Acoustic vowel reduction in Creek: Effects of distinctive length and position in the word

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Abstract

Eight speakers (4 male and 4 female) of the Muskogee dialect of Creek pronounced a set of words illustrating the vowels and diphthongs of Creek. These recordings were analyzed acoustically and data on vowel duration and vowel formant frequencies are presented in this paper. The ratio of the durations of distinctively long and short vowels was 1.8 - this ratio showed a sex difference, being larger for female speakers than it was for male speakers. Final lengthening was also observed: both distinctively long and short vowels were longer in word final position than in word initial position. The vowel formant data showed two additive, orthogonal phonetic vowel reduction processes: short vowel centralization and positional reduction. *Short vowel centralization* has been found in many languages. Distinctively long vowels in Creek tended to be more peripheral in the acoustic vowel space than were the distinctively short vowels. *Positional reduction* is also evident in these data: vowels in word final position were reduced relative to vowels in word initial position. Short vowel centralization was preserved in both positions in the word. Positional reduction has been documented in several languages, and these results from Creek lend support to the hypothesis that it is a general property of speech production. The results of this acoustic-phonetic study, the first such study of Creek, are discussed in light of cross-linguistic phonetic trends.

Introduction

Creek is a Muskogean language spoken by several thousand individuals in eastern Oklahoma and central Florida. The largest dialect of Creek is Muskogee, followed by the Oklahoma Seminole and Florida Seminole dialects. Other languages in the family include Choctaw, Chickasaw, Alabama, Koasati, Apalachee, Hitchiti and Mikasuki.

This paper describes an acoustic-phonetic study of the vowels in the Muskogee dialect of Creek, in which patterns of vowel duration and vowel formant frequency were examined. The study described in this paper builds on the phonemic descriptions of Haas (1940, 1977a,b) to provide the first acoustic-phonetic study of Creek vowels.

The six distinctive vowels of Creek contrast for length, frontness, and height as shown in (1). In addition to these monophthongal vowels there are three diphthongs /ey/, /oy/, and /aw/[1], which will be touched on briefly in this report. We will also discuss briefly consonant-vowel interactions in the realization of short /a/.

(1) The distinctive vowels of Creek.

	short vowels		long vowels	
	front	back	front	back
nonlow	i	o	i:	o:
low	a		a:	

The data reported here bear on a couple of important issues in phonetic theory. Lindblom (1963) proposed a model of vowel reduction which related vowel quality with vowel duration. In this model, short vowels are centralized relative to long vowels because of vowel target 'undershoot' in short vowels. This account predicts that, all other things being equal, the short vowels of Creek will be more centralized than the long vowels. As we will see, this prediction holds for the Creek vowels (as was noted by Haas, 1940).

We recorded examples of the Creek vowels in both the first and last syllables of words and because the words were pronounced in isolation these positions are respectively utterance initial and final as well. Numerous previous studies have found final lengthening in a variety of different languages (see review in Lehiste, 1970). As we

[1]The transcriptions are in the Americanist tradition (Pullum & Ladusaw, 1986), which, for the transcriptions in this paper, differs from the IPA in the following: /ey/-[eɪ], /oy/-[oɪ], /aw/-[aʊ], /c/-[tʃ].

will see below, vowels in final position in Creek words were longer than vowels in initial position.

These two findings (short vowel centralization and final lengthening) set the stage for the most interesting of our results. We found that, in Creek, final vowels are centralized relative to initial vowels. We call this phenomenon *positional reduction*. A few recent reports have found similar effects variously attributed to supralaryngeal declination (Vaissière, 1986; Vayra & Fowler, 1992; Krakow, Bell-Berti & Wang, 1995), initial strengthening (Jun, 1993; Fougeron & Keating, 1997), or final fade (Herman, Beckman, & Honda, 1997). Our study is similar to the study of Swedish vowels reported by Nord (1986) in that we find that final vowels though longer than initial vowels are nonetheless reduced. Nord attributes a similar effect in his data to 'force-dependent' factors (attributing this to Lindblom, 1968). We will return to a discussion of 'force' factors in the conclusion, and here wish only to note that, unlike short vowel centralization and final lengthening, positional reduction has been observed in only a few languages (English, Swedish, Korean & Italian), so this new data from Creek is an important addition to the literature.

In addition to the phonetic description of the Creek vowel system presented in the results section, the paper briefly touches on consonant-vowel interactions in the realization of short /a/, and on vowel formant trajectories of the diphthongs.

Method

Speakers

Eight speakers of the Muskogee dialect of Creek (4 women, 4 men) participated in this study. They were all native speakers of Creek who speak the language with their friends and family, and speak English with people who don't speak Creek. Their ages ranged from the early 50s to the late 80s at the time that these recordings were made. Some of the individual differences observed in these data might be due to dialect differences. However, this study was not designed to explore dialect differences, so the discussion here will focus on phonetic patterns which characterize these speakers as a group.

Word list

A word list illustrating phonetic contrasts in Creek was constructed in collaboration with the Creek linguist Margaret Mauldin. The portion of this list which dealt with vowel contrasts is shown in (2). The long and short monophthongal vowels [a, a:, i, i:, o, o:] appeared in word initial and final position in near minimal sets. The list also contained words which contrast three additional instances of low vowels and a set of words to illustrate the diphthongs.

(2) Words illustrating the Creek vowel contrasts.

	Initial vowels		Final vowels	
/a/	atá:pa	wooden paddle	locá	turtle
/a:/	a:tamí	car	pocá:	grandfather
/i/	itó	tree	pací	pigeon
/i:/	í:ta	another	ocí:	pecan
/o/	opá	owl	focó	duck
/o:/	ó:fa	inside	kacó:	berry

Variation in /a/		Diphthongs	
lácci	branch	óywa	water
láksa	hoof	láwki:	deep (of water)
lá:ksa	liar	lêykeys	I'm sitting down

Accent marks are used in transcribing Creek to indicate pitch (´ indicating high pitch and ˆ indicating falling pitch) and following Haas (1977a) high pitch is only marked on the last vowel in the word which has high pitch. For example, /a:tamí/ *car* has high pitch throughout, while /atá:pa/ *wooden paddle* has high pitch on the first two syllables and a fall to low pitch in the last syllable. These pitch patterns are shown in figure 1. Obviously, there are a number of detailed aspects of the pitch system in Creek which should be studied in future research. Future study may shed light on such details as the fundamental frequency (F0) dip in the second syllable of /a:tamí/ and the rising pitch over the first two syllables in /atá:pa/. For the purposes of the present paper it suffices to point out that the accent marks in our transcriptions should be interpreted as indicating the location of the last high pitched syllable of the word.[2]

[2]In particular it is important to note that the accent marks should not be interpreted as marking syllables which are longer, louder, or more prominent than the other syllables in the word. The marks are merely a convenient typographical convention to indicate the pitch pattern of a word.

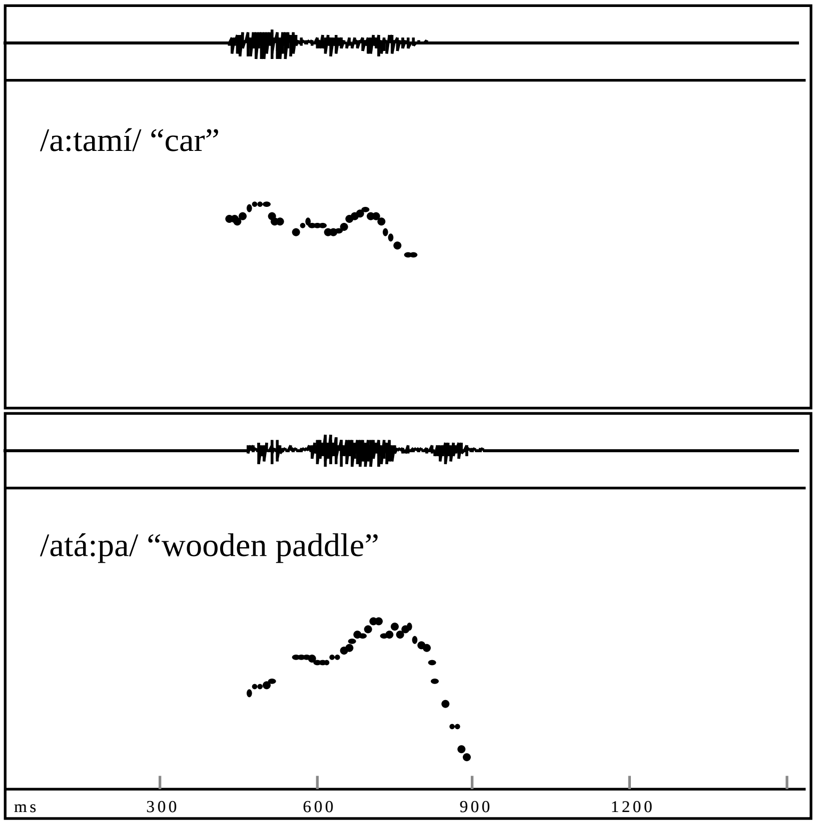

Figure 1. Example F0 traces of the words /a:tamí/ *car* and /atá:pa/*wooden paddle* showing the meaning of the accent marks in our transcription of Creek. In /a:tamí/ F0 remains high through-out the word while in /atá:pa/ F0 is high up to the end of the second syllable and then falls to a very low value. The speaker is JM, a male speaker with a low pitch range - from 50 Hz to 150 Hz in these graphs.

Recordings

Each recording session took about 45 minutes - including time to discuss the word list (only the vowel portion of the list is shown in (2)). Two to four speakers participated in each session. Speaker MM participated in each session and read each word first, then the other speakers also produced the word. We were careful to encourage the speakers to avoid imitating MM and our impression is that this instruction was taken seriously, leading to discussions of the words and occasionally to decisions by a speaker to use a different, more familiar word than the one intended. Two repetitions of the word list were recorded for each speaker in each session.

Six speakers were recorded with a Sure SM48 hand-held unidirectional microphone, which was passed from speaker to speaker during the recording session,

remainder of the variance is due to a combination of individual differences among the speakers, within-speaker variation across the two repetitions of each word, and measurement error.

The **position** of the vowel in the word had a reliable effect on vowel duration [$F(1,164) = 62.0$, $p<0.01$]. Vowels in word final position were longer on average (201 ms) than vowels in word initial position (148 ms). This factor also interacted with the distinctive vowel **length** factor [$F(1, 164) = 5.9$, $p<0.05$] - the difference between initial and final position was larger for distinctively long vowels than it was for distinctively short vowels. This interaction is shown in Figure 2.

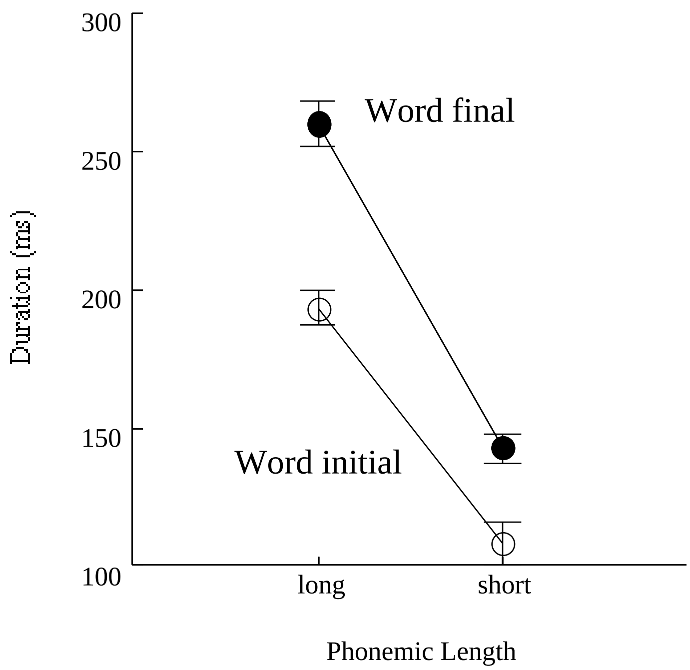

Figure 2. Average vowel duration as a function of position of the vowel in the word, and the distinctive length of the vowel. The average duration difference between final and initial position was greater for distinctively long vowels than it was for distinctively short vowels. The error bars show the standard error of the mean.

It can also be seen in figure 2 that distinctive vowel **length** was reflected in the physical duration of the vowel [$F(1, 164)=231.3$, $p<0.01$]. As mentioned above, the average duration of the long vowels was 225 ms, while the average duration of the short vowels was 124 ms. This duration difference gives a ratio of 1.81 (=225/124), i.e. long vowels were not quite twice as long as short vowels. Interestingly, this ratio is essentially preserved in both word initial (1.805) and word final (1.827) positions, but shows more variation as a function of the sex of the speaker.

Speaker **sex** had a reliable effect on vowel duration [F(1,164)=25.8, p<0.01]. Women's vowels were on average longer than men's vowels (191 ms versus 158 ms). However, this difference was mediated by distinctive vowel length, as indicated by a reliable **sex** by **length** interaction [F(1, 164) = 4.8, p<0.05]. This interaction is shown in figure 3. As the figure shows, the greatest difference between men and women was in the durations of the long vowels, with only a small difference seen in the durations of the short vowels. The average durations in Figure 3 give long/short vowel duration ratios of 1.87 for women and 1.76 for men.

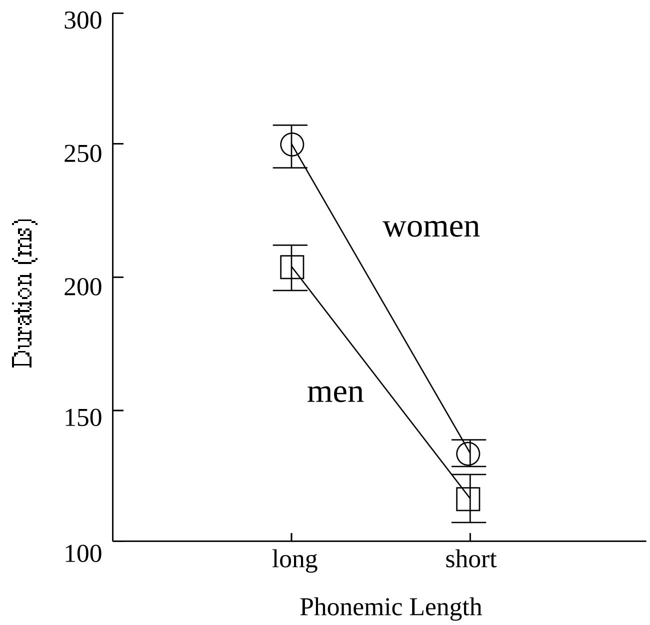

Figure 3. Average vowel duration as a function of the distinctive vowel length and the sex of the speaker. Men and women differed from each other more in the durations of their long vowels than they did in the durations of their short vowels. The error bars show the standard error of the mean.

Vowel **quality** also had a reliable effect on vowel duration [F(2,164)=3.79, p<0.05]. The low vowels [a] and [a:] were on average shorter than the high ([i] and [i:]) and mid vowels ([o] and [o:]), respectively 163, 175, and 186 ms. However, vowel **quality** interacted with word **position** [F(2,164)=5.2, p<0.01] and inspection of this interaction showed that vowel quality had no effect on duration in word final position (all average durations about 200 ms) while there was a large effect of vowel quality on duration in word initial position (low = 123 ms, high front = 150 ms, and mid back = 172 ms).

None of the other interactions in the ANOVA reached statistical significance.

Interim discussion of vowel duration findings

Several of the vowel duration patterns found in Creek have been noted in other languages. Of course, that physical vowel duration is strongly correlated with distinctive vowel length is to be expected, however some of the ways that this distinctive length contrast is mediated by, or interacts with, other factors is of some interest.

It has been noted for several languages that syllables in phrase or utterance final position, as the final syllables in these isolated word productions were, tend to be longer than initial or medial syllables (Lehiste, 1970; Nakatani, O'Connor & Aston, 1981; see below). This phenomenon has been called phrase final lengthening and pre-boundary lengthening, and has been described as a local tempo change as opposed to a change in gestural amplitude (Edwards, Beckman, Fletcher, 1991). There is some evidence (Buckley, 1998) that for a variety of languages iambic lengthening fails to occur in final syllables. Buckley speculates (fn. 5) that this failure of durational contrast in final syllables may be related to final lengthening, though our data (figure 2) suggests that a loss of durational contrast is not a necessary result of final lengthening.

It has also been noted in other studies that women tend to produce longer vowels in stressed position in English and in other ways provide stronger acoustic cues for linguistic contrasts than do men (Byrd, 1992; Whiteside, 1996). In this connection it is interesting that the vowel duration differences between men and women observed here were greater for the distinctively long vowels than they were for the distinctively short vowels. This interaction can be taken as suggesting that the gender difference was not one of different speaking rates over all, but rather a difference in the phonetic realization of the length contrast.

Finally an interaction of vowel quality and vowel duration has also been noted in many languages (Lehiste, 1970), however the pattern observed in these Creek data differs from the pattern usually found. Namely, rather than the more usual inverse correlation of vowel height and duration such that low vowels are long and high vowels are short, here we found that the low vowels had the shortest average duration. It is interesting that this pattern was only observed for vowels in word initial position. This may be due to the fact that the low initial vowels occurred in words of three syllables while the others occurred in two-syllable words. Several researchers (Lehiste, 1970; Nakatani et al., 1981) have found that vowel duration is inversely proportional to the number of syllables in a word. This effect occurs in several languages including German (Malmberg, 1944), English (Jones, 1942), Dutch (Nooteboom, 1972), Hungarian (Tarnóczy, 1965), French (Roudet, 1910), Finnish (Iivonen, 1974), Estonian (Eek & Remmel, 1974), Swedish (Lindblom, Lyberg & Holmgren, 1981) & Spanish (Hutchinson, 1973). If a similar effect occurs in Creek this would explain the shorter durations of the low vowels in word initial position. Further research on prosodic aspects of Creek would clarify this result.

The acoustic vowel space of Creek

Figure 4 shows the acoustic vowel space formed by the Creek long and short monophthongal vowels produced by women (top panel) and men (bottom panel). The vertical and horizontal dimensions in these graphs represent the frequencies of the two lowest vocal tract resonances (F1 and F2) and the ellipses encompass approximately 90% of the measured values of each vowel.

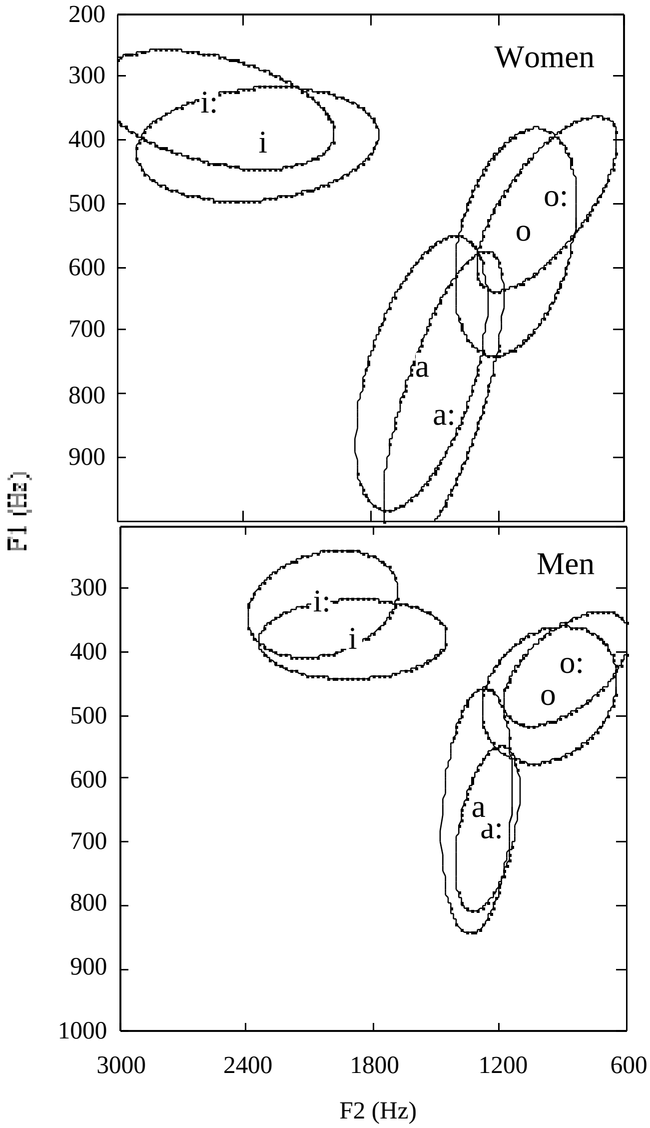

Figure 4. Overview of the Creek acoustic vowel space for women (top panel) and men (bottom panel). The placement of the vowel symbols indicates the average formant values for each vowel and the ellipses indicate the principal components of variation, encircling approximately 90% of the measured values of each vowel.

As with the duration data we will explore several sources of the variance indicated by these ellipses using analysis of variance, but from figure 4 we can note some general features of the Creek acoustic vowel space. First, note that the formant frequencies of the long and short vowel pairs are very similar, as indicated by their largely overlapping ellipses. This suggests that these vowel pairs are distinguished primarily by duration. Second, note that the men and women have different ranges of vowel formant frequencies. This is a reflection of an average difference in male and female vocal tract length due to the lowering of the male larynx during puberty. Third, note that for both male and female speakers the vowel triangle formed by the short vowels is contained within the vowel triangle formed by the long vowels. This is easiest to see by noting the locations of the vowel symbols - the average formant frequencies - in figure 4. The reduction of the vowel triangle size for short vowels compared with long vowels indicates that the short vowels are somewhat centralized relative to the long vowels (Lindblom, 1963). The related language Chickasaw shows a pattern of short vowel centralization (Gordon, Munro & Ladefoged, 1997) as do many other languages (Lehiste, 1970: 30-3; see below).[4]

The F1 values of the monophthongal vowels in initial and final position were entered into an ANOVA with the same independent variables that were used in the analysis of the duration data: (1) **position** in the word - initial vs. final; (2) **sex** of the speaker - male vs. female; (3) distinctive vowel **length** - long vs. short; and (4) vowel **quality** - low, high front, and mid back. This statistical model accounted for about 89% of the variance in the data (R^2=0.893).

As expected, F1 frequency was affected by vowel **quality** [$F(2,164) = 582$, $p<0.01$]. This can be seen in the vertical dimension of figure 4, the low vowels had the highest F1 frequencies, the high vowels had the lowest F1 frequencies and the mid vowels had F1 frequencies between these. In addition there was a small overall effect of vowel **length** on F1 frequency [$F(1,164) = 5.07$, $p<0.05$], however this effect is best interpreted by reference to the interaction between vowel **quality** and vowel **length** [$F(2, 164) = 13.3$, $p<0.01$]. This interaction can be seen in figure 4 as the tendency for distinctively short vowels to have slightly less extreme F1 frequencies than the long vowels - short vowel centralization. The overall effect of vowel length falls out from the fact that for two of the vowels ([i] and [o]) centralization results in a higher F1 frequency for the short vowels, while only for short [a] does centralization result in a lower F1 frequency.

The **sex** of the speaker also had a significant effect on F1 frequency [$F(1,164) = 83.2$, $p<0.01$]. This effect, probably of vocal tract length differences between men and women, has been observed in numerous previous studies (see for example Peterson &

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[4]One reviewer suggests an additional observation. The ranges of the vowel formant frequencies (the area covered by each elipse) seem to be smaller than they could have been given Manuel & Krakow's (1984; Manuel, 1990) claim that small vowel inventories allow large vowel variation. The formant ranges in figure 4 certainly appear to be smaller than those found for Chickasaw (Gordon, Munro & Ladefoged, 1997) and Navajo (McDonough & Austin-Garrison, 1994; McDonough, Ladefoged & George, 1993) - two other languages with small vowel inventories and distinctive vowel length.

Barney, 1952; Fant, 1973; and Bladon, Henton & Pickering, 1986). **Sex** also interacted with vowel **quality** [F(2,164) = 11.5, p<0.01]. This interaction is shown in figure 5, which plots the mean values for male and female speakers in one graph. Notice that men and women differ on the vertical location of the mean values, the F1 frequency, more for the vowels [a:] and [a] than they do for the vowel [i:] and [i], with the sex difference for [o:] and [o] intermediate between the differences seen for the low and high vowels. This pattern of male/female difference in F1 has been found in previous research and may be due to differences in vocal tract geometry or speaking style (see Fant, 1973 for a discussion of this).

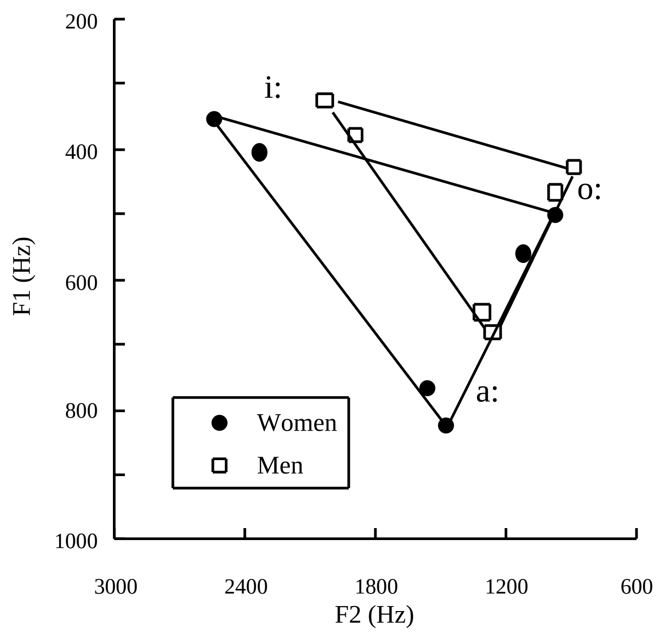

Figure 5. Average F1 and F2 frequencies of the monophthongal vowels of Creek produced by women (filled symbols) and men (open symbols). The size of the acoustic vowel space for each group of speakers is indicated by lines connecting the formant values of the distinctively long vowels (short vowel mean values are not labeled but appear near the relevant long vowels). Note that the size of the space is larger in the speech of women.

The only other significant effect in the statistical analysis of vowel F1 frequency was a reliable interaction between vowel **quality** and the **position** of the vowel in the word [F(2,164) = 6.8, p<0.01]. This interaction is shown on the vertical dimension of figure 6. On average, final vowels were closer to the center of the vowel space than were vowels in the initial syllable of the word. So, for example final [o:] had a higher F1 frequency than did initial [o:] and final [a:] had a lower F1 frequency than did initial [a:]. The vowel centralization that we see in figure 6 is reminiscent of the vowel centralization that we saw in figures 4 & 5 which was a function of the distinctive length of the vowel.

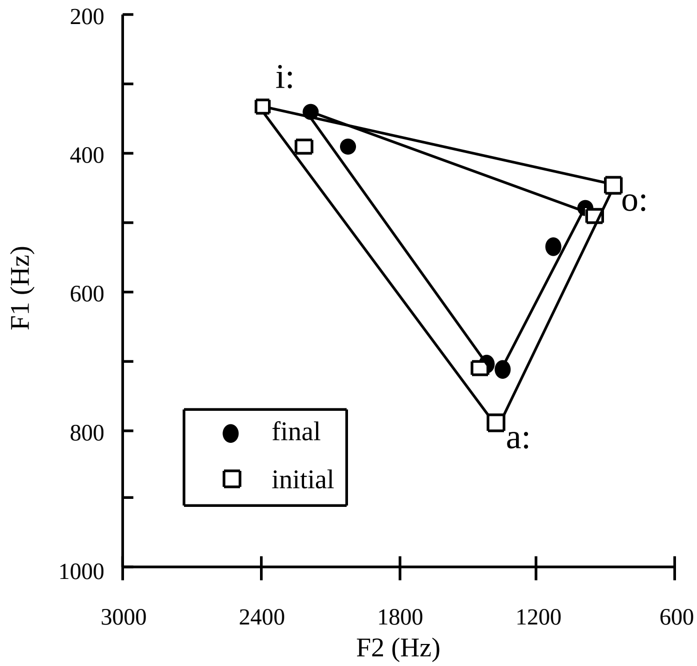

Figure 6. Average F1 and F2 frequencies of the monophthongal vowels of Creek produced in word/utterance final syllables (filled symbols) and in word/utterance initial syllables (open symbols). The size of the acoustic vowel space for each position is indicated by lines connecting the formant values of the distinctively long vowels (short vowel mean values are not labeled but appear near the relevant long vowels). Note that the size of the space is larger in word-initial syllables.

The F2 values of the monophthongal vowels were also analyzed in an ANOVA with the same factors that were tested in the analysis of F1 variation. This statistical model accounted for about 95% of the variance in the data (R^2=0.949).

Not surprisingly, vowel **quality** had a significant effect on F2 frequency [$F(2,164) = 1358.4$, $p<0.01$]. This can be seen in figures 4-6 as the offset along the horizontal axis of the high front vowels [i: i] relative to the low central vowels [a: a], which are also horizontally offset relative to the mid back vowels [o: o]. As with F1, the interaction of vowel **quality** and vowel **length** was significant [F[1,164) = 21.4, p<0.01]. This interaction can also be seen in figures 4-6 -- the short front vowel has a lower value of F2 than the long front vowel, while the short back vowel has a higher value of F2 then the long back vowel. As with F1, the F2 data suggest that short vowels are somewhat centralized relative to the long vowels.

It is also not surprising that the **sex** of the speaker had a significant effect on F2 frequency [F(1,164) = 197.6, p<0.01]. The **sex** of the speaker also interacted with vowel **quality** [F(2,164) = 29.6, p<0.01]. However, the pattern of the interaction is the mirror image of the pattern we saw in F1 (see figure 5). Where in the F1 data we found that the male and female speakers differed primarily for the non-front vowels, for F2 we find that the largest difference between men and women was for the vowels [i:] and [i] - the horizontal dimension in figure 5. The overall pattern of gender differences in the vowel space then are that men and women are not very different for the vowels [o:] and [o], differ mainly on F2 for [i:] and [i] and mainly on F1 for [a:] and [a]. Nonuniform formant differences such as this have been noted in research on other languages (e.g. Fant, 1973).

The only other reliable effect in the F2 analysis of variance was an interaction between the **position** of the vowel in the word (initial vs. final) and vowel **quality** [F(2,164) = 27.1, p<0.01]. As can be seen in figure 6, the range of F2 values was on average reduced in word final position, paralleling the positional reduction of F1 described earlier.

The F3 frequency data were analyzed in an analogous ANOVA design, however the data proved to have more random variation than did the F1 and F2 data. Only 51% of the variance was accounted for by the ANOVA model ($r^2 = 0.508$). Three effects in this analysis were reliable. The **sex** of the speaker had a reliable effect on F3 [F(1,164)= 60.19, p<0.01]. The average F3 for female speakers was 2657 Hz while the average F3 for male speakers was 2372 Hz. Vowel **quality** also was significant [F(2,164) = 25.14, p<0.01]. The front vowels [i:] and [i] had a higher average F3 (2691 Hz) than did the low vowels [a:] and [a] (2466 Hz) and the back vowels [o:] and [o] (2386 Hz). These two effects (**sex** X **quality**) interacted with each other [F(2,164) = 17.23, p<0.01]. Inspection of the data suggests that this was primarily due to a large difference between the measured values of F3 for male and female speakers for [i:] and [i] (male = 2397 Hz, female = 2984 Hz). The average female F3 values for the other vowels were much lower than this (about 2500 Hz) and we suspect that the F2 and F3 frequencies in the front vowels may have been very similar to each other, with the result that the F4 was measured as F3 in some cases.

Additional observations

In this section we will present acoustic vowel formant data regarding consonant-vowel interactions in the Creek short /a/ and data on the Creek diphthongs. The analysis here is less systematic than the analysis in the previous section in that we do not explore the statistical sources of variation in the formant data.

Variation in Short /a/

In addition to the forms examined in the previous section, we recorded three words which allowed us to explore some consonantal influences on the phonetic realization of short /a/. These were /lácci/ *branch*, /láksa/ *hoof*, and /lá:ksa/ *liar*. We measured the first and second formants in all of the /a/ vowels in these words (and the /a:/ in /lá:ksa) and we also took measurements from the final vowel of /atá:pa/ *wooden paddle*. The formant measurements reported in this section were made in the same way that the earlier measurements were made.

Figure 7 shows average F1 and F2 for the short and long low vowels in this data set. The range of variation which can be seen in this figure runs from the quite centralized variant in /lácci/ to the much lower and backer long /a:/s in /lá:ksa/ and /a:tamí/. Looking at just the long vowels (the points shaded gray in figure 7) we find that /a:/ after palatal /c/ is higher than the others (lower F1) and /a:/ in /lá:ksa/ is backer than the others (lower F2). This variation seems to reflect a constraint on tongue-body position imposed by the neighboring consonants. A high tongue body position is required by the palato-alveolar consonant /c/ and a back tongue body position is required by the velar consonant /k/.

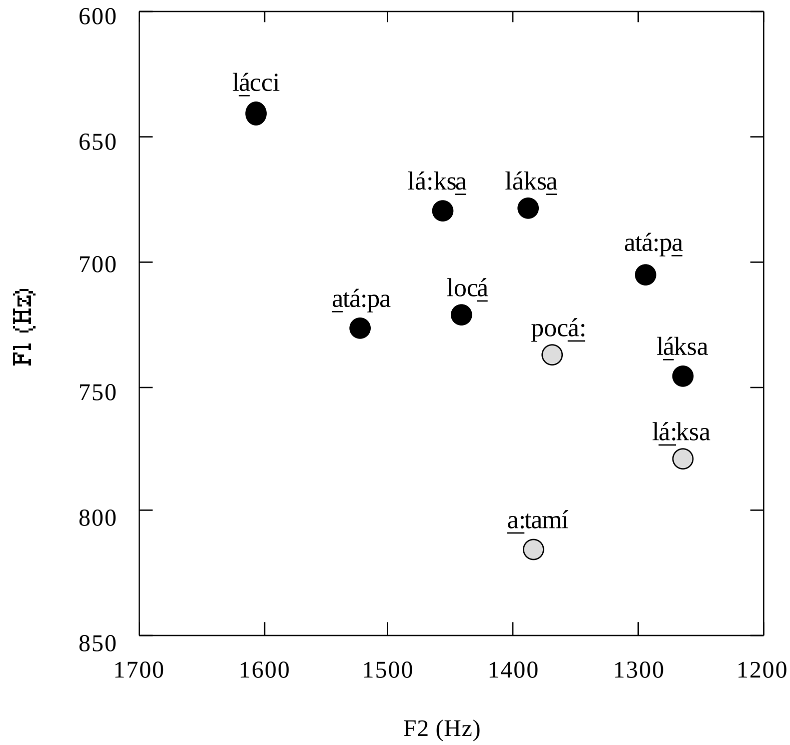

Figure 7. Average formant values for low vowels in various consonant contexts. Formant values taken from distinctively long vowels are shaded gray and formant values taken from distinctively short vowels are shaded black. The vowel which was measured is underlined in the label for each point. These values are averages over all eight speakers in this study.

The realization of short /a/ (the black points in figure 7) also seems to be affected by the tongue body of neighboring consonants. Short /a/ is backer preceding /k/ and is fronted preceding /cc/ and /t/. Final short /a/ following the coronals /s/ and /c/ fall between these extremes. The formant frequencies of the final vowel in /atá:pa/ indicate that this vowel is pronounced with the tongue relatively low and back and could be taken to suggest that the /a/ preceding /k/ is closer to the default or preferred tongue position for /a/.

The pattern of consonant vowel interactions that we see in these measurements is reasonable given the tongue positions of the neighboring consonants. Also, the effects which we observe here may be influenced by vowel-to-vowel coarticulation effects (Öhman, 1966; Choi & Keating, 1991) - a factor which was not controlled in the present word list. Still, the combination of lower F1 and higher F2 in the /a/ in /lácci/ suggest to us that it would not be incorrect to transcribe this vowel phonetically as [´].

Diphthongs

Among the words which we recorded were three designed to illustrate the diphthongs of Creek - /oy/, /aw/, and /ey/. These words were /óywa/ *water*, /láwki:/ *deep* and /lêykeys/ *I'm sitting down* (we measured /ey/ in the first syllable). Figure 8 shows average formant trajectories of these diphthongs with the average vowel formants of the monophthongal vowels and the /a/ of /lácci/. For comparison, the average F1-F2 trajectory of /o:/ is also shown in figure 8.

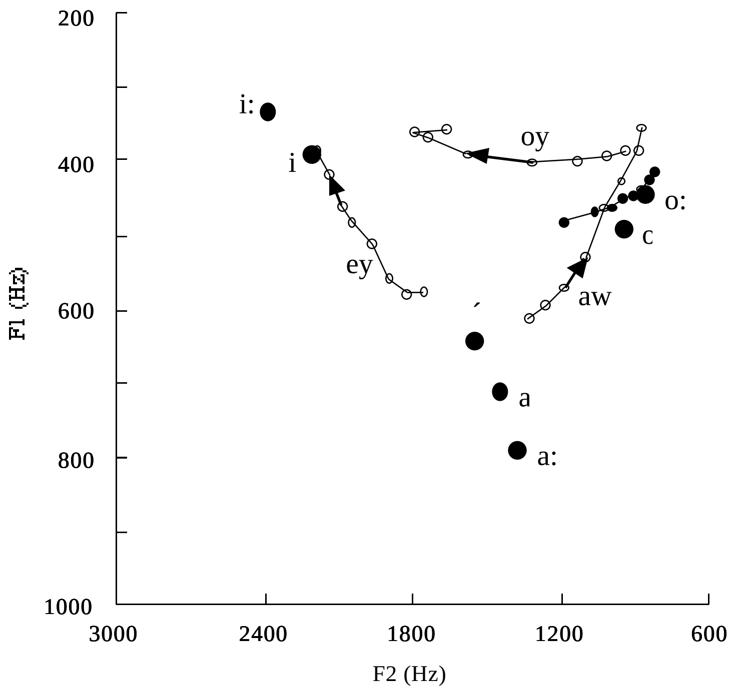

Figure 8. Time-normalized average formant trajectories of the Creek diphthongs /oy/, /aw/ and /ey/. The points in each trajectory were taken at intervals of 1/10 of the diphthong duration (over the middle 80% of the vowel) and the arrows indicate the direction of the trajectory from the beginning to the end of the diphthong. Average vowel formants from the preceeding section are replotted here for reference and [´] indicates the average formant values of /a/ in /lácci/. To compare formant movements during diphthongs and formant movements during a monophthong, the average F1-F2 trajectory of the vowel /o:/ is also shown in this figure.

The formant trajectories in figure 8 were produced using a different speech analysis package (Waves+, Entropic Research Laboratory) from the one used for the vowel steady-state measurements. The words were digitized at 16 bits, 16 kHz (with an appropriate digital anti-aliasing filter) and the diphthong portions of the words were labeled by reference to acoustic waveforms and time-aligned digital spectrograms. Formant trajectories during these portions of the acoustic waveforms were then calculated by autocorrelation LPC analysis (down-sampled frequency: 10 kHz; window size: 0.049 sec.; preemphasis: 0.7; LPC order: 12; step-size: 0.01 sec) and then hand-corrected with the formant trajectories overlaid on digital spectrograms. The formant trajectories were then time normalized to ten equally spaced points through the diphthong and the middle eight of the average F1/F2 estimates are shown in figure 8 - disregarding the edges of the trajectories which were most affected by the neighboring consonants.

The diphthong formant trajectories in figure 8 illustrate that in each of the diphthongs there is a substantial amount of formant movement as would be expected from their transcriptions. It is interesting that /ey/ and /aw/ start at a similar F1 value - both rather mid compared to the F1 level reached in /a/. To our ears an accurate phonetic transcription of /aw/ should start at [ø] rather than [A]. Note also that the off-glide of /oy/ does not reach the area of the acoustic vowel chart for /i/. We suspect that this will not prove to be a consistent property of /oy/ but rather is caused by coarticulation with the following /w/ in /óywa/. We also note that one of our speakers (FG) seemed to produce this vowel as a monophthongal /o:/ rather than the diphthong /oy/.

Conclusion

The main findings of this study of the Creek vowels are summarized in (3). We will comment here on three selected aspects of these findings as they relate to language universals and the language-specific phonetics of Creek.

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(3) Summary of the main findings of this study.

I. Vowel duration

a. Long vowels are on average about 1.8 times as long as short vowels.

b. Vowels in final position are longer than vowels in initial position.

c. The difference between long and short vowels is greater in final syllables than in initial syllables.

II. The Acoustic Vowel Space

a. In this three vowel system, the back vowel /o/ has a higher F1 (i.e. is more mid) than the front vowel /i/.

b. Distinctively short vowels are somewhat centralized relative to distinctively long vowels.

c. Vowels in final syllables are centralized relative to vowels in initial syllables despite the fact that vowels in final syllables are longer.

III. Gender differences

a. The duration distinction between long and short vowels is greater in women's speech than in men's speech.

b. Vowel formants in women's speech are generally higher in frequency than they are in men's speech.

c. The differences between women's and men's acoustic vowel spaces were non-uniform.

IV. Additional observations

a. The formant values of /a/ are effected by the tongue body position of neighboring consonants.

b. The rising diphthongs /ey/ and /aw/ start from a mid to low-mid vowel height.

Final lengthening

We noted earlier that the position of the vowel in a word had a reliable impact on the vowel's duration. Vowels in word final position were longer than vowels in word initial position. Because the recorded utterances in this study were isolated words, word initial and final positions were also utterance initial and final (though final lengthening may occur at word endings even when they are not utterance final, Lehiste, 1972). As noted briefly above, several researchers have found that vowels in utterance final position are longer, all other things being equal, than vowels in non-final position. This 'final lengthening' phenomenon is very common cross-linguistically. The literature on final lengthening in English is quite extensive and we will not review it here (see Klatt, 1976; and Edwards, Beckman & Fletcher, 1991 for reviews). In addition, final lengthening has been found in acoustic-phonetic studies of a wide variety of languages as indicated in (4).

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(4) Languages in which final lengthening has been found. References to relevant acoustic-phonetic studies are given for each language.

Swedish (Lindblom, Lyberg & Holmgren, 1981)

Dutch (Hofhuis, Gussenhoven & Rietveld, 1995)
German (Delattre, 1966)
Spanish (Delattre, 1966; Hutchinson, 1973)
French (Delattre, 1966; Fletcher, 1991; Fletcher & Vatikiotis-Bateson, 1991)
Italian (D'Imperio & GiliFavela, 1998)
Russian (Zlatoustova, 1954)
Czech (Dankovica, 1997)
Finnish (Lehtonen, 1974)
Hungarian (Fónagy & Magdics, 1960)
Mandarin (Shen, 1992)
Japanese (Kaiki, Takeda, & Sagisaka, 1990)
Hebrew (Berkovits, 1994)
Muskogee Creek (this study)

In addition to the languages listed in (4) final lengthening has been found in musical performance (Carlson, Friberg, Frydén, Granström & Sundberg, 1987), in infant babbling (Vihman, 1996, pp. 189ff), and in bird song and insect chirps (Cooper, 1976). Nickerson, Stevens, Boothroyd & Rollins (1974) also found that final lengthening does not occur in speech produced by the deaf. These results lead to the speculation that this phonetic effect has some general cause which may not be particular to language - perhaps in motor performance or planning (Sternberg, Wright, Knoll & Monsell, 1980). However, in the few comparative studies which have been conducted it has been found that languages differ in the amount of final lengthening they show (Delattre, 1966; Hallé, Boysson-Bardies & Vihman, 1991). For example, Delattre (1966) found that the ratio of final syllable to non-final syllable durations was 1.53 for English, 1.50 for German, 1.17 for Spanish and 1.78 for French.[5] We can here note that this ratio for Creek vowels was 1.35 - that is, the Creek final vowels were about one and one/third longer than the initial vowels. Of course, such language comparisons are confounded with any number of possible language-specific differences (in e.g. vowel quality or phonotactics, not to mention possible differences in the performances of the groups of speakers) which make such comparisons problematic. Nonetheless, the magnitudes of the cross-linguistic differences which have been observed suggest that it is

[5] In addition to this evidence of linguistic variation in final lengthening, Ho (1976) found an interesting interaction between final lengthening and duration associated with tonal distinctions in Beijing Mandarin. In some phrase final positions short tones were shorter than average while long tones were longer.

reasonable to assume that whatever the general causes of final lengthening may turn out to be, these motivating factors are implemented differently in different languages.

Short vowel centralization

Figure 4 showed that, in Creek, the distinctively short vowels are somewhat centralized relative to the distinctively long vowels. In connection with that figure we noted that Lehiste (1970) reported that this had been found in a number of languages. In a survey of the literature we have found that short vowel centralization is indeed very common, but perhaps not universal (5). As indicated in (5b) some studies have found no differences between the formant values of long and short vowels. Behne, Moxness & Nyland (1996) noted in their study of Norwegian that though the differences between long and short vowels rarely reached statistical significance the short vowels tended to be somewhat centralized (this may also be the case in the Fischer-Jørgensen, 1972 study). Gordon (1996) reports very briefly on the vowels of Hupa and notes some tendency for centralization of short [a] but not [o] in Hupa, and describes the long and short front vowels as [I] and [e:] though no duration data, or word list are given. Apparently, short vowel centralization is not as uniformly present cross-linguistically as final lengthening.

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(5) Results of a survey of the literature on short vowel centralization. These studies reported vowel formant measurements in ‘quantity’ languages where the primary distinction between long and short vowels is vowel duration and the long short pairs are phonetically transcribed as having the same vowel quality.

(a) Quantity languages in which short vowels are more central than long vowels.

Serbo-Croatian (Lehiste & Ivic, 1986)
Czech (Straka, 1959)
Hungarian (Tarnóczy, 1964)
Cairo Arabic (Norlin, 1984)
Scottish Gaelic (Ladefoged, Ladefoged, Turk, Hind, & Skilton, 1997)
Aleut (Cho, Taff, Dirks, & Ladefoged, 1997)
Navajo (McDonough, Ladefoged & George, 1993;
McDonough & Austin-Garrison, 1994)
Toda (Shalev, Ladefoged & Bhaskararao, 1993)
Cantonese (Lee, 1983)
Thai (Abramson & Ren, 1990)

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