ALLOPHONY-DRIVEN STRESS IN MUNSTER IRISH

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1. Introduction

The aim of this paper is to present and evaluate new evidence for the effect of [ax] on the stress pattern of Munster Irish (MI). Previous descriptions of MI's stress system (Ó Cuív 1944, Ó Sé 1989, 2008, Blankenhorn 1981, Gussman 2002, Hickey 2011, 2014) claim that default stress falls on the initial syllable. Coda consonants do not contribute to a syllable's weight so the default initial stress pattern is demonstrated by words with two or three short vowels, as in (1).

(1) a. [ˈsoləs] 'light' [ˈbatə] 'stick'
b. [ˈokəɹəx] 'hungry' [ˈfaɹəgʲə] 'sea' (Gussman 2002)

Stress is described as shifting away from an initial syllable and onto a long vowel or diphthong, as in (2).

(2) a. [gaˈdiː] 'thief' [kaˈɹʰiːs] 'Lent'
b. [əməˈdaːn] 'fool' [məˈkaːntə] 'modest' (Gussman 2002)

Lastly, syllables containing the vowel-consonant sequence [ax] are described as attracting stress away from a short vowel, but not a long vowel or diphthong, as in (3).

(3) a. [bəˈkax] 'lame' [kəˈlʲax] 'hag'
b. [kəˈdʲaxtə] 'company' [ləˈgaxəɹ] 'weakness' (Gussman 2002)
c. [ˈtuːtax] 'crude, awkward' [ˈʃeːʃax] 'melodic' (Teanglann.ie 2013)

Theories such as Hayes (1995)'s metrical theory and de Lacy (2002)'s theory of sonority driven stress cannot account straightforwardly for the stress system described above. Some proposals have posited modifications to Hayes (1995)'s metrical theory to account for the MI system (Doherty 1991, Green 1996, Rowicka 1996, Iosad 2013, Bennett 2012 & 2015).

Previous descriptions of MI stress utilized impressionistic methods (O'Rahilly 1932, Ó Cuív 1944, Breatnach 1947, Blankenhorn 1981, Ó Sé 1989, Ó Siadhail 1989, Gussman 2002, Hickey 2014). Some impressionistic descriptions of stress have recently been shown to not be reliable because a listener's ability to determine the stress pattern of a language is biased by the acoustic cues of their native language's stress pattern (Bowern 2013, Shih 2018). The majority of impressionistic descriptions of Irish are written by native speakers of English. Consequently, an acoustic analysis of a native MI speaker's stress pattern is presented here to provide concrete evidence of the stress pattern the speaker produces and avoid the interference of a native English speaking investigator's L1 perceptual bias. Windsor et al. (2018) also provides another recent phonetic analysis of MI stress, which compares word-level stress with phrase-level accent.

The results presented below provide evidence that stress does fall on the second vowel in CVCax words and it is confirmed that the first vowel reduces: i.e. /CVCax/ → [Cəˈ Cax]. However, in all other word forms, it is argued that stress falls on the initial syllable, even in words with the shape [CVCV:]. In addition, it is argued that /a/ never reduces before [x]: i.e. [ˈCax.Cax], *[Cax.Cəx]. Evidence for stress and resistance to vowel reduction is found in the first formant (F1).

The phonological analysis presented argues that MI feet are influenced by allophony: stress falls on the second syllable in [Cəˈ Cax] because falling on the first syllable would prevent vowel reduction. This analysis is sketched in the tableau below. The constraint *[−LOW]X prevents a low vowel from centralizing before [x]; REDUCE requires short unstressed vowels to reduce to [ə], and TROCHEE requires feet to be left-headed.

(1) *Allophony-driven stress in MI, in brief*

/bakax/	*[−LOW]X	REDUCE	TROCHEE
☞ (a) (bə.ˈkax)			*
(b) (ˈba.kəx)	*!		
(c) (ˈba.kax)		*!	
(d) (ba.ˈkax)		*!	*

While the 'allophony-driven stress' (de Lacy 2006) pattern exists in the phonological module of the one speaker discussed here, an analysis of the extent to which it holds in other speakers of Munster Irish is reserved for future research.

The structure of this paper is as follows. Section 2 provides background information on the language and its phonotactics. Section 3 details the methods used to conduct the acoustic experiment and §4 presents the results. Section 5 presents a phonological analysis, and §6 concludes.

2. Munster Irish

Irish is a Celtic language of the Goidelic subfamily, and is spoken in the Republic of Ireland and Northern Ireland. Irish is spoken mainly in government-designated and -protected Irish speaking communities called Gaeltachtaí, in the Republic of Ireland. While Irish English is the dominant language spoken in the Republic of Ireland, Irish is an official national language.

The Gaeltachtaí are clustered in three main regions: Ulster in the north, Connaught on the west coast, and Munster in the south. Linguistic research has focused on these larger regions, but MI consists of dialects spoken in the discontiguous communities of the Dingle peninsula on the west coast, West Muskerry in central Munster, and Ring on the east coast. The differences between the dialects spoken in Munster are significant, but beyond the scope of this paper. Here, I will analyze the dialect of a speaker born and raised in Gorta Dubha, which is a village on the Dingle peninsula.

All Irish dialects have contrasts in both consonant palatalization and vowel length. Syllables onsets can contain zero, one, two, or three consonants. Syllable codas can consist of zero, one, or two consonants (e.g. [tʌsʲkʲ] ‘circumstance’). The Irish surface consonant inventory, adapted from Ní Chiosáin (1999), is summarized in (4).

(4) *MI surface consonant inventory (adapted from Ní Chiosáin 1999)*

	Labial	Coronal	Velar	Glottal
Stops	p pʲ b bʲ	t tʲ d dʲ	k kʲ g gʲ	
Fricatives	f fʲ v vʲ	s ʃ	x xʲ ɣ ɣʲ/j	h hʲ
Nasal	m mʲ	n nʲ	ŋ ŋʲ	
Lateral		l lʲ		
Rhotic		ɹ ɹʰ		

The Irish vowel inventory consists of five peripheral vowels with both long and short counterparts and schwa, as in (5), as well as the diphthongs [əi], [əu] (Breatnach 1947), [iə], and [uə] (Ó Sé 2000).

(5) *MI surface vowel intentory*

	Front	Central	Back
High	iː ɪ		uː ʊ
Mid	eː ɛ	ə	ɔ oː
Low			a aː

There are few restrictions between rhyme and coda type, so a long vowel or diphthong can be followed by a coda consonant both word-finally and word-internally, shown in (6). However, Ní Chiosáin (1999) claims that non-homorganic consonant clusters —that do not consist of a sonorant followed by a voiceless stop— are separated by an epenthetic [ə] in a non-palatalized environment or [ɪ] in a platalized environment, as in (7).

(6) Branching rhymes followed by coda consonants

a. [fəib] 'problem' b. [paːɹʰk] 'field'
[ləum.pə] 'lamp' [baːɹ.dəl] 'drake'

(7) Coda clusters separated by epenthetic vowels

a. [bɔɹ.əb] 'abrupt' b. [kɔl.əm] 'dove'
c. [anʲɪvʲiː] ?? (Ní Chiosáin 1999)

2.1 Stress

All MI descriptions (O'Rahilly 1932, Ó Cúiv 1944, Breatnach 1947, Blankenhorn 1981, Ó Siadhail 1989, Ó Sé 1989, Gussman 2002, Hickey 2014) agree that when a word consists of only short vowels the stress is on the first syllable. They also agree that if the second syllable contains a long vowel, it will be stressed. Most descriptions agree that the syllable [ax] can also attract stress, as in [bəˈkax], but not from a long vowel (i.e. [ˈCVː.Cax], *[CVːˈCax]).

For CVCax words, Gussman (2002) claims that [ax] sequences always belong to the same syllable and the sonority of the vowel attracts stress, consistent with de Lacy (2004)'s theory of sonority driven stress (though cf. Shih 2018). O'Rahilly (1932), Blankenhorn (1981), and Gussman (2002) also claim that unstressed syllables are shortened and centralized, or reduced. O'Rahilly (1932) observes, however, that vowel reduction is blocked if the second stressed syllable contains either [iː] or [uː].

There is some disagreement regarding the effect of certain onset consonants on the stress pattern described above. O'Rahilly (1932), Blankenhorn (1981), and Ó Siadhail (1989) claim that the onset consonant in an [ax] syllable affects whether or not that syllable can attract stress: when a second [ax] syllable begins with [l], [n], or [ɹ] the initial vowel is lost making the [ax] syllable initial and stressed. Ó Siadhail (1989) adds that [l], [n], and [ɹ] onsets cause the second syllable to be stressed when all vowels are short and the initial vowel is not low. Hickey (2014) disagrees by claiming that the sonority of the onset determines the stressability of [ax] such that oral and nasal obstruents allow [ax] to be stressed, but [ɹ] and [h] do not. Ó Cúiv (1944) and Ó Siadhail (1989) agree that an [h] onset prevents a second [ax] syllable from attracting stress, and Ó Siadhail (1989) specifies that the [h] onset only prevents [ax] from being stressed in Dunquin, co. Kerry (on the Dingle Peninsula) and it makes the stressing of [ax] optional in the West Muskerry gaeltacht. The ability of onset consonants to affect stress placement does not follow from a number of current metrical theories which claim that stress placement can be determined by syllable weight, which is defined by the rhyme—nucleus and coda (e.g. Hayes 1995, cf. Goedemans 1998, Gordon 2004).

Examples of word shapes and their stress are provided in the appendix.

The goal of this paper is to provide acoustic evidence for the word stress system of MI by analyzing the recording of a native speaker of MI. Measuring various acoustic properties will determine that this speaker utilizes short vowel reduction, and also uses F1 to distinguish stressed from unreduced unstressed vowels. Short vowel reduction indicates that stress is overwhelmingly initial, except in words with the shape /CVCax/, which are realized as [CəˈCax].

3. Methods

The goal of the experiment was to elicit a variety of MI words in specific prosodic and segmental contexts so as to determine the correlates of and segmental influences on word-level stress.

The target words were existing MI words, initially collected from the online pronunciation database at http://www.teanglann.ie (2013). The target words were verified by two consulting native speakers of a Connacht dialect and one native speaker of MI. The shapes of the target words allowed comparison of the acoustic properties of [x], [a], [aː], and other short and long vowels in both initial and peninitial positions. I assumed that comparing properties of these segments in different environments should be sufficient to identify acoustic properties that differed significantly between these three segments, and thus could be ascribed to phonological metrical prominence.

MI stress has been described to fall mainly on the first or second syllable of a word, so the target list was restricted to roots with two syllables. Wug words were used when stimuli shapes were rare in the teanglann (2013) database.

Vowel length and syllable shape were controlled so as to test only the forms that are crucial to the described stress pattern. The default stress pattern should be easily detectable in words with two short vowels, as in (8a). In order to determine the acoustic properties that differentiate stress on long and short vowels in MI, roots with a long vowel in each position of a disyllabic word were also included, as in (8b). Lastly, the properties of the [ax] syllable were tested in each position adjacent to a short and a long vowel, as in (8c). The word shapes in (8) are also marked with the expected position of stress, based on traditional descriptions.

(8) <u>Stimuli shape</u>

(a)	ˈCV.CV	(b)	ˈCV:.CV	(c)	CV.ˈCax
			CV.ˈCV:		ˈCax.CV
			ˈCV:.CV:		ˈCV:.Cax
					Cax.ˈCV:
					ˈCax.Cax

The vowel and consonant qualities in each position were also restricted to include the vowels [i] and [u] (the most common vowels) and crucially [a], which occurs in the [ax] sequence. Some shapes were rare, so a few words with [o] were also included. The complete list of stimuli is provided in Appendix 1. Vowel identity was included as a factor in the statistical analysis since the vowels vary in inherent duration and inherent F0.

While long vowels are reported to attract stress in MI, coda consonants are not claimed to contribute to syllable weight. For this reason and to restrict the number of shapes tested, no syllables with coda consonants were included, except for the [Cax] syllables in (8c). Consonant voicing and manner can affect a preceding vowel's length (van Santen 1992), so medial consonants were limited to the voiceless stops ([p], [t], and [k]) and fricatives ([f], [s], and [x]). Voiceless intervocalic obstruents are both easy to segment and have a smaller effect on preceding vowel duration than do voiced obstruents (van Santen 1992: p.528-9 and others cited therein). Words with medial fricatives were also included in order to increase the number of real-word stimuli.

There were a total of 69 target words. Seven words of each shape were included, except for CV.Cax words – 13 words were included because this shape is crucial to the issue under contention. The target word list was copied three times and randomized (using Microsoft Excel's RAND function) to create three sets of stimuli, each with different orders. The three sets of words were combined into a single list. Filler sentences were inserted after every five stimuli. PsychoPy2 (Pierce 2009, <u>http://www.psychopy.org</u>) was used to generate a presentation of the stimuli such that each item appeared alone on a computer screen.

The subject produced each target word within the two frame sentences in (9). The subject saw the sentences and practiced using them with a few words before the experiment began. Target words were produced phrase-medially in order to avoid phrase-final lengthening effects (van Santen 1992). Two sentences were used to vary any prosodic (intensity) effects of focus on new vs. old information, following Shih (2018).

(9) Frame sentences

(a) Frame 1: Dúirt Bríd an focal ____ sular imigh sí.
[duːɹʰtʲ.bɹiːdʲ.an.fʌ.kl.______ sʌ.lɹ.ɪ.mɪg.ʃiː]
"Bríd said the word____ before leaving."

(b) Frame 2: Abair ____ faoi d'anáil.
[a.bɹʰ. ____.fʷi.da.nalʲ]
"Say ____ under your breath."

The subject (M3) was a 74 year old male native speaker of Irish from the Corca Dhuibhne Gaeltacht on the Dingle Peninsula. M3 spoke only Irish until age 10, at which time he had a cleft palate repaired and learned English during his hospital stay. He had difficulty only in producing voiceless coronal stops, which were often fricated. M3 continues to speak MI on a weekly basis with his sister on the telephone. M3 was recorded in his home and was given the frame sentences to learn. He then began recording with non-target words in order to familiarize himself with the task. He read individual target words written in standard Irish orthography on a computer screen. He then said the word out loud within each of the two frame sentences, and pressed the space bar in order to move on to the next word, continuing at his own pace.

Recordings were made using a head-mounted AKG C420 condenser microphone in order to maintain a constant distance between the mouth and the microphone, with the goal of eliminating amplitude variation due to head movement. The microphone was connected to a Marantz PMD670 solid state recorder, which recorded using 44.1 kHz sample rate and 16 bit quantization rate in mono. The data was saved as a RIFF (.wav) file to ensure that no information was lost due to a lossy compression codec. The participant's recordings were saved in a coded file, which was then segmented manually using Praat (Boersma & Weenink 2013, www.praat.org).

Segmentation was done by hand using primarily the waveform and secondarily F2 to determine where segments began and ended. Vowels were taken to begin at the zero-crossing of the first upswing of the first non-deformed period and ended at the zero-crossing of the last downswing of the last non-deformed period. If the boundary was unclear based on the waveform, vowel boundaries were determined by the presence of a robust F2 in the spectrogram, as long as there was a robust F1 underneath. Fricatives were taken to begin at the zero-crossing of the first downswing of the last non-deformed period of the preceding vowel and ended at the zero-crossing of the first upswing of the first non-deformed period of the following vowel. Fricatives boundaries were confirmed by the onset and offset of noise in the spectrogram.

M3 had a minor speech impediment which made it difficult for him to produce coronal stops, and he has had limited contact with MI in day-to-day life over the past 50 years. While his speech impediment does not likely affect potential correlates of stress, it is possible that the way he speaks is no longer the norm or understood by anyone outside his family. Analyzing data from only one speaker has the possibility of describing an idiolectal difference that is not representative of the stress pattern produced more widely in MI, as it is used daily. However, if the speaker is cognitively intact, his phonological system represents a possible state of the Phonological Module, and so is relevant to evaluating theories of that module’s representational and computational properties. I have reproduced the same experiment in multiple gaeltachtaí of the Munster region of Ireland and in future work I plan to analyze those field recordings for comparison and to determine the stress correlates of MI across speakers and across counties in Munster.

4. Results

This section reports the results of measurements of both vowels and [x] fricatives in M3's target words. A variety of acoustic properties have been associated with the phonetic realization of metrical heads – i.e. word stress. So, for target vowels, the fundamental frequency (F0), quality (F1 and F2), duration, intensity, and spectral balance were calculated. F0 allows comparison of the pitch of the target segments in different environments in order to determine if pitch is correlated with the described stress pattern. F1 and F2 provide information on vowel quality, and determine to what degree vowel reduction is a productive predictor of stress placement. Duration (normalized for speech rate)[1], intensity, and spectral tilt relate to the articulatory effort involved in a segments' production, which provides further evidence of stress placement. Spectral tilt measures the difference between intensity at higher and lower frequencies, which correlates with the amount of vocal effort expended in the production of a vowel (Sluijter & van Hooven 1996). In addition to the stress predictions of traditional descriptions, Shih (2018) predicts that final lengthening and shifts in the degree of focus on a target word will cause durations to vary between syllable positions and intensities to vary between the two frame sentences. For the fricative in [Cax] syllables duration, center of gravity, and intensity were measured. According to Gordon et. al (2002), center of gravity is a reliable means of distinguishing place of articulation amongst most fricatives.

For statistical analysis, Student's t-test was used in Microsoft Excel to determine where there was variation within the M3 data. These tests were used to determine which acoustic properties correlate with word-level stress. If a disyllable has culminative stress on one syllable, the two syllables should differ with statistical significance in at least one of the acoustic properties mentioned above. However, there is a problem with using Student's t-test to do multiple comparisons within the same dataset: it increases the possibility of a Type I error. The analysis presented here assumes a restricted p-value threshold of 0.01 rather than the more generous standard of 0.05 in order to adjust for family-wise error and avoid capitalizing on chance. Consequently, future analysis will include a linear mixed effects model (Baayen et al. 2008). At this point, the results reported here may thus be considered suggestive, but not definitive.

F1 proved to be the most useful measure for indicating whether or not a vowel was reduced to [ə]. The vowels [a] and [ə] significantly differed in height, but their distribution was not indicative of the traditionally described stress pattern. For example, an initial short [a] adjacent to a long vowel did not reduce, but adjacent to an [ax] syllable it did. Crucially, these two measures also indicated that the vowel in an [ax] syllable does not reduce to generate [əx]. In the following sections the mean values of each measure are presented with the standard deviation in parentheses.

Section 4.1 presents the results for words with only short vowels in order to determine the default stress pattern and its acoustic correlates. §4.2 presents the results from words with long vowels in each syllable position and in §4.3 results of words with an [ax] syllable in each position are provided. §4.4 discusses whether these results support or refute the traditional stress description.

[1] Vowel duration was normalized by determining the ratio of the duration of a fixed part of the frame sentence for each token to the mean duration of that part over all tokens, and then calculating target vowel duration using that ratio.

4.1 Short Vowels: CVCV

The traditional stress descriptions state that default stress falls on the initial syllable. Analyzing words with two short vowels in open syllables should provide evidence of the default stress pattern.

Acoustic properties of short vowels will be compared here. Assuming that a stressed vowel should differ significantly in at least some acoustic stress correlate when compared to an unstressed vowel traditional descriptions would predict that in CVCV words the initial vowel should differ acoustically from the final vowel.

In words with the shape CVCV, mean F1 was higher on average in initial syllables (section 4.1.1), while mean spectral tilt (§4.1.2) and duration (§4.1.3) were higher on average in final syllables than initial ones. Intensity rose from initial to final syllables in frame 1, but fell in frame 2 (§4.1.4), and F0 did not vary consistently between syllables (§4.1.5).

4.1.1 Formants

The goal in measuring F1 and F2 is to determine whether vowel height and/or backness are affected by stress, either phonologically or phonetically. Munster Irish is described as having vowel reduction in its unstressed syllables. So, the final syllable in CVCV words – which is reportedly unstressed – should contain a schwa. As schwa is centralized, its mean height and/or backness should differ significantly from other vowels, which are all peripheral.

Focusing on just the vowel [a], initial [a] and final [ə] differed significantly in height (F1), but not backness (F2), as shown in (10). This difference accords with the traditional description that CVCV words should have the form [CVCə], containing a stressed initial full vowel followed by an unstressed and reduced final vowel.

(10) *CVCV Formant Mean Comparisons*

CVCV	**F1**	**F2**
Vowel [a]	624 (115)	1565 (193)
Vowel [ə]	432 (96)	1585 (205)
p-value	$p < 0.01$	$p = 0.7641$

However, M3 produced both CaCə and CəCə words, which could suggest that vowel reduction might not correlate precisely with lack of stress. The two CəCə words were also extremely common words—[ˈpətə] '(cooking) pot' and [ˈkəpə] '(drinking) cup'. It is possible that the schwa in the stressed syllable here is underlying, according with Green (1996:4)'s proposal.

4.1.2 Spectral Tilt

In CVCV words, spectral tilt distinguished vowels by syllable position: (11) shows that initial vowels had a lower average spectral tilt than final vowels ($p < 0.01$) in both frame sentences. A higher spectral tilt indicates a reduced vowel, so the final vowels were more reduced than initial ones.

(11) *CVCV Spectral Tilt Means*

Syllable	**Stress**	**Stimulus**	**Frame 1**	**Frame 2**
1	stressed	ˈCV̲CV	36.6 (3.8)	36.5 (4.4)
2	unstressed	ˈCVCV̲	43 (3.5)	41.8 (3.5)

These distinctions also take into account the CəCə words mentioned above, which suggests that even in those words the final vowel was more reduced than the initial one. Unlike F1, the spectral tilt data does correlate vowel reduction with the described stress pattern based only on CVCV words discussed so far.

4.1.3 Duration

Vowel durations normalized for speech rate differed significantly between syllable positions in CVCV words, but not as predicted by the described stress pattern: the average final vowel was significantly longer than the average initial vowel in frame 1, but the duration difference in frame 2 was on the border of statistical significance, as shown in (12).

(12) *CVCV Vowel Mean Duration (ms)*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**	**Both frames**
Stressed	1	ˈCV.CV	93 (24.3)	115 (29.7)	104 (28.9)
Unstressed	2	ˈCV.CV	119 (38.3)	122 (31.6)	120 (34.4)
p-values			0.0005	0.0166	< 0.01

The extended duration of final vowels could be due to the lengthening effect of being at a final word or phrase boundary (van Santen 1992, Shih 2018) and, crucially, does not correlate with the default initial stress pattern described for all Irish dialects. Windsor et al (2018) also found that vowel duration was not a significant correlate of stress in Munster Irish.

4.1.4 Intensity

Intensity differed significantly between the frame sentences in CVCV words as well as between syllable positions, although not as predicted by the described stress pattern and the differences in first and second syllable intensity were close to the border of statistical significance. As shown in (13), intensity rose from the first to second syllable in CVCV words in frame 1 ($p = 0.004$), but fell from the first to second syllable in frame 2 ($p = 0.004$). As will be shown later, whether the intensity rose or fell in a given utterance was not systematic across the entire data set. Thus both duration and intensity are likely not correlates of Munster Irish stress.

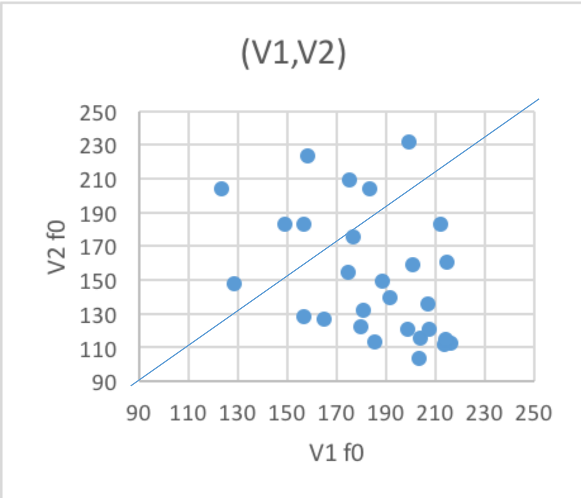
(13) *CVCV Vowel Intensity Means*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**
Stressed	1	ˈCV.CV	72.2 (5.16)	77.8 (4.88)
Unstressed	2	ˈCV.CV	75.4 (3.09)	72.2 (3.67)

4.1.5 F0

In CVCV stimuli, F0 contours did not consistently rise or fall from syllable to syllable. For CVCV syllables, of 28 tokens, 20 had falling contours and 8 had level or rising contours. The difference in rise, level, or fall varied among the tokens. The graph in (14) shows the F0 slopes in CVCV words. In the top left token, for example, F0 started at 123Hz and ended on 204Hz.

(14) *CVCV F0 Contours*



If F0 was consistently level, then all points should be clustered around the diagonal line running from the origin to (250, 250). If F0 was consistently rising, then all points should be above the diagonal line, and vice versa for a consistent fall. It is clear in this graph, however, that there is no systematicity in whether F0 fell or rose over the syllables, and by how much. In other words, it seems that, in CVCV words, an F0 slope's beginning and end point was effectively random given the conditions examined here. Such variation may have been determined by other factors like the intonation of the sentence, or focus.

4.1.6 Summary

The acoustic properties of CVCV syllables are consistent with the description that vowel reduction occurs in the second (unstressed) syllable. The second syllable had a higher F1 relative to [a], and had a higher spectral tilt – both expected if the vowel was [ə]. However, final vowels were longer than initial vowels, intensity varied by frame sentence, and F0 slope did not seem to correlate with any of the measured factors. So, there was no clear connection between syllable position or stress and duration, intensity, and F0.

4.2 Long Vowels: CV:CV, CVCV:, CV:CV:

The traditional stress descriptions state that the leftmost long vowel is stressed: i.e. [ˈCV:.CV], [CV.ˈCV:], [ˈCV:.CV:]. Analyzing words with long vowels should therefore provide evidence of how vowels differ in stressed and unstressed positions.

Acoustic properties of long vowels will be compared here both within stimuli shape, and across stimuli shape. Within stimuli, the leftmost stressed vowel should differ significantly in at least some acoustic stress correlate when compared to the other vowel. Across stimuli, stressed long vowels should share some common acoustic property with each other and with short stressed vowels.

At first glance, long vowels appear to support the traditional description, but some crucial distinctions were not made, such as between stressed and unstressed final F1 and between stressed and unstressed spectral tilt.

4.2.1 F1

In section 4.1.1, F1 was determined to be a significant correlate of Vowel Reduction, so in this section only F1 measures will be compared. As the traditional description predicts, overall F1 of long vowels did significantly differ between syllable position ($p < 0.01$) but not by stress ($p = 0.225$). On average an initial long vowel was lower than a final one; (15) shows that the average F1 value of initial long vowels was higher than final long vowels ($p < 0.01$).

The problem encountered with the interpretation of the F1 results for CVCV syllables was that syllable position and stress status were correlated: the first syllable was always stressed, and the second unstressed. However, this is not the case for long vowels: the stimuli contain initial stressed and unstressed long vowels, and final stressed and unstressed long vowels. As (15) shows, initial long vowels are significantly lower overall than final long vowels. However, vowel height does not correlate with stress: the mean F1 of initial stressed long vowels is significantly different from that of final stressed long vowels ($p < 0.01$), and the mean F1 of final stressed long vowels is not significantly different from that of final unstressed long vowels ($p = 0.225$).

(15) *F1 Means (Hz) of Long Vowels*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**
Stressed	1	CV:CV:	530 (118.9)	487 (99.7)
Stressed	1	CV:CV	529 (133.7)	507 (121.7)
Stressed	2	CVCV:	361 (63.3)	345 (38.8)
Unstressed	2	CV:CV:	366 (77.6)	372 (57.6)

A final vowel that follows either a short [a] or a long vowel is unstressed, and therefore a reduced vowel (i.e. schwa), in traditional descriptions. The t-tests in (16) confirm that [ə] does not significantly differ in height based on the adjacent vowel's length and an unstressed [ə] does significantly differ in height from a stressed [a].

(16) *Unstressed [ə] Comparisons for CV:Cə*

[ə] in…	**F1**	**F2**
CaCə	432 (96)	1585 (205.2)
CV:Cə	466 (78.2)	1330 (148.5)
p-value	0.594	< 0.01
CaCə	624 (114.7)	1565 (193)
CV:Cə	466 (78.2)	1330 (148.5)
p-value	< 0.01	< 0.01

A short [a] vowel preceding a long vowel is described as unstressed in traditional descriptions. However, the table in (17) shows that an unstressed [a] in a CaCV: word is not reduced to [ə] – its

F1 is higher than schwa's. The lack of reduction further suggests that Vowel Reduction is not precisely correlated with a lack of stress, based on the described pattern.

(17) *Unstressed Short Vowel Comparison*

Formants	**F1**	**F2**
[a] in Ca̲CV:	574 (44)	1501 (90)
[ə] in CVCə̲	432 (96)	1585 (205)
p-value	$p < 0.01$	$p = 0.1138994$

Since an unstressed [a] adjacent to a long vowel does not reduce, it is potentially indistinguishable from a stressed [a] and the table in (18) reflects this: there is no significant difference between a stressed and an unstressed [a] vowel.

(18)

[a] in…	**F1**	**F2**
Ca̲Cə	624 (115)	1565 (193)
Ca̲CV:	574 (44)	1501 (90)
p-value	$p = 0.0921$	$p = 0.1986$

So long vowels differ in height depending on whether they are in the first or second syllable. However, when a long vowel is adjacent to a short [a] vowel, which is described as unstressed, the [a] is indistinguishable in quality from a stressed [a] – i.e. initial 'unstressed' [a] does not undergo vowel reduction.

4.2.2 Spectral Tilt

Spectral tilt is a measure of vowel reduction. If vowel reduction correlates with the described stress pattern, spectral tilt should be higher in an unstressed syllable, such as the final syllable of CV:CV: words.

Spectral tilt of long vowels significantly differed between frame sentences for a few word shapes and so comparisons were made within each frame sentence.[2] The only significant difference, however, was found between syllable positions in Frame 2 ($p < 0.01$). The table in (19) shows that on average when uttered within the second frame sentence long vowel spectral tilt was higher in final syllables than initial ones, which includes final long vowels that would be described as both stressed and unstressed. In other words, spectral tilt in frame 2 did not distinguish between stressed and unstressed final long vowels, but did distinguish between initial and final long vowels.

(19) *Long Vowel Spectral Tilt Means*

Syllable	**Stress**	**Word Type**	**Frame 1**	**Frame 2**
1	stressed	ˈCV̲:̲CV:	36.5 (3.7)	38.5 (7)
1	stressed	ˈCV̲:̲CV	37.3 (5.6)	43.9 (5.3)
2	stressed	CVˈCV̲:̲	42.4 (5.0)	45.0 (8.05)
2	unstressed	ˈCV:CV̲:̲	35.1 (11.8)	47.6 (7.5)

[2] Frame 1—stressed vs. unstressed: $p = 0.962$, initial vs. final: $p = 0.346$
Frame 2—stressed vs. unstressed: $p = 0.0139$

Unlike with long vowels, short vowels differed significantly between syllable positions in both frame sentences (p-value < 0.01), but no significant difference was found between syllables described as stressed and unstressed (frame 1: p = 0.15, frame 2: p = 0.198).

Table (20) shows that in both frames, the average spectral tilt was higher in final syllables, which suggests that final short vowels are more reduced than initial short vowels.

(20) *Short Vowel Spectral Tilt Means*

Position	Stress	Word Type	Frame 1	Frame 2
1	stressed	ˈCV̲CV	36.6 (3.8)	36.5 (4.4)
1	unstressed	CV̲ˈCV:	37.1 (3.2)	35.6 (4.3)
2	unstressed	ˈCV:CV̲	40.4 (6.6)	43.9 (5.4)
2	unstressed	ˈCVCV̲	43 (3.5)	41.8 (3.5)

Comparison of spectral tilt in CVCV and CVCV: words is instructive. For CVCV words, the initial syllable's value was 36.6/36.5 and the final syllable's was 43/41.8. For CVCV: words, the initial syllable was 37.1/35.6, and the final syllable was 42.4/45.0. So, the initial syllable in both CVCV and CVCV: words was the same (p = 0.129), and the final syllable in both types was the same (p = 0.384). Thus, spectral tilt does not correlate with stress here – if it did, spectral tilt in CVCV: words should show the opposite pattern to CVCV words.

Crucially, (21)-(22) show that a stressed and unstressed [a] have the same spectral tilt, and that the spectral tilt of an unstressed [a] was significantly lower than that of an unstressed [ə].

(21)

[a] in ...	**Frame 1**	**Frame 2**
Ca̲Cə	36.5 (3.9)	37 (4.5)
Ca̲CV:	37 (3.1)	35.6 (4.3)
p-value	p = 0.7226	p = 0.4680

(22) *Unstressed Short Vowel Spectral Tilt Comparison*

	Frame 1	Frame 2
[a] in Ca̲CV:	37.1 (3.2)	35.5 (4.3)
[ə] in CVCə̲	43.5 (3.8)	41.8 (3.6)
p-value	p = 0.000357	p = 0.00250

So the spectral tilt of long vowels and the short vowels adjacent to them relates to syllable position and not stress. Spectral tilt therefore does not provide evidence for the traditional descriptions.

4.2.3 Duration

The duration of long vowels in CV:CV, CVCV:, and CV:CV: words differed significantly by both syllable position (p < 0.01) and stress (p < 0.01), but not according to the traditional description. Long vowels in a final syllable were significantly longer than long vowels in an initial syllable, and unstressed long vowels were significantly longer than stressed long vowels. As (23) shows, however, while long vowels do differ in duration the difference is due to position not stress: initial long vowels are significantly shorter than final long vowels ($p < 0.01$). Importantly, stressed final long vowels have the same duration as unstressed final long vowels ($p = 0.13$).

(23) *Long Vowel Duration Means (ms)*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**	**Both Frames**
Stressed	1	ˈCV:.CV	163 (35.0)	179 (54.0)	171 (45.5)
Stressed	1	ˈCV:.CV:	153 (33.8)	168 (38/4)	160 (36.6)
Stressed	2	CV.ˈCV:	259 (49.4)	259 (78.9)	259 (65)
Unstressed	2	ˈCV:.CV:	288.5 (78.8)	276 (70.8)	282 (73.3)

The short vowels in the word shapes discussed in this section are described to be unstressed, but their durations were not found to significantly differ as traditional descriptions would predict. In an initial syllable, the short stressed and unstressed vowels in (24) do significantly differ ($p < 0.01$), but no significant difference was found between the final unstressed short vowels ($p = 0.15$). Comparison of amalgamated duration values revealed a significant difference between syllables described as stressed and unstressed ($p < 0.01$), but no significant difference between syllable positions ($p = 0.23$). These results show that unstressed short vowels are significantly longer than stressed short vowels.

(24) *Short Vowel Duration Means (ms)*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**	**Both Frames**
Unstressed	1	CV.ˈCV:	128 (33.4)	161 (84)	130 (60.9)
Unstressed	2	ˈCV:.CV	117 (25.5)	114 (30.8)	116 (27.9)
Unstressed	2	ˈCV.CV	119 (38.3)	122 (31.6)	120 (34.4)
Stressed	1	ˈCV.CV	93 (24.3)	115 (29.7)	104 (28.9)

4.2.4 Intensity

Just as with short vowels in the previous section long vowel intensities significantly differed between frame sentences. Among the long vowel word shapes uttered in Frame 2, intensity differed significantly between syllable positions ($p < 0.01$), but not by stress ($p = 0.937$). On average an initial syllable uttered in frame 2 had a higher intensity than a final syllable in the same environment. No significant difference was found between syllable or stress positions in frame 1 (syllable position: $p = 0.069$, stress position: 0.446).

(25) *Long Vowel Intensity Means*

Stress	Syllable	Word Type	Frame 1	Frame 2
Stressed	1	ˈCV:.CV	75.1 (2.39)	79.14 (1.2)
Stressed	1	ˈCV:.CV:	73.9 (3.35)	78.0 (4.7)
Stressed	2	CV.ˈCV:	77.0 (3.61)	76.0 (2.89)
Unstressed	2	ˈCV:.CV:	74.7 (3.80)	76.3 (2.45)

Short vowels also demonstrated a significant intensity difference only between syllable positions within the second frame sentence ($p < 0.01$). As with long vowels, the average short vowel uttered in frame 2 was significantly more intense in an initial syllable than a final one. No significant difference was found between syllables described as stressed and unstressed in either frame (Frame 1: $p = 0.014$, Frame 2: $p = 0.117$) or between syllable positions in the first frame ($p = 0.064$).

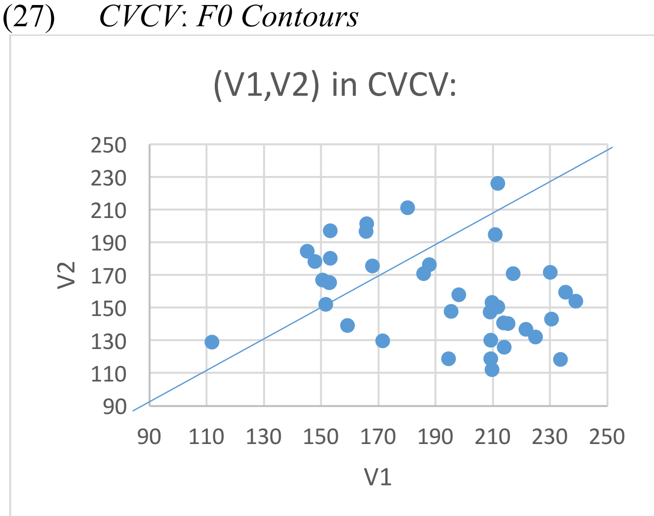
(26) *Short Vowel Intensity Means*

Stress	Syllable	Word Type	Frame 1	Frame 2
Unstressed	1	CV.ˈCV:	73.6 (4.18)	78.05 (2.77)
Stressed	1	ˈCV.CV	72.2 (5.16)	77.8 (4.88)
Unstressed	2	ˈCV:.CV	73.3 (4.37)	72.6 (4.01)
Unstressed	2	ˈCV.CV	75.4 (3.09)	72.2 (3.67)

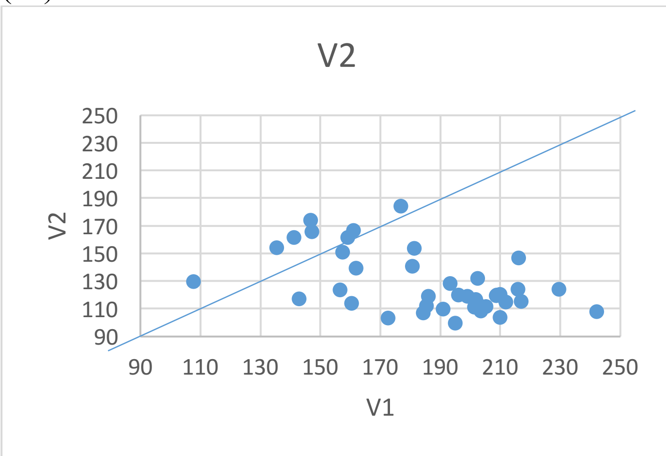
4.2.5 F0

The F0 pattern in CVCV words can also be seen for CVCV: and CV:CV words: there is no consistency as to whether F0 rises, falls, or is level, or where F0 starts and where it ends in a given word. In short, F0 does not correlate with the described stress pattern. The F0 contours for CVCV: and CV:CV words are plotted in (27) and (28), respectively.

(27) *CVCV: F0 Contours*



(28) *CV:CV F0 Contours*



In (28) it appears as though F0 is more consistently falling than rising, but there are still several points above the line and no such pattern is visible in (27).

The two tables in (29) summarize the inconsistency of the F0 ranges for all of the short and long vowels. While the first syllable's F0 range is quite consistent (around 110Hz to 240Hz), the second syllable's F0 minimum is consistent at 100Hz, but the maximum varies in the second syllable from around 210-230Hz for CVCV, CVCV: and CV:CV: to 184Hz for CV:CV.

(29) *F0 contours for short and long vowels*

V1	**min**	**max**	**diff**
CVCV	123	216	93
CVCV:	112	239	127
CV:CV	108	242	134
CV:CV:	109	240	131
V2	**min**	**max**	**diff**
CVCV	104	231	127
CVCV:	112	226	114
CV:CV	99	184	85
CV:CV:	103	213	110

As F0 does not seem to be correlated with stress or syllable position, it will not be discussed as a potential correlate of stress below.

4.2.6 Summary

Words with long vowels provide clear evidence that duration, F1, and spectral tilt are influenced by syllable position. However, there is no clear evidence that stress influences these acoustic properties. Intensity differed by frame sentence, and the determinants of F0 contours are unknown.

4.3 [ax]

The results presented above have failed to identify a clear acoustic correlate of the stress pattern in traditional descriptions. Syllable position clearly influences certain acoustic properties – vowel quality, duration, spectral tilt, and intensity. However, there is no clear evidence that stress influences those properties. The only significant effect relates to the second (i.e. unstressed) syllable in CVCV words, which has the acoustic characteristics of a reduced vowel. However, the first vowel of CVCV: words does not reduce even though it is traditionally reported to be unstressed.

The traditional stress descriptions state that the leftmost [Cax] syllable is stressed unless it is adjacent to a long vowel: i.e. [CV.ˈCax], [ˈCax.CV], [ˈCV:.Cax], [Cax.ˈCV:], [ˈCax.Cax]. Analyzing words with [Cax] should therefore provide evidence of how [Cax] vowels differ in stressed and unstressed positions.

Acoustic properties of [Cax] vowels will be compared here both within stimuli shape, and across stimuli shape. Within stimuli, the leftmost stressed [Cax] vowel should differ significantly in at least some acoustic stress correlate when compared to an unstressed short vowel. Across stimuli, stressed [Cax] vowels should share some common acoustic property with each other and with short and long stressed vowels.

In this section, the vowels in [Cax] syllables will be analyzed and compared to adjacent long and short vowels in order to determine their behavior with respect to the described stress pattern. The crucial stress-attracting [Cax] syllable is found in words with the shape CVCax. According to previous descriptions, words with the shape CaxCV: should contain an unstressed [Cax], so these two word shapes will be compared as examples of a stressed final [a] in a [Cax] syllable and an unstressed initial [Cax] vowel, respectively.

Of all the measures tested here, F1 demonstrated the most significant stress effects, which suggest varying degrees of vowel reduction. According to F1 data, unstressed short vowels are significantly higher in the second syllable of CVCV words and in the initial syllable of CVCax, but not in [Cax] syllables. Comparatively, [Cax] vowels were lower in initial syllables and in the final syllable of CVCax words, but unstressed [Cax] vowels were not as high as unstressed short vowels. In addition, spectral tilt demonstrated that [Cax] vowels are intermediate in degree of reduction between short and long vowels, but showed that they vary only by syllable position.

4.3.1 Formants

Overall and within each frame sentence, the F1 of [ax] vowels significantly differed between both syllable position ($p < 0.01$) and described stress position ($p < 0.01$). On average an initial [ax] vowel was lower than a final one and a stressed [ax] vowel was lower than an unstressed one.

(30) *F1 Means (Hz) of vowels in all word shapes*

Stress	**Syllable**	**Word Type**	**Frame1**	**Frame2**	**Both Frames**
stressed	1	ˈCax.CV	713 (88.6)	685 (46.1)	699 (71.2)
stressed	1	ˈCax.Cax	693 (74.5)	699 (77.8)	696 (75.3)
unstressed	1	Cax.ˈCV:	604 (96.6)	645 (69.9)	624 (85.6)
stressed	2	CV.ˈCax	647 (116.6)	583 (73.9)	614 (102)
unstressed	2	ˈCax.Cax	573 (62.8)	525 (69.2)	548 (69.9)
unstressed	2	ˈCV:.Cax	584 (78.3)	540 (72.8)	562 (78)

A significant difference was found between the F1 of stressed and unstressed initial [Cax] vowels, but only in the first frame sentence (frame 1: $p < 0.01$, frame 2: $p = 0.4$). As the described stress pattern would predict, the average stressed initial [ax] vowel was lower than the average unstressed initial [ax] vowel in the first frame. However, stressed and unstressed final [ax] vowels were on the border of statistical significance in both frames (frame 1: $p = 0.03$, frame 2: $p = 0.04$). Comparisons between word types of amalgamated F1 data in (31) reveal that CaxCV: and CVCax words did not significantly differ in height from each other, but did significantly differ from other word types. So, an unstressed initial and a stressed final [Cax] vowel are the same height, which differs significantly from the heights of both stressed initial and unstressed final [Cax] vowels.

(31) *p-values of [Cax] vowel comparisons from both frames*

	ˈCax.Cax	Cax.ˈCV:	CV.ˈCax	ˈCax.Cax	ˈCV:.Cax
ˈCax.CV	p = 0.8726	p < 0.01	p < 0.01	p < 0.01	p < 0.01
ˈCax.Cax		p = 0.0002	p < 0.01	p < 0.01	p < 0.01
Cax.ˈCV:			p = 0.6066	p < 0.01	p = 0.0014
CV.ˈCax				p = 0.0003	p = 0.0049
ˈCax.Cax					p = 0.959

In other words, all of position, stress, and frame sentence affected vowel height. [a] in final syllables is higher than in initial syllables; for example, initial stressed [Cax] is around 700Hz, while final stressed [Cax] is 647Hz; initial unstressed [Cax] is 604Hz, and final unstressed [Cax] is around 580Hz (frame 1: $p=0.00046$, frame 2: $p<0.01$). However, [a] in stressed syllables is lower than in unstressed syllables; for example, initial stressed [Cax] is around 700Hz, compared to initial unstressed Cax (604Hz), final stressed Cax is around 650Hz (frame 1), while final unstressed Cax is around 580Hz (frame 1: $p<0.01$, frame 2: $p<0.01$). Finally, frame sentence also affected height, but not always in precisely the same way. For example, initial unstressed Cax is around 600Hz in Frame 1, but near 650Hz in Frame 2, and final stressed Cax is 647Hz in Frame 1, but 583Hz in Frame 2.

Schwa distribution has been shown not to necessarily correlate with the described stress pattern because M3 produced both stressed [ə]s in CəCə words and unstressed full [a]s in CaCV: words, but CVCax words contained initial [ə] and a final [a], as traditional descriptions predict. (32) shows that the average short initial vowel in CVCax words is clearly raised such that its F1 is significantly different from a stressed [a], but not an unstressed [ə] and (33) shows that the average second vowel in the CVCax words significantly differed in height from unstressed [ə] and not stressed [a]. So the vowels in CVCax words parallel the height of an unstressed [ə] followed by stressed [a].

(32) *Formant Means (Hz) of initial vowel in CVCax*

	F1	**F2**
CVCax	443 (115)	1521 (200)
CaCə	624 (115)	1565 (193)
p-value	< 0.01	0.395
	F1	**F2**
CVCax	443 (115)	1521 (200)
CaCə	432 (96)	1585 (205)
p-value	0.715	0.222

(33) *Formant Means (Hz) of final vowel in CVCax*

	F1	F2
CVCax	614 (102)	1491 (207)
CaCə	624 (115)	1565 (193)
p-value	0.723	0.170
	F1	**F2**
CVCax	614 (102)	1491 (207)
CaCə	432 (96)	1585 (205)
p-value	< 0.01	0.0842

On the other hand, (34) shows that the vowel in what would be described as an unstressed [Cax] syllable, such as in CaxCV: words, had an F1 that significantly differed from an unstressed [ə], but not a stressed [a]. So unstressed [Cax] is also not reduced, which again refutes the possibility of Vowel Reduction being correlated with the described stress pattern.

(34) *Formant Means (Hz) of initial vowel in CaxCV*:

	F1	F2
CaxCV:	624 (85.6)	1529 (153.4)
CaCə	624 (114.7)	1565 (193)
p-value	0.98857	0.4565
	F1	**F2**
CaxCV:	624 (85.6)	1529 (153.4)
CaCə	432 (93)	1585 (205)
p-value	< 0.01	0.2619

Further evidence that the initial vowel in CaxCV: did not reduce was found in comparisons with other word shapes. F1 of the [Cax] vowel in CaxCV:, in the second frame only, was on the border of significantly different from the initial vowel in CaxCV (p = 0.038) and CaxCax (p = 0.028), which did not significantly differ from each other (p = 0.474), in addition to the final vowel's F1 in CVCax (p = 0.037). So the [a] in CaxCV: did not reduce, but [a] was generally affected by stress: [a] was lower when stressed. In the first frame, however, the [a] in CaxCV: did not significantly differ from the second [a] in CaxCax words (p = 0.253), which would be described as unstressed.

So far, (32)-(34) have shown that the [ax] vowel in positions described as both stressed and unstressed did not have F1 quite as high as an unstressed [ə]'s F1. One further set of comparisons with CaxCax words would provide concrete evidence of whether or not [ax] vowels reduced to [ə].

(35) *Formant Means (Hz) of initial vowel in CaxCax*

	F1	F2
CaxCax	696 (75.3)	1560 (188)
CaCə	624 (114.7)	1565 (193)
p-value	0.0052	0.9293
	F1	**F2**
CaxCax	696 (75.3)	1560 (188)

CaCə	432 (93)	1585 (205)
p-value	< 0.01	0.6498

(36) *Formant Means (Hz) of final vowel in CaxCax*

	F1	F2
CaxCax	548 (69.9)	1372 (213.3)
CaCə	624 (114.7)	1565 (193)
p-value	0.0029	0.00166
	F1	**F2**
CaxCax	548 (69.9)	1372 (213.3)
CaCə	432 (93)	1585 (205)
p-value	< 0.01	0.0007

(35) and (36) confuse any clear notions of whether all [ax] vowels were always either reduced or not. In (35) the average initial vowel of CaxCax words significantly differed from both a stressed [a] and an unstressed [ə] and in (36) the average final vowel of CaxCax words also significantly differed from both stressed [a] and unstressed [ə]. When compared to an unstressed [a], as in CaxCV:, however, the results vary by frame sentence such that in frame 1 the final vowel of CaxCax words was the same as unstressed [Cax], but in frame 2 the initial vowel of CaxCax words was the same as the unstressed [Cax] vowel, as shown in (37).

(37) *p-values for F1 comparison of CaxCax with unstressed [ax]*

Syllable	Frame 1	Frame 2
1 CaxCax	0.003	0.0267
2 CaxCax	0.265	< 0.01

Putting all of the results above together, it seems that unstressed short vowels reduce in two situations: in the second syllable of CVCV, and in the initial syllable of CVCax. The [a] in Cax syllables does not reduce in any unstressed position: neither in CaxˈCV:, nor in ˈCaxCax. However, stressed Cax is lower than unstressed Cax.

4.3.2 Spectral Tilt

Unlike F1, spectral tilt measures for [ax] vowels significantly varied ($p = 0.003$) only by syllable position in the first frame sentence, as shown in (38). Spectral tilt for [Cax] vowels clearly did not vary according to described stress position ($p = 0.586$). In the second frame sentence, however, p-values for both syllable and stress position comparisons were very close to the border between a significant difference and similarity, 0.018 and 0.02 respectively. Comparisons between frame sentences of syllable and stress positions also resulted in borderline differences, shown in the last column of (39).

(38) *Spectral Tilt Means of [ax] vowels*

Stress	Syllable	Word Type	Frame 1	Frame 2
stressed	1	ˈCax.CV	35.6 (5.0)	37.9 (3.2)
stressed	1	ˈCax.Cax	33.3 (5.1)	35.3 (6.2)

unstressed	1	Cax.ˈCV:	34.8 (3.8)	37.6 (3.0)
stressed	2	CV.ˈCax	38.4 (3.02)	38.8 (1.94)
unstressed	2	ˈCax.Cax	37.4 (2.3)	46.0 (4.3)
unstressed	2	ˈCV:.Cax	39.5 (1.97)	40.7 (1.8)

(39) *Means & p-values from [ax] syllable spectral tilt comparisons*

	Frame 1	**Frame 2**	**Frames 1 vs. 2**
Initial	35 (4.6)	37 (4.4)	p = 0.01995
Final	37 (2.9)	40 (4.7)	p = 0.02725
p-value	0.00266	0.01836	
Stressed	36 (4.5)	37 (4.5)	p = 0.15579
Unstressed	36 (3.6)	40 (4.6)	p = 0.0031
p-value	0.5860	0.0200	

If spectral tilt only differed between syllable positions, then within one position [Cax] vowels should not differ by described stress position. In accordance with this prediction, no significant difference was found between stressed and unstressed initial [Cax] vowels in either frame (frame 1: p = 0.6, frame 2: p = 0.8) or between stressed and unstressed final [Cax] vowels in either frame (frame 1: p = 0.2, frame 2: p = 0.2).

As mentioned above, spectral tilt correlated with Vowel Reduction and so the following comparisons determine that a [Cax] vowel is intermediate in its degree of reduction (i.e. F1 lowering). In other words, the vowel in [Cax] was not as high as an unstressed [ə] and it was not quite as low as a stressed long [aː]. Unlike F1, spectral tilt values shown in (40)-(41) indicate that both the initial and final vowels in CVCax words significantly differed from an unstressed [ə], but only in frame 1. Comparisons of the vowels in CaxCax words with stressed [a] and unstressed [ə] further demonstrated differences between the frame sentences in whether or not [Cax] vowels reduced.

(40) *Spectral Tilt Means & p-values of initial vowel in CVCax*

	Frame 1	**Frame 2**
CVCax	39 (2.8)	39 (3.3)
CaCə	37 (3.8)	37 (4.5)
p-value	0.0424	0.2817
	Frame 1	**Frame 2**
CVCax	39 (2.8)	39 (3.3)
CaCə	44 (3.8)	42 (3.6)
p-value	0.0033	0.0418

(41) *Spectral Tilt Means & p-values of final vowel in CVCax*

	Frame 1	**Frame 2**
CVCax	37 (3.2)	38 (3.4)
CaCə	42 (3.8)	37 (4.5)
p-value	0.0132	0.6893

	Frame 1	Frame 2
CVCax	37 (3.2)	38 (3.4)
CaCə	44 (3.8)	42 (3.6)
p-value	0.0001	0.0105

The spectral tilt values in (42) indicate that the average [Cax] vowel described as unstressed significantly differed from an unstressed [ə] in both frames and not from a stressed [a] in either frame, so it was clearly not reduced.

(42) *Spectral Tilt Means & p-values of initial vowel in CaxCV*:

	Frame 1	Frame 2
CaxCV:	35 (3.8)	38 (3)
CaCə	37 (3.8)	37 (4.5)
p-value	0.2932	0.7385

	Frame 1	Frame 2
CaxCV:	35 (3.8)	38 (3)
CaCə	44 (3.8)	42 (3.6)
p-value	< 0.01	0.0060

In (43) the spectral tilt of the average initial [Cax] vowel in a CaxCax word differed significantly only from an unstressed [ə] and only in the first frame. In (44) the average final [Cax] vowel in a CaxCax word differed significantly from an unstressed [ə] in frame 1, but a stressed [a] in frame 2.

(43) *Spectral Tilt Means & p-values of initial vowel in CaxCax*

	Frame 1	Frame 2
CaxCax	33 (5.1)	35 (6.2)
CaCə	37 (3.8)	37 (4.5)
p-value	0.1332	0.5022

	Frame 1	Frame 2
CaxCax	33 (5.1)	35 (6.2)
CaCə	44 (3.8)	42 (3.6)
p-value	0.0001	0.0147

(44) *Spectral Tilt Means & p-values of final vowel in CaxCax*

	Frame 1	Frame 2
CaxCax	38 (2.3)	46 (4.3)
CaCə	37 (3.8)	37 (4.5)
p-value	0.5633	0.0043

	Frame 1	Frame 2
CaxCax	38 (2.3)	46 (4.3)
CaCə	44 (3.8)	42 (3.6)
p-value	0.0012	0.0805

In summary, spectral tilt showed that [Cax] vowels vary by syllable position, rather than stress, and are intermediate in degree of reduction between short and long vowels. In other words, the vowel in [Cax] was not as high as an unstressed [ə] and it was not quite as low as a stressed long [aː], and its height varied depending on the syllable it occured in.

4.3.3 Duration

Unlike with long and short vowels, the normalized durations of [Cax] vowels differed by described stress position ($p < 0.01$) and not syllable position ($p = 0.03$) such that on average a stressed [Cax] vowel was longer than an unstressed [Cax] vowel, shown in (45).

(45) *Mean Durations (ms) of [ax] vowels*

Stress	Syllable	Word Type	Frame 1	Frame 2	Both Frames
Stressed	1	'Cax.CV	87 (25.6)	108 (30.9)	97 (30.1)
Stressed	1	'Cax.Cax	85.4 (22.0)	120 (28.4)	103 (30.7)
Unstressed	1	Cax.'CV:	89 (23.3)	119 (25.2)	104 (28.3)
Stressed	2	CV.'Cax	94 (41.7)	119 (58.7)	107 (52.2)
Unstressed	2	'CV:.Cax	55 (21)	74 (30)	65 (27)
Unstressed	2	'Cax.Cax	63 (27.8)	85 (23.7)	74 (27.8)

No significant difference was found between stressed and unstressed initial [Cax] vowels in either frame (frame 1: $p = 0.6$, frame 2: 0.9). In frame 1 the average unstressed initial [Cax] vowel was longer than a stressed one and in frame 2 the reverse was true. On the other hand, significant differences between stressed and unstressed final [Cax] vowels were found in both frames ($p < 0.01$). As the described stress pattern would predict, the average stressed final [Cax] vowel was significantly longer than an unstressed one.

So, for [Cax], final unstressed vowels were significantly shorter than initial stressed, initial unstressed, and final stressed vowels. However, initial stressed vowels were not different in duration from initial unstressed vowels. Therefore, there is a conditional effect of stress: stress affects vowel duration of [a] in final position.

4.3.4 Intensity

The intensity of [Cax] vowels differed by described stress position ($p = 0.001$) and not syllable position ($p = 0.2$) in frame 1 and both syllable ($p < 0.01$) and described stress position ($p < 0.01$) in frame 2. The means are shown in (46).

(46) *Mean Intensities of [ax] vowels*

Stress	Syllable	Word Type	Frame 1	Frame 2
Stressed	1	'Cax.Cax	72.6 (2.59)	76.4 (1.98)
Stressed	1	'Cax.CV	72.5 (2.58)	76.6 (2.8)
Unstressed	1	Cax.'CV:	71.8 (2.19)	76.5 (2.43)
Stressed	2	CV.'Cax	75.45 (3.65)	73.3 (3.24)
Unstressed	2	'Cax.Cax	70.8 (5.44)	69.5 (4.09)
Unstressed	2	'CV:.Cax	72.2 (3.66)	70 (3.3)

No significant difference was found between stressed and unstressed initial [Cax] vowel intensities in either frame (frame 1: p = 0.38, frame 2: p = 0.9), but a significant difference was found between stressed and unstressed final [Cax] vowel intensities in both frames (frame 1: p = 0.0015, frame 2: p = 0.0004). So, a stressed final [Cax] vowel is significantly more intense than an unstressed final [Cax] vowel, but initial [Cax] vowel intensities do not vary. In short, there is another condition on the effect of stress: stress affects [Cax] vowel inensity in final position.

4.3.5 Summary

F1 and spectral tilt showed the most complex results for [Cax] syllables while duration and intensity demonstrated stress effects on [Cax] syllables only in final position. All of position, stress, and frame sentence affected vowel height: [a] in initial syllables is lower than in final syllables, [a] in stressed syllables is lower than in unstressed syllables, and initial unstressed [a] was lower in frame 2, but final stressed [a] was lower in frame 1. The [a] in [Cax] syllables does not reduce in any unstressed position, but stressed [Cax] is lower than unstressed [Cax]. Thus according to F1 data, unstressed short vowels reduce only in two situations: in the second syllable of CVCV and in the initial syllable of CVCax. Spectral tilt further demonstrated that [Cax] vowels are intermediate in degree of reduction between short and long vowels, but showed that they vary only by syllable position.

4.4 [Cax] Fricatives

Traditional descriptions of MI stress (O'Rahilly 1932, Ó Cuív 1944, Breatnach 1947, Blankenhorn 1981, Ó Sé 1989, Ó Siadhail 1989, Gussman 2002, Hickey 2014) all claim that coda consonants do not contribute to the attraction of stress to a syllable. Bennett (2015) thus analyzed the fricative in an [ax] syllable as having properties more like a glide so that it would be syllabified within the nucleus rather than as a coda and so it would contribute to a syllable's stress attraction.

Acoustic properties of [Cax] fricatives will be compared here both within stimuli shape, and across stimuli shape. Assuming that [Cax] fricatives vary with respect to stress, stressed ones should share some common acoustic property with each other, which differs from that of unstressed ones. Traditional descriptions would thus predict that a [Cax] fricative adjacent to a CV syllable should differ from a [Cax] fricative adjacent to a CV: syllable and the initial [Cax] fricative should differ from the final [Cax] fricative in CaxCax words.

In this section I analyze three properties of [ax] fricatives in order to determine that they do not differ in place of articulation (center of gravity), intensity, or duration based on whether or not they occur in a stressed syllable. The place of articulation of [ax] fricatives did not vary by either stress or syllable position, but the fricatives differed in duration and intensity based solely on the syllable in which they occur. [Cax] fricatives were found to be more intense in initial syllables and longer in final syllables.

4.4.1 Center of Gravity

The center of gravity (cog) of a fricative is similar to vowel formant measures in that it correlates with place of articulation. A higher cog value indicates that a fricative was produced further forward in the oral tract, while a lower cog means the fricative was produced further back. However, cog can also be lowered by the presence of voicing in a fricative.

Overall and within each frame sentence, the cog of the fricatives in [Cax] syllables was found not to significantly vary between described stress position (p = 0.984) or syllable position (p = 0.621). CVCax was the only word shape for which the cog was found to significantly differ between frame sentences (p = 0.006); the average cog of the [Cax] fricative in CVCax words was higher in frame 2 than frame 1, which suggests it was produced further back in the oral cavity in frame 1 than in frame 2.

(47) *Center of Gravity means for [Cax] fricatives*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**
Stressed	1	ˈCax.Cax	2211 (790.4)	2066 (692)
Stressed	1	ˈCax.CV	1958 (462.6)	1792 (378.8)
Unstressed	1	Cax.ˈCV:	1799 (525.3)	1638 (251.2)
Stressed	2	CV.ˈCax	1682 (477.4)	2028 (645.4)
Unstressed	2	ˈCax.Cax	2491 (571.9)	2554 (779.9)
Unstressed	2	ˈCV:.Cax	1525 (299)	1705 (545)

4.4.2 Intensity

In both frame sentences the intensity of [Cax] fricatives varied by syllable position, but not by described stress position, as shown in (48) and (49). In both frames, the average intensity was higher in an initial [Cax] syllable than a final one.

(48) *Intensity (Hz) means of [Cax] fricatives*

Stress	**Syllable**	**Word Type**	**Frame 1**	**Frame 2**
Stressed	1	ˈCax.Cax	59.4 (4.32)	57.1 (3.7)
Stressed	1	ˈCax.CV	58.9 (2.57)	58.3 (2.02)
Unstressed	1	Cax.ˈCV:	59.5 (2.93)	58 (3.02)
Stressed	2	CV.ˈCax	54.1 (3.2)	52.4 (3.57)
Unstressed	2	ˈCax.Cax	52.2 (2.44)	50.7 (1.8)
Unstressed	2	ˈCV:.Cax	55.5 (2.64)	53.2 (2.76)

(49) *Means & p-values for intensity (Hz) of [Cax] fricatives*

	Frame 1	**Frame 2**
Initial	59.3 (3.31)	57.8 (2.99)
Final	54 (3.1)	52.2 (3.16)
p-value	**< 0.01**	**< 0.01**
Stressed	56.6 (4.21)	55.1 (4.22)
Unstressed	55.7 (4.02)	54.2 (3.98)
p-value	**0.2029**	**0.2031**

4.4.3 Duration

The duration of [Cax] fricatives significantly varied depending on the frame sentence in which they were uttered, such that the average duration was longer in the first frame sentence than the second. In both frames the duration of [Cax] fricatives varied significantly by syllable position and not described stress position, as shown in (50)-(51) below. On average a final [Cax] fricative was significantly longer than an initial one.

(50) *Duration (ms) means of [Cax] fricatives*

Stress	Syllable	Word Type	Frame 1	Frame 2
Stressed	1	ˈCax.Cax	99 (37.2)	84 (51.7)
Stressed	1	ˈCax.CV	103 (24.9)	82 (21.6)
Unstressed	1	Cax.ˈCV:	86 (23.7)	67 (19.1)
Stressed	2	CV.ˈCax	221 (45.8)	151 (42.4)
Unstressed	2	ˈCax.Cax	215 (65.7)	121 (26.9)
Unstressed	2	ˈCV:.Cax	216 (36.5)	144 (48.5)

(51) *Means & p-values for duration (ms) of [Cax] fricatives*

	Frame 1	**Frame 2**
Initial	96 (29.7)	78 (34.4)
Final	218 (49.1)	143 (42.6)
p-value	**< 0.01**	**< 0.01**
Stressed	161 (72.1)	117 (53.1)
Unstressed	172 (76.1)	110 (47.5)
p-value	**0.3757**	**0.4195**

Crucially, no significant difference was found between stressed and unstressed [Cax] fricatives in an initial or a final syllable, p-values are shown in (52).

(52) *P-values for duration (ms) of un/stressed [Cax] fricatives*

	Frame 1	**Frame 2**
Initial	0.0296	0.0227
Final	0.6318	0.5587

4.4.4 Summary

In summary, the [x] fricatives in [Cax] syllables were not found to vary in place of articulation. Their intensity and duration varied, but with regard to syllable position, not stress: [x] in initial [Cax] syllables was shorter and more intense than in final position. Consequently, [x] did not vary with respect to stress.

5. Discussion and Phonological Analysis

In this section I will argue for an alternative analysis of MI stress based on the data presented in section 4. I claim the following four key properties of MI stress:

(53) *Key properties of MI stress based on M3's results*
- (a) Stress falls on the initial syllable by default ([ˈCV.CV], [ˈCV. CV:], [ˈCV:.CV:])
- (b) Unstressed short vowels in open syllables reduce (/CVCV/ → [ˈCV.Cə])
- (c) [ax] attracts stress away from short vowels (/CVCax/ → [Cə.ˈCax])
- (d) /a/ never reduces before [x] (/CaxCax/→[CaxCax], *[CaxCəx])

I argue here that the results support some, but not all of the claims of traditional descriptions, which have generally agreed on four key properties of the MI stress system in (54). Crucially, I argue that the results support claims (a), (c), and (d), but not (b), in (54) and I add claim (d) in (53). A full account of the stress pattern indicated by the results for each stimuli shape is presented in table (55) below.

(54) *Traditional key properties of MI stress*
- (a) Stress falls on the initial syllable by default ([ˈCV.CV], [ˈCV:.CV:])
- (b) Long vowels attract stress away from short vowels ([CV.ˈCV:])
- (c) Unstressed short vowels reduce (/CVCV/ → [ˈCV.Cə])
- (d) [ax] attracts stress away from short vowels (/CVCax/ → [Cə.ˈCax])

The results presented in section 4 suggest that vowel reduction is related to a lack of stress in short vowels. In [CVCV] words, the final vowel reduces to schwa while the initial vowel does not (§4.1.1). If vowel reduction correlates with stress (i.e. foot heads), then in such words the final vowel must be unstressed while the initial vowel is stressed. However, in [CVCV:] words, the initial vowel did *not* reduce (§4.2.1): the F1 of [a] in [CaCə] and in [CaCV:] was not significantly different. If unstressed short vowels reduce, then the [a] in [Ca:CV] cannot lack stress. I conclude, therefore, that stress in [CVCV:] words is on the initial syllable.

In fact, using vowel reduction to determine metrical stress leads to the conclusion that stress almost always falls on the initial syllable. For almost all word shapes, the measured acoustic properties distinguished initial from final syllables, but not traditionally stressed from unstressed syllables. I conclude that MI – or at least M3's MI – has a quantity-insensitive metrical system.

The sole exception is in words with the shape [CVCax], where the initial vowel is reduced (§4.3.1) (recall that the F1 of the first vowel in CVCax words did not differ from the F1 of reduced vowels in CaCə words ($p = 0.715$). The presence of reduction indicates that stress falls on the second syllable; this finding accords with the traditional description. Further evidence that the second syllable in [CVCax] is stressed is found in duration (§4.3.3): the final [a] is significantly longer in CVCax than in CaxCax and CV:Cax words – in these latter forms, the second syllable is reported to be unstressed. In addition, the F1 of [a] in CVCax is significantly lower than the [a]'s in CaxCax and CV:Cax.

In summary, in CVCV: words, if stress fell on the long vowel in the second syllable (as described), the short vowel in the first syllable should reduce but it does not; so, the first syllable must be stressed. In CVCax words, the short vowel in the first syllable reduces so stress must fall on the second syllable. In short, the initial syllable is always stressed, except in CVCax words. An important additional observation is that /a/ never reduces before [x]. While there is a distinction in height between stressed and unstressed [a] before [x], the [a] is not the same as a [ə] (§4.3.1). The proposal that stress is overwhelmingly initial in M3's MI is consistent with the results. There is no phonetic evidence against initial stress in all word shapes, except CVCax, since F1 does not make any distinction between stressed and unstressed vowels that do not reduce—i.e. in CV: and [Cax] syllables.

Table (55) presents a proposal about the phonological output realization of each word shape, including stress placement according to the pattern demonstrated by F1 and duration in the rightmost column. In the Phonological Output, brackets mark foot boundaries, and ˈ marks the metrical head.

(55) *Surface realizations of all 9 target word shapes*

Stimuli	**Phonetic Form**	**Phonological Output**
CVCV	CVCə	(ˈCa.Cə)
CaCV:	CVCV:	(ˈCV)CV:
CV: CV	CV:Cə	(ˈCV:)Cə
CV: CV:	CV:CV:	(ˈCV:)CV:
CaxCV	CaxCə	(ˈCax.Cə)
CVCax	CəCax	(Cə.ˈCax)
CaxCax	CaxCax	(ˈCax.Cax)
CaxCV:	CaxCV:	(ˈCax)CV:
CV: Cax	CV: Cax	(ˈCV:) Cax

The reader will have noticed that in all words feet appear at the left edge. In some words, this strict left-edge orientation creates a metrical problem. In [CVCV:] words, for example, the foot could encompass the initial and second syllables: e.g. [(ˈCV.CV:)]. However, such a foot is trimoraic, and exceeds the common trochaic binary maximum (Élias-Ulloa 2005). I argue for analytical reasons below that such trimoraic feet are banned in MI, so the monomoraic foot of [(ˈCV)CV:] is preferred.

5.1 Allophony-Driven Stress

The key question is why stress avoids the initial syllable in CVCax words. A successful explanation must also explain why stress falls on the initial syllable in CV:Cax words.

I claim that this system can be explained if MI presents a case of 'allophony-driven stress' (cf. de Lacy 2006). In essence, stress falls on the second syllable in CVCax because doing so avoids a conflict: i.e. the need to reduce a short unstressed vowel vs. the ban on reducing /a/ before [x]. For example, for /bakax/, the losing candidate *[(ˈba.kax)] has stress on the initial syllable, but by doing so fails to reduce the /a/ in the second syllable (recall that /a/ cannot reduce before [x]). By shifting the stress to the second syllable, as in [(bə.ˈkax)], all unstressed vowels can successfully be reduced.

5.2 Default foot shape

The default foot shape in MI is a left-aligned moraic trochee: i.e. (CVCV) or (CV:). The constraints below are responsible for this shape:

(56) *Foot constraints*

(a) ALLFTL(=ALIGN-L(PrWd, Ft)) "The left edge of every PrWd is aligned with the left edge of some foot" (McCarthy & Prince 1995)

(b) TROCHEE "Assign a violation for each foot whose head is not leftmost" (Prince & Smolensky 2002)

(c) FTMIN "Assign a violation for every foot that has fewer than two moras" (Élias-Ulloa 2005)

(d) FTMAX "Assign a violation for every foot that has more than two moras." (Élias-Ulloa 2005)

The following tableau shows the constraints' usefulness in generating the correct output of words with short vowels.

(57) *CVCV… words*

/faɹagʲa/	ALLFTL	FTMAX	TROCHEE	FTMIN
☞ (a) (ˈfa.ɹə)gʲə				
(b) fə(ˈɹagʲə)	*!			
(c) (ˈfa.ɹə.gʲə)		*!		
(d) (fə.ˈɹa)gʲə			*!	
(e) (ˈfa)ɹa.gʲə				*!

5.3 Primacy of left-edge alignment

The output of /CVCVː/ words shows that ALLFTL and FTMAX must outrank FTMIN. In the following tableau, the winner [(ˈga)diː] has a degenerate foot because the alternative – *[ga(ˈdiː)] has a foot that is not leftmost. The loser *[(ˈga.diː)], on the other hand, fatally violates FTMAX because it has a trimoraic foot. The fact that the long vowel does not shorten indicates that vowel length is preserved with the constraint IDENT-LENGTH, as shown by candidate (d).

(58) *CVCVː words*

/gadiː/	ALLFTL	FTMAX	IDENT-LENGTH	TROCHEE	FTMIN
☞ (a) (ˈga)diː					*
(b) gə(ˈdiː)	*!				
(c) (ˈga.diː)		*!			
(d) (gə.ˈdiː)		*!		*	
(e) (ˈga.də)			*!		

5.4 Reduction

Another important aspect of MI's stress system is its vowel reduction. The constraint REDUCE is used here to ban short unstressed full (non-schwa) vowels. This constraint is similar to those found in Crosswhite (1999) and de Lacy (2006). It outranks all faithfulness constraints that would preserve features ('IDENT-F'). The other rankings given in the tableau are justified below.

(59)

/bata/	ALLFTL	FTMAX	IDENT-LENGTH	REDUCE	TROCHEE	FTMIN	IDENT-F
☞ (a) (ˈba.tə)							*
(b) (ˈba.ta)				*!			
(c) (ˈbə.tə)							**!

Importantly, reduction of /a/ is blocked when it precedes [x]. For example, /lʲaxtax/ *leachtach* 'strewn with grave-mounds' surfaces as [ˈlaxtax], not *[ˈlax.təx]. Vowel reduction is clearly blocked in this situation, and the blocking constraint will be called $*V^{-LOW}X$ here – a constraint that is violated by a sequence of a low vowel followed by an [x].

(60) *CaxCax words*

/lʲaxtax/	*V^{-LOW}X	ALLFTL	FTMAX	IDENT-LENGTH	REDUCE	TROCHEE	FTMIN	IDENT-F
☞ (a) (ˈlʲax.tax)					*			
(b) (ˈlʲax.tax)	*!							*

While I will not address the exact formulation of *V^{-LOW}X here, I will make a few remarks. The following [x] does not necessarily appear in the same syllable as the [a]: e.g. [bə.ˈka.xə] 'lame (pl.)' (Green 1996:4). It is possible that there is some featural incompatibility between [a] and [x]. However, the vowel [a] is [+low] while [x] is [–low] (Chomsky & Halle 1968:305), so it is unlikely that an OCP-like constraint is responsible here. It is possible that the lowering effect of [x] is similar to guttural lowering (e.g. Aymara – Hardman et al. 1988, Semitic – McCarthy 1994). In this case, [a] and [x] would share the feature [pharyngeal] (McCarthy 1994), and *V^{-LOW}X would be a constraint that promotes sharing of [pharyngeal] features.

5.5 Allophony-driven stress

The ranking presented above has an important feature: *V^{-LOW}X and REDUCE both outrank TROCHEE. The effect of this ranking is to produce allophony-driven stress in just one case: CVCax words. The following tableau shows how such inputs emerge.

(61) *CVCax words: Allophony-driven stress*

/bakax/	*V^{-LOW}X	ALLFTL	FTMAX	IDENT-LENGTH	REDUCE	TROCHEE	FTMIN	IDENT-F
☞ (a) (bə.ˈkax)						*		*
(b) (ˈba.kəx)	*!							*
(c) (ˈba.kax)					*!			

Candidate (a) wins because it only violates the low-ranked TROCHEE. The competitor *[(ˈ ba.kəx)] loses because it reduces /a/ before [x], violating *V^{-LOW}X. The competitor *[(ˈ ba.kax)] loses because the /a/ in [kax] is unstressed, and so violates REDUCE. In other words, *[(bə.ˈ kax)] wins because it avoids violating both *V^{-LOW}X and REDUCE; it manages to do so by shifting the stress to the second syllable. So, stress falls on the second syllable in CVCax words because otherwise [ax] would appear in a reduction context.

The ranking above *only* applies to CVCax words, and not other words in which [ax] is peninitial. For example, in CV: Cax words, stress falls on the initial syllable because no other candidate can have a left-aligned foot that preserves underlying length:

(62) *CV:Cax words*

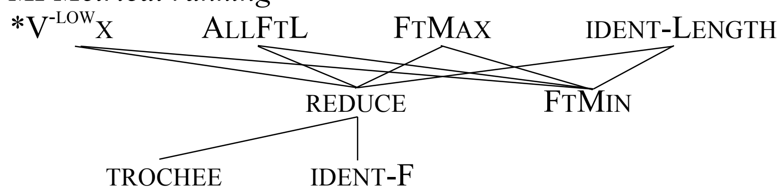
/tuːtax/	$*V^{-LOW}X$	ALLFTL	FTMAX	IDENT-LENGTH	REDUCE	TROCHEE	FTMIN	IDENT-F
☞ (a) (ˈtuː)tax					*			
(b) (ˈtuː)təx	*!							*
(c) (tuː.ˈtax)			*!					
(d) (tə.ˈtax)				*!		*		*
(e) tuː(ˈtax)		*!						

In the tableau above, stress falls on the initial syllable because falling on the peninitial syllable would result in an ill-formed foot: either not leftmost (candidate e), or too large (candidate c).

5.6 Ranking Summary

In summary, MI metrical structure involves an initial trochaic foot except in one case: CVCax words have an initial iambic foot. This iambicity is driven by the need to avoid having an [ax] in a reduction context. The final ranking is provided below:

(63) *MI Metrical ranking*



- Tableau (58) shows that ALLFTL, FTMAX, and IDENT-LENGTH outrank FTMIN.
- Tableau (60) shows that $*V^{-LOW}X$, ALLFTL, FTMAX, and IDENT-LENGTH outrank REDUCE.
- Tableau (62) shows that REDUCE outranks both TROCHEE and IDENT-F

5.7 Open vs. Closed Syllables

So far, I have argued for two vital properties of MI stress are that short vowels reduce and /a/ does not reduce before [x], but the data I have presented does not rule out another theoretical possibility. In order to simplify the stimuli set and establish a baseline of the acoustic properties of MI stress the experiment presented in this paper tested only disyllabic words with open syllables. However, it is also possible that /a/ does not reduce before other coda consonants as well.

The analysis laid out above predicts that unstressed short vowels reduce in open syllables, but not with a [x] in coda position, shown in (64a-b). There is not currently sufficient data to determine whether blocking vowel reduction is a unique property of [x] or if it is a general property of coda consonants in MI. Future extensions of this research will test the prediction in (64c) that other coda consonants could prevent a short vowel, like /a/, from reducing in the same way that [x] has been shown to do here.

(64) *Vowel reduction predicted by the current analysis*

(a)	/CVCV/ → [ˈCV.Cə]	/CV:CV/ → [ˈCVː.Cə]
(b)	/CVCax/ → [Cə.ˈCax]	/CaxCV/ → [ˈCax.Cə]
(c)	/CVCVC/ → [CəˈCVC]	/CVCCV/ → [ˈCVC.Cə]

6. Conclusion

This paper provides new evidence for a stress pattern that differs from previous descriptions of MI: stress falls on the initial syllable except in CVCax words, where it is peninitial/final. There is generally no clear acoustic correlate of stress, but there are clear patterns of phonological vowel reduction. If vowel reduction indicates lack of stress, then it is clear that the second vowel in CVCV and CV:CV words, and the first vowel in CVCax words, is unstressed.

Stress falls on the second syllable in CVCax words, as shown by vowel reduction of the first vowel, and duration and F1 of the second vowel relative to words with [ax] in unstressed second position (i.e. CaxCax and CV:Cax).

The OT analysis presented in section 5 argues that [Cax] syllables attract stress away from initial short vowels in order to avoid having an irreducible vowel in a reduction context. M3's MI system can therefore be seen as a case of 'allophony-driven' stress: where feet differ from their default shape in order to optimize distribution of stress-driven allophones.

Future work on this topic will consist of a more sophisticated statistical analysis of data from multiple native MI speakers to determine whether or not the pattern found in this paper also applies more generally in MI. Other future work on this topic will also include an analysis of trisyllabic words to determine the full stress pattern of the language.

7. References

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8. Appendix

Word shape	Transcription	Orthography	Translation
CVCV	(ˈ katʲ ə)	caite	adj. worn, consumed, spent
	(ˈ batə)	bata	n. stick
	(ˈ hakə)	haca	n. hockey
	(ˈ pətə)	pota	n. earthenware, iron, pot
	(ˈ kəpə)	cupa	n. cup
	(ˈ ʃ opə)	siopa	n. shop, store
CVCV:	(ˈ bæ)hu:	beathú	n. feeding, nourishment
	(ˈ da)tu:	deatú	v. smoke
	(ˈ fo)su:	fosú	n. stay, support
	(ˈ sa)ti:	sataí	adj. stuck
	(ˈ ta)ki:	tacaí	n. supporter, backer
	(ˈ to)si:	tosaí	n. forward (sports)
	(ˈ ta)ku:	tacú	v. support, back, hold up
CV: CV	(ˈ ka:)kə	cáca	n. cake
	(ˈ ko:)tə	cóta	n. coat
	(ˈ da:)tə	dáta	n. date, time period
	(ˈ pa:)pə	pápa	n. pope
	(ˈ pi:)sə	píosa	n. piece, bit
	(ˈ po:)kə	póca	n. pocket
	(ˈ so:)pə	sópa	n. soap
CV: CV:	(ˈ ba:)su:	bású	n. execution
	(ˈ ko:)ko:	cócó	n. cocoa
	(ˈ da:)ti:	dátaí	n. dates, time periods
	(ˈ pa:)ti:	pátaí	n. kids
	(ˈ sa:)su:	sású	n. satisfaction, gratification, pleasure
	(ˈ ʃ i:)ke:	sícé	n. psyche
	(ˈ vo:)ti:	vótaí	n. votes
CaxCV	(ˈ baxtə)	bachta	n. bog cutting, (turf) bank

	(ˈ kaxpə)	cachpa	wug
	(ˈ kaxtə)	cachta	n. confinements, bondages, duresses, hardships, privations
	(ˈ paxtə)	pachta	wug
	(ˈ ʃ axpə)	seachpa	n. stop
	(ˈ taxtə)	tacta	n. strangulation
CaxCV:	(ˈ bax)tu:	bachtú	n. baking
	(ˈ gax)to:	gachtó	wug
	(ˈ ʃ ax)si:	seachsaí	n. axis
	(ˈ ʃ ax)to:	seachtó	num. seventy
	(ˈ ʃ ax)tu:	seachtú	adj. seventh
	(ˈ tax)pa:	tachpá	wug
	(ˈ pax)ti:	pachtaí	n. pancakes
CV: Cax	(ˈ ba:)pax	bápach	wug
	(ˈ fa:)sax	fásach	n. waste, desert; uncultivated, uninhabited region; empty, deserted place
	(ˈ ga:)fax	gáifeach	adj. dangerous, terrible
	(ˈ hu:)tax	Hútach	adj. similar
	(ˈ ʃ a:)pax	seápach	adj. pretty
	(ˈ ʃ e:)ʃ ax	séiseach	adj. tuneful, melodic
	(ˈ tu:)tax	tútach	adj. crude, awkward
CaxCax	(ˈ bax)tax	bachtach	wug
	(ˈ kax)tax	cachtach	wug
	(ˈ fax)tax	fachtach	wug
	(ˈ l^j ax)tax	leachtach	1. adj. strewn with grave mounds, memorial cairns 2. n. liquid
	(ˈ pax)tax	pachtach	wug
	(ˈ ʃ ax)tax	seachtach	adj. seventh
	(ˈ tax)tax	tachtach	adj. choking
CVCax	(bəˈ kax)	bacach	1. n. lame person 2. n. beggar 3. mean, despicable person
	(bəˈ ʃ ax)	biseach	n. (of health) improvement, recovery
	(kəˈ tax)	catach	1. adj. curly, curly-haired 2. adj. (of sheep) crop-eared 3. adj. (of page) dog-eared 4. adj. (of limb) twisted
	(təˈ sax)	tosach	n. beginning, commencement, origin
	(dəˈ ʃ ax)	deoiseach	adj. Diocesan
	(kəˈ hax)	cuthach	n. rage, fury
	(gəˈ tax)	Gotach	1. n. goth 2. adj. gothic 3. stammering, lisping, indistinct