vowel deletion, as described in Section 2. The final vowel in our third syllable stress items was frequently deleted, rendering the stressed syllable at the right edge of the prosodic domain. The L tone may start earlier in third syllable stress words owing to the time required to rise to the stress syllable and then fall at the end of the prosodic word.

There are several avenues for future research. First, a limitation of the pitch analysis is the sparseness of our pitch sampling. Our key dependent measurements were f0 turning points, e.g., maxima and minima, but these may under-determine the phonologically relevant aspects of the pitch contour. In future work, we plan to take up modelling of the entire pitch contour, based on stochastic models of our competing hypothesis (see, e.g., Shaw & Kawahara 2018; Zhang et al. 2019; Kawahara et al. 2022). Second, the pitch contour that results from our OT analysis is notably exactly the same as what would be expected from a lexicalized L+H pitch accent. We argued against this analysis in the general case, but given the phonetic ambiguity, it is possible that some speakers have induced G4. The likelihood of lexicalization of this sort, i.e., tonogenesis (Stacy, 2004), may hinge on evidence for G3, the mobile tone grammar, elsewhere in the language. One promising domain for future work is stress placement in the verbal domain. Additionally, G3 vs. G4, make different predictions for productivity, which we hope to test experimentally.

Finally, our broader theoretical hypothesis of "mobile" boundary tones opens up new analytical possibilities for prosodic systems. For example, "mobile" boundary tones may also be needed for "phrase languages" (in the terminology of Féry 2017), such as Inuktitut, Hindi and Korean, in which tones are associated with higher prosodic units rather than word-level lexical stress or pitch accents. The surface position of these phrasal tones is therefore dictated by other aspects of the grammar. For example, the location of tones associated with prosodic domains in Inuktitut is variable Arnhold et al. (2018, to appear), which is consistent with our "mobile" boundary tone analysis. Arnhold (2019) makes use of this possibility to provide a fresh take on Finnish pitch accent, deriving the position of focus from phonological phrasing. One question is which kinds of prosodic domains allow these variable tones. Although comparing prosodic domains across languages is often non-trivial, the mobile boundary tone of Blackfoot discussed here is likely introduced by a smaller domain (what we referred to as the phonological word) than focus in Finnish. Precisely which prosodic domains can introduce tones is a fruitful area for future research.

8 Summary

We investigated the phonological status of the L tone at the left edge of the Blackfoot prosodic word domain, using converging evidence from pitch contours and phonological facts. We argued that the L tone is introduced by the prosodic word domain but surfaces elsewhere, immediately preceding the pitch peak of a H tone associated with the stressed syllable. The drift of the L boundary tone towards the stressed syllable may function to enhance the perceived prominence of the H on the stressed syllable. On this analysis, the rising pitch contour on the stressed syllable derives from an interaction between word and phrasal prosody, where word prosody is reduced to the lexically-specified location of stress, and phrasal prosody emerges from the interaction of constraints controlling tone and tone location.

Our typological aim was to situate Blackfoot within a typology of intonational grammars that vary in how pitch targets introduced by prosodic domains dock to segmental strings. Clearly, Blackfoot is intermediate between a language with static boundary tones and lexicalized pitch accents, suggesting the need for a broader typology of boundary tones. Our Optimality Theory analysis also predicts an empirical range of languages which flesh out exactly this typology.

Our analysis of Blackfoot therefore forces us to decompose what a boundary tone is. "Boundary tones" emerge because markedness requires a tone for each prosodic domain. The location on the surface is dictated by the the grammar. Such an analysis predicts the existence of "mobile" boundary tones, which are introduced by the prosodic domain but appear elsewhere on the surface. We argued for the existence of these mobile boundary tones using evidence from Blackfoot, but there is evidence from other "phrase languages" that this sort of decomposition is necessary.

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