

AN ACOUSTIC-PHONETIC DESCRIPTION OF VOWELS IN CROW (APSÁALOOKE)

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ABSTRACT

In this study we present a preliminary acoustic-phonetic analysis of three long vowels /i:/, /a:/, /u:/ in Crow and their short counterparts /i/, /a/, /u/. The target vowel tokens were surrounded by alveolar obstruents and produced by a single female speaker who was literate in Crow. Duration and formant measurements were analyzed. In particular, we investigated the amount of spectral change in the formant trajectories by obtaining F1, F2 and F3 values at 30 equally spaced time points from the central portion of the vowel.

Preliminary formant and duration measurements indicate unambiguous separation of /a:/, /a/, /u:/ and /u/. However, no formant or duration differences were identified for /i:/ and /i/. In fact, the formant trajectories of these two vowels were shown to overlap in the vowel space. Finally, all vowels show a considerable amount of spectral change, highlighting the importance of formant trajectories when characterizing Crow monophthongs.

Keywords: Crow, Siouan, acoustic-phonetics, vowels

1. INTRODUCTION

Crow (Apsáalooke) is a Siouan language spoken predominantly in and around the Crow reservation in south-eastern Montana. The most comprehensive account that we have of Crow is found in [3], which states that there are fewer than 1500 speakers of the language. The grammar provides a descriptive account of the phonology, morphology and syntax of the language.

According to Graczyk [3], the vowel system of Crow includes five long vowels (/i:/, /e:/, /a:/, /o:/, /u:/), three of which have short counterparts (/i/, /a/ and /u/), two diphthongs (/ia/, /ua/), and one marginal diphthong (/ea/). As is the case for many lesser-described languages, relatively little is known about the acoustic-phonetic properties of the sounds of Crow. This is because most linguistic research on these languages tends to focus on describing their phonology, morphology and syntax (e.g., [2], [5], and [7]). Another contributing factor to the lack of

phonetic analyses in Crow and other lesser-described languages is the lack of high-quality audio recordings suitable for phonetic research. However, with the development of sophisticated and portable recording equipment over time, it is now possible to obtain ample high quality data for acoustic-phonetic analyses.

For example, Simonian [8] is one of the few studies that looks at the acoustic properties of the vowels in Crow. In this study of one male speaker, the author measured the F1 and F2 values of the Crow vowels at three equally spaced time points (25, 50, 75%) through the vowels' duration. Simonian [8] found that, on average, long and short vowels had clear duration differences. He further found that both monophthong and diphthongs showed some degree of formant movement, with a greater degree of movement in the diphthongs than the monophthongs. Interestingly, he also found that back vowels showed more movement than front vowels (although the mid-back vowels (/e:/ and /o:/) were under-represented).

Simonian's [8] findings are in line with other studies that claim that monophthongs may be more dynamic than previously thought. For example, [4, 9, 10] claim that measurements of spectral change (movement in formant trajectories) are necessary for the characterization of vowels. Furthermore, some studies [e.g., 8, 6] have shown that it is possible to measure the dynamic properties of vowels in lesser-described languages. For example, Kashima and colleagues [6] measured vowels in Nambo across multiple-time points. The authors found the vowels to be clearly monophthongal and therefore do not report any information about formant trajectories, however, the fact that such a complex method of formant measurement could be applied to these languages, suggests that it is likely to work in other lesser described languages, such as Crow.

Thus the aim of the present study is to extend upon the work of [8] and present a preliminary sophisticated acoustic-phonetic analysis of three long vowels in Crow, /i:/, /a:/, /u:/, and their shorter counterparts, /i/, /a/, /u/. In particular, we investigate whether there is unambiguous separation of these long and short vowels in terms of (1) duration and (2) the vowel space. We also investigate whether spectral

change (or movement in formant trajectories) is important for characterizing monophthongs in Crow.

2. METHOD

2.1. Participants

The data for this study were produced by one female native speaker of Crow, in her early 50's. In addition to being a native speaker, the participant was literate in the Crow language. Although there are a number of Crow speakers, we could only investigate one speaker at this time due to the availability of the recording data.

2.2. Vowel tokens

The target words were obtained from a large scale project where approximately 5000 words for an online dictionary were recorded, in addition to some narrative material. The data were collected during fieldwork during the summers of 2015 and 2016. The dictionary recordings came from a project conducted by The Language Conservancy in conjunction with the Crow Language Consortium and the Little Big Horn College, which was designed to document and develop pedagogical material for Crow.

For our analysis, we selected 20 target words, which contained one of the following target vowels (/i:/, /i/ /a:/, /a/, /u:/, /u/). The mid vowels (/e:/ and /o:/ are not included in this study due to the lack of tokens by the speaker in this consonantal context. A word was considered a "target word" if it contained one of the 6 Crow vowels surrounded by obstruents (preferably at least one of which was voiceless, e.g., /s/, /t/), produced in stressed and unstressed positions. These target words were repeated 2-3 times, resulting in a total of 47 tokens.

2.3. Acoustic analyses

The start and end boundary of each vowel token was hand segmented by one of two native speakers of English. For differentiating between voiceless obstruents and the vowel, the ability to track pitch in Praat was used. To separate the vowel from a voiced obstruent, changes in intensity were used alongside the decline in measurable F2 and F3 values for plosives and the presence of high-frequency noise for fricatives. These segments were then checked by an English speaker who is familiar with the Crow language. We used the same method for obtaining formant measurements as previously used in acoustic-phonetic descriptions of English [e.g., 1, 10] and other lesser-described languages, such as Nambo [6]. In this method, F1, F2 and F3 measurements were obtained at 30 equally-spaced time points in the

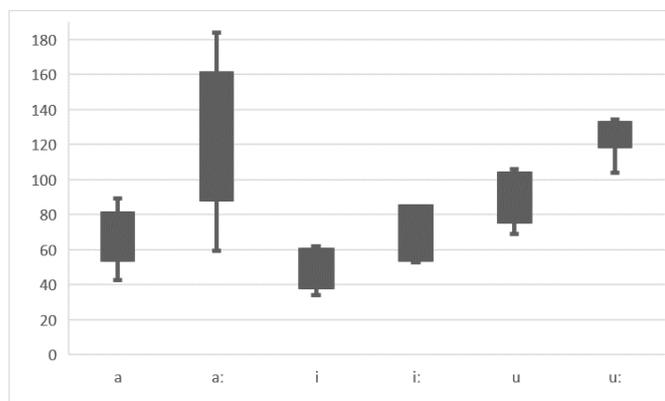
central portion (20-80%) of the vowel. These measurements were then smoothed using a script in Matlab. The 30 formant values for each measurement were then transformed using the discrete cosine transform (DCT) in order to smooth and characterize the formant trajectory. The DCT produces coefficients that correspond to different aspects of the trajectory, e.g., 0th coefficient: formant trajectory means; 1st coefficient: magnitude and direction of the trajectory (see [1] for a detailed explanation of this method).

3. RESULTS

3.1. Duration

The average duration values of the Crow vowels are shown in Figure 1. A clear length distinction can be observed for both /a:/-/a/ and /u:/-/u/, however, we do not observe a length difference for /i:/-/i/. Paired-samples t-tests confirmed the significant differences between /a:/-/a/ ($p = <.001$) and /u:/-/u/ ($p = .023$). The length difference between /i:/ and /i/ did not reach significance ($p = .160$).

Figure 1: Duration (in milliseconds) of long and short vowels in Crow.



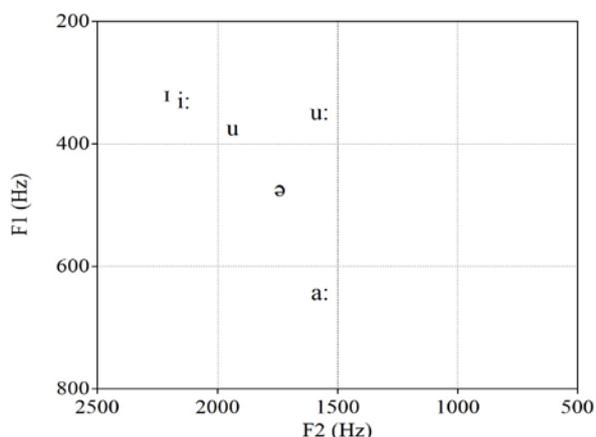
3.2. Formant measurements

Table 1 shows the average F1, F2 and F3 values in Hz for the six Crow vowels. The F1 and F2 values from the table have been used to plot the vowels in the vowel space (Figure 2). As can be observed, there is unambiguous separation of /a:/, /a/, /u:/ and /u/. However, it seems that /i:/ and /i/ are almost inseparable because of the similarities in the F1 and F2 values. It is important to note here that Graczyk [3] describes the vowels /i/ and /a/ in the context we have selected as surfacing as [ɪ] and [ə], respectively. We have used those forms in our figures to both avoid ambiguity and to test whether these symbols do indeed accurately describe these vowels in this context.

Table 1: Average duration (ms), F1, F2 and F3 values in Hz (standard deviation is provided in parentheses).

Vowel	No. of tokens	Duration (ms)	F1	F2	F3
i	5	51 (11.8)	320 (27.4)	2210 (69.2)	3026 (78.4)
i:	5	67 (16.2)	331 (28.2)	2140 (238.9)	2944 (59.3)
a	14	69 (14.3)	474 (109.5)	1740 (85.2)	3067 (119.9)
a:	12	129 (41.2)	644 (116.3)	1571 (83.7)	3172 (100.8)
u	5	89 (14.8)	375 (16.4)	1936 (178.3)	2838 (184.7)
u:	6	125 (10.9)	349 (33.1)	1574 (360.4)	2768 (154.5)

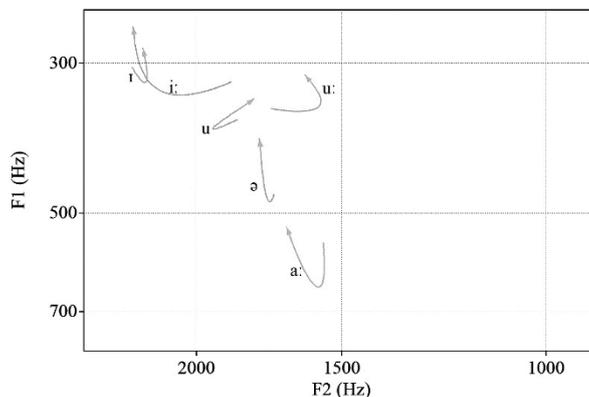
Figure 2: A vowel plot showing the median average F1 and F2 values of the vowels in Crow.



To understand how Crow monophthongs change over time, the averaged formant trajectories for the three long and three short vowels were mapped on to the plot in Figure 3. To do this, we averaged the F1 and F2 values for each vowel at each of the 30 time points. The arrows in Figure 3 therefore show the movement of the vowel from the first time point measured until the thirtieth (the arrowhead). The plot shows a considerable degree of spectral change in all six vowels measured. Visual observation of vowel plot suggests some degree of formant movement in either F1, F2 or both. For example, all of these vowels are characterized by an initial drop in F1, followed by a raise in F1 after. Some vowels (e.g., /i:/ and /a:/) are also characterized by an increase in F2, indicating movement toward the front of the vowel space.

Whereas, /ɪ/, /u/ and /u:/ all show the opposite direction of spectral change, as indicated by the decrease in F2. The Crow vowel /i:/, seems to display the largest amount of spectral change, while there seems to be a clear overlap of /ɪ/ and /i:/.

Figure 3: Acoustic plotting of the formant trajectories of the six vowels in Crow.



4. DISCUSSION

The aim of this study was to present a preliminary acoustic analysis of six vowels in Crow, using state-of-the-art techniques. In particular, we employed a more sophisticated measure of spectral change (formant trajectory) to determine the dynamic properties that characterize these vowels.

Our duration analyses suggest a clear length distinction between /a:/- /a/ and /u:/- /u/, yet this was not the case for /i:/- /i/. Our formant measurements indicate a similar pattern as we observe clear separation of all vowels except /i:/ and /i/ whose average F1 and F2 values are almost inseparable. Furthermore, our findings indicate that Graczyk's [3] description of the vowel qualities seem to be accurate when described acoustically. In particular, we observe that /a/ indeed surfaces as [ə] when surrounded by voiceless obstruents. However, our results suggest that /i/ may not surface as [ɪ]. Further evidence (particularly that from a different speaker) is needed to confirm whether or not [ɪ] is the appropriate symbol in this context. Additionally, in Figure 1, we observe an interesting case of a very fronted /u/, which is similar to the /u/ fronting observed in Australian English [1]. Future analyses, with more speakers will be required to determine whether /u/ may be a better symbol for the representation of this vowel. Given that some of these vowels were produced in stressed and unstressed positions, it could be argued that word-level stress might influence the duration and formant characteristics of these vowel. However, the stress system of Crow is more an interaction of intensity and

pitch that is not equivalent to the notions of stress that exists in English. So while it is possible, there are no sources that state that Crow vowels change quality based on stress. We will examine the effects of stress on vowels in future studies with a larger corpus.

Turning to our analysis of spectral change in the formant trajectory, our preliminary analyses indicate the dynamic nature of the Crow vowels. Our findings are consistent with earlier findings by Simonian [8], who found that there was considerable movement in these vowels. Short vowels have a smaller degree of movement than their long counterparts. In particular, /i:/ shows a great deal of spectral change across both F1 and F2 dimensions. The amount of spectral change or formant movement in these vowels may also be related to a more open vowel space, however future studies would need to be conducted to confirm this. However, our findings do support previous studies which suggest that measurements of spectral change can be used to describe vowels acoustically. That is, our findings suggest that measurements of the formant trajectories need to be included to appropriately characterize vowels in Crow.

Another interesting observation in our preliminary data is the lack of separation between /i:/ and /i/. Not only do we see no difference between the long and short vowels in terms of their duration, but there is also very little difference between the two in terms of their average F1 and F2 values. If duration does not differentiate the two, then it raises the question of what spectral information is required separate them. Or perhaps we are observing a phenomenon particular to our selected speaker. In order to further determine what separates /i/ from /i:/, we would need to first compare these tokens to the same vowel in other contexts. We would also need to compare these findings with other speakers in our corpus. Finally, more sophisticated statistical analyses [e.g., 11] may help us determine the acoustic cue that separates these vowels. Based on the present data, we do know that in order to separate /i/ from /i:/, one would need to take into consideration the entire formant trajectory of each vowel, as the /i/ vowel clearly overlaps with the /i:/ vowel.

6. CONCLUSION

In conclusion, our preliminary acoustic analysis of the vowels in Crow indicates that the Crow vowel space is more complex than previously expected. In particular, our findings are in line with a previous acoustic analysis of Crow [8]. Although we do see unambiguous separation for /a:/ and /a/ and /u:/ and /u/, this is not the case for /i:/ vs. /i/. We are currently investigating the dynamic features of the monophthongs in Crow and in particular the lack of separation between /i/ and /i:/. This additional

research which will include more than one speaker and additional tokens is needed in order to make definitive conclusions about the nature of the Crow vowel system.

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8. REFERENCES

- [1] Elvin, J., Williams, D., Escudero, P. 2016. Dynamic acoustic properties of monophthongs and diphthongs in Western Sydney Australian English. *J. Acoust. Soc. Am.* 140(1), 576-581
- [2] Gordon, R. G. Jr. 1972. Pitch accent in Crow. *Internation J. of Am. Ling.* 38(3), 191-200
- [3] Graczyk, R. 2007. *A Grammar of Crow*. University of Nebraska Press.
- [4] Jacewicz, E., Fox, R. A. (2013). Cross-dialectal differences in dynamic formant patterns in American English vowels. In: Morrison, G.S., Assmann, P.F. (eds), *Vowel Inherent Spectral Change*, edited Berlin: Springer, 177-198.
- [5] Kaschube, D. V. 1967. Structural elements of the language of the Crow Indians of Montana. University of Colorado Studies, Series in Anthropology. 14. University of Colorado Press: Boulder, CO.
- [6] Kashima, E., Williams, D., Ellison, M.T., Schokkin, D., Escudero, P. 2016. Uncovering the acoustic vowel space of a previously undescribed language: The vowels of Nambo. *J. Acoust. Soc. Am.* 139(6), EL252-EL256.
- [7] Lowie, R. H. 1941. The Crow language: Grammatical sketch and analyzed text. *Univeristy of California Publications in American Archaeology and Ethnology.* 39 (1), 1-142, University of California Press: Berkeley and Los Angeles.
- [8] Simonian, J. 2015. A Plotting of the Vowels of Crow. California State University, Fresno
- [9] Watson, C. I., Harrington, J. 1999. Acoustic evidence for dynamic formant trajectories in Australian English vowels. *J. Acoust. Am. Soc. Am.* 106, 458-468.
- [10] Williams, D., Escudero, P. 2014. A cross-dialectal acoustic comparison of vowels in Northern and Southern British English. *J. Acoust. Soc. Am.* 136, 2751-2761.
- [11] Williams, D., Escudero, P., Gafos, A. 2018. Spectral change and duration as cues in Australian English listeners' front vowel categorization. *J. Acoust. Soc. Am.*, 144(3), EL215-EL221.