Linguistic aspects of voice quality with special reference to Athabaskan[*]

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1. Introduction

Many languages of the world use differences in voice quality or phonation type to contain linguistic functions. Thus, in certain languages, lexical items are differentiated solely on the basis of differences in voice quality. For example, in Jalapa Mazatec, an Otomanguean language spoken in Mexico (Kirk et al. 1993), the three words /já/ meaning 'tree', /já̤/ meaning 'he wears' and /já̰/ meaning 'he carries' differ only in the voice quality associated with the vowel. In the first word, the vowel is characterized by modal voicing, the default type of voice quality found in all languages of the world and involving regular, periodic vibration of the vocal folds. The second word contains a breathy voiced vowel, which is marked by a greater aperture of the vocal folds relative to modal voice (Ladefoged 1971, Laver 1980). The increased opening of the vocal folds allows more air to pass through the glottis and creates turbulence not present with modal phonation. Finally, the third word has a creaky vowel, which involves a more tightly adducted glottis than either modal or breathy voice (Ladefoged 1971, Laver 1980). This laryngeal setting gives the auditory impression of a "rapid series of taps, like a stick being run along a railing" (Catford 1964:32).

Within the Athabaskan language family, although voice quality is not known to contrast in vowels, many languages distinguish between modal voiced and creaky voiced sonorants. For example, in Hupa, the word /xoŋ̰/ 'fire' with a final creaky voiced velar nasal contrasts with the word /xoŋ/ 's/he' containing a final modal voiced velar nasal. In addition to this (somewhat limited) use of distinctive voice quality, in most, if not all, Athabaskan languages, non-modal voice qualities arise as predictable variants of modal phonation in certain contexts. For example, vowels adjacent to phonemic glottal stop are often realized with a creaky voice quality immediately adjacent to the glottal closure. Similarly, vowels in the vicinity of phonemic /h/ also typically display some breathiness.

This paper examines some of the linguistic uses of different voice qualities, in particular, the two most common types of non-modal voice, breathy and creaky voice, and their phonetic realization in a number of languages, focusing on the Athabaskan languages, Hupa and Western Apache. The organization of the paper is as follows. Section 2 discusses some of the phonetic correlates of voice quality differences, and how they can be discovered using relatively basic acoustic analysis techniques (see Epstein and Ladefoged this volume for further discussion of phonetic aspects of voice quality). Section 3 focuses on some interesting timing and phonological issues relevant to the realization of phonation differences. This section also presents results of an acoustic study of allophonic creaky voice in the vicinity of ejectives in two Athabaskan languages: Hupa and Western Apache. Finally, section 4 summarizes the paper.

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[*] Many thanks to the kind speakers of the various languages discussed here who so generously contributed data and to participants at the Voice Quality Workshop at the 2001 Athabaskan conference at UCLA for stimulating discussion.

2. Acoustic correlates of voice quality

2.1. Creaky voice

Creaky voice and breathy voice are readily differentiated from each other and from modal voice by looking at basic acoustic displays such as waveforms and spectrograms. Creaky voice is characterized by irregularly spaced glottal pulses and reduced acoustic intensity relative to modal voice. Both of these properties are evident in the spectrogram and waveform excerpt in figure 1 of the Hupa word /k^j’aʔaʔ/ ‘woodtick’ (female speaker) in which the sequence of phonemic glottal stop + vowel + phonemic glottal stop is realized as a creaky vowel (between 295 and 380 milliseconds) which then becomes more modal briefly (between 380 and 420 milliseconds) before returning to creak and culminating in the final glottal closure; thus, phonetically [k^j’aa̰aa̰ʔ/]. The waveform corresponds to the portion of the spectrogram between 350 and 430 milliseconds, and thus encompasses both creaky (between 350 and approximately 380 milliseconds) and modal phases (after 380 milliseconds). The phonetic transcription under the spectrogram indicates the approximate location of different acoustic events.

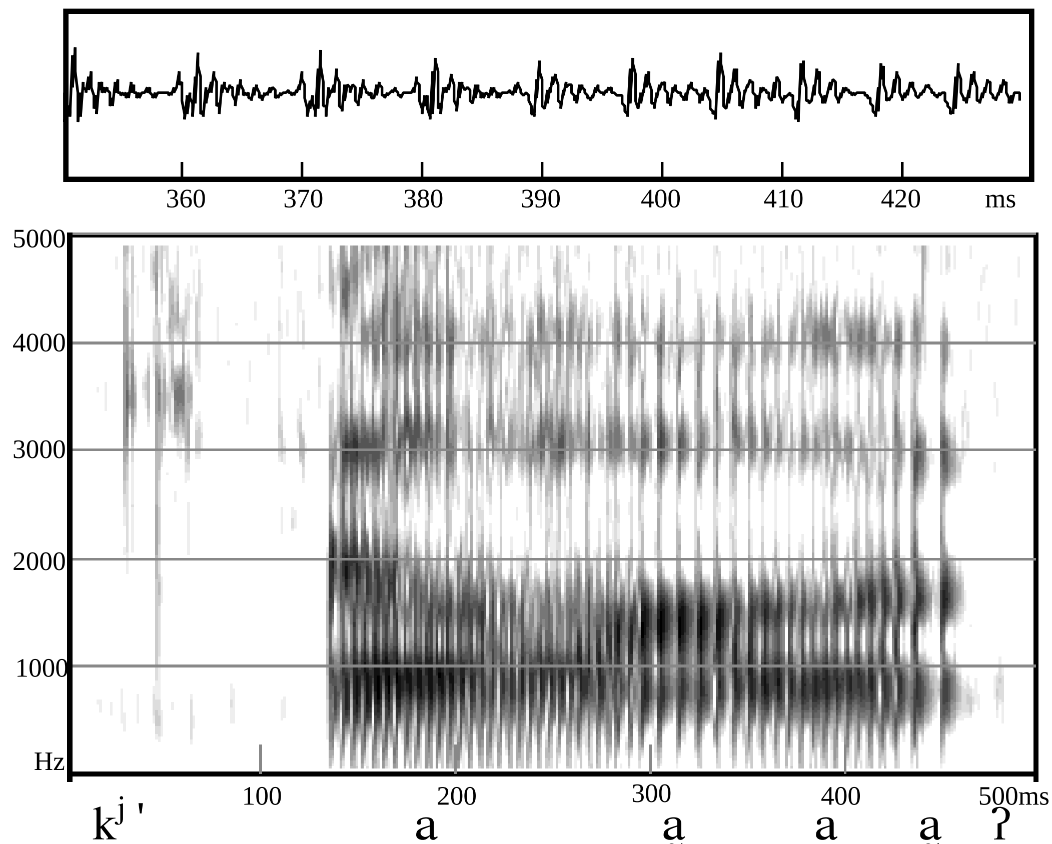
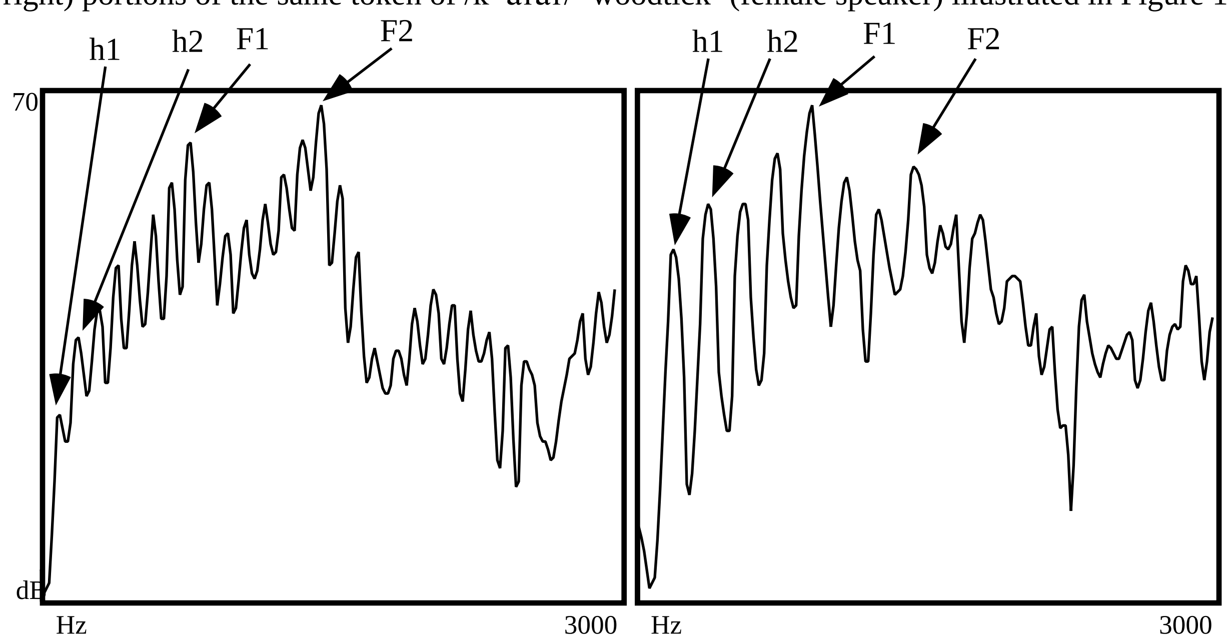


Figure 1. Waveform and spectrogram of the Hupa word /k^j’aʔaʔ/ ‘woodtick’ (female speaker)

Not only are the pitch periods associated with creaky voice irregular in terms of their duration compared to modal voice, they are also considerably longer than those characteristic of modal phonation, reflected in the relatively infrequent pitch cycles in the waveform and the greater distance between the vertical striations representing pitch periods in the spectrogram. The increased length of the pitch cycles is indicative of a lowered fundamental frequency (the acoustic correlate of the perceptual property of pitch) for creaky voice relative to modal voice. Creaky voice is associated with lowered fundamental frequency values (relative to modal phonation) in many languages, synchronically or diachronically, e.g. Mam (England 1983), Northern Iroquoian languages such as Mohawk, Cayuga, and Oneida (Chafe 1977, Michelson 1983, Doherty 1993).

Creaky voice is also distinguished from modal voice in terms of its spectral properties as evidenced by other types of acoustic displays. Creaky voice is characterized by a shallower spectral tilt than modal voice (see Kirk et al. 1993, Silverman et al. 1995 on Jalapa Mazatec): the decrease in energy as frequency increases is relatively small for creaky voice compared to modal voice. This difference in spectral tilt can be quantified by comparing the relative intensity of different harmonics for the two voice qualities. One such relative measure involves subtracting the intensity of the first harmonic, equivalent to the fundamental frequency, from the intensity of the second harmonic (h2-h1). Other spectral tilt measures entail subtracting the intensity of the first harmonic from the intensity of harmonics closest to formants such as the first (F1-h1) or second formants (F2-h1). For all of these spectral tilt measures, the expectation is that h2-h1, F1-h1 and F2-h1 values will be larger for creaky voice than for modal voice, meaning that intensity values at higher frequencies relative to intensity values at lower frequencies are comparatively great for creaky phonation. Differences in spectral tilt of this sort are evident in the power spectra in figure 2 taken from creaky (on the left) and modal (on the right) portions of the same token of /kʲ’aʔaʔ/ ‘woodtick’ (female speaker) illustrated in Figure 1.



Creaky/a̰/ Modal /a/

Figure 2. FFT spectra of creaky and modal phases of the vowel /a/ in the Hupa word /kʲ’aʔaʔ/ [kʲ’aa̰aa̰ʔ/] (female speaker)

The creaky sample is marked by a steep increase in intense as one progressively moves from low frequency components such as h1 up through higher frequency landmarks: h2, F1, and F2. In contrast, the modal phase of the vowel shows a relatively small increase in intensity moving from h1 to F1 and even has a drop in intensity going from F1 to F2. An additional point of interest is that the fundamental frequency (equivalent to the first harmonic) is substantially lower in frequency in the creaky sample than in the modal sample.

2.2. Breathy voice

Differences between breathy voice and modal voice are also evident in the same types of displays used to discern differences between creaky and modal phonation. Like creaky voice, breathy voice is typically associated with a reduction in acoustic intensity (see Fischer-Jørgensen 1967 on Gujarati, Thongkum 1988 on Kui and Chong, Traill and Jackson 1988 on Tsonga) and a lowering of fundamental frequency (see Hombert et al. 1979 for an overview) relative to modal voice. In addition, breathy voice is marked by the presence of substantial aperiodic or noisy energy in the signal, unlike modal and creaky voice. The leakage of air through the partially open glottis widens the bandwidth of individual formants, thereby obscuring formant structure. The combination of poorly defined formant structure and increased turbulence reduces the definition and complexity of individual pitch periods observed in waveforms of breathy vowels. These characteristics of breathy voice can be seen in the spectrogram and excerpted waveform of the Hupa word /tʃ’ahl̥/ ‘frog’ (female speaker) in figure 3 containing a vowel which starts off modal (170 milliseconds) before ending breathy (between 190 and 220 milliseconds) before the final /h/, which is voiceless and thus lacks pitch cycles.

Breathy voice is also associated with spectral characteristics which differentiate it from modal voice as well as from creaky voice. Breathy voice characteristically displays the greatest decrease in intensity of spectral components at higher frequencies. Thus, breathy voice occupies one end of a continuum of spectral tilt with creaky voice at the other extreme and modal voice occupying an intermediate position. We saw earlier in figure 2 that low frequency components are relatively weak for creaky voice compared to modal voice. Low frequency components in breathy vowels are conversely relatively intense compared to modal voice. Figure 4 contains representative breathy (on the left) and modal (on the right) phases of the vowel in the same token displayed in figure 3.

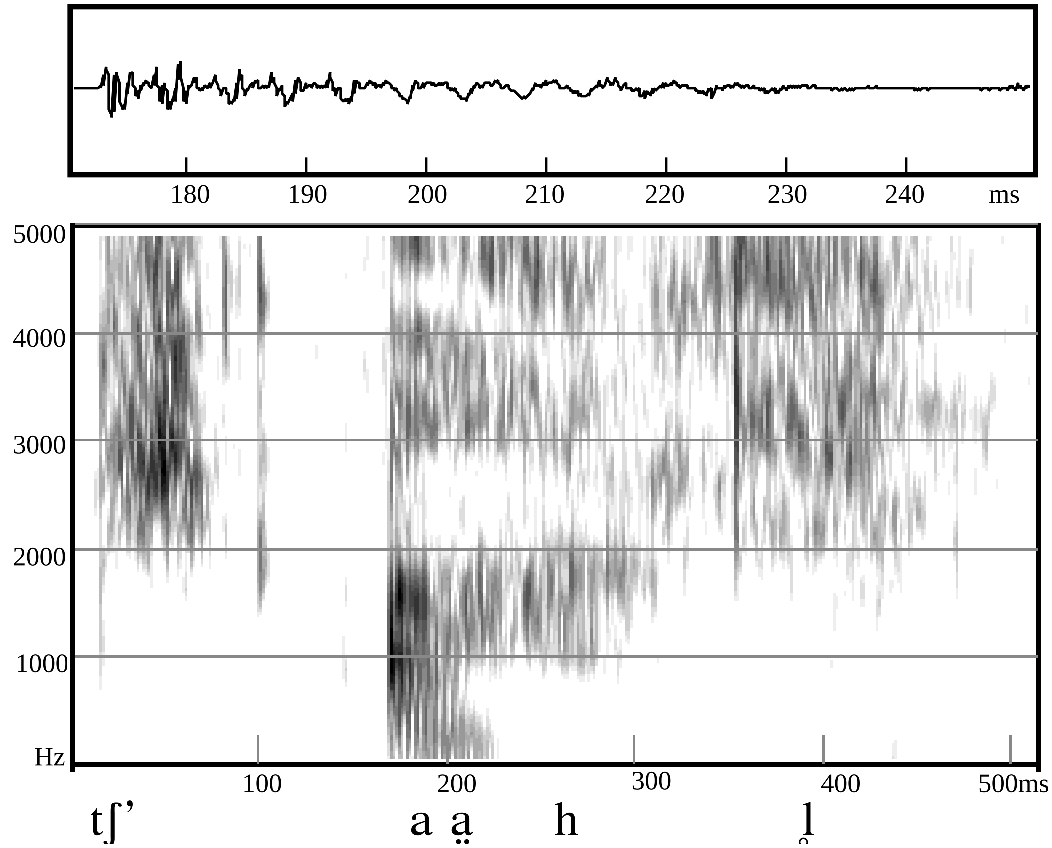


Figure 3. Waveform and spectrogram of the Hupa word /tʃ’ahl̥/ ‘frog’ (female speaker)

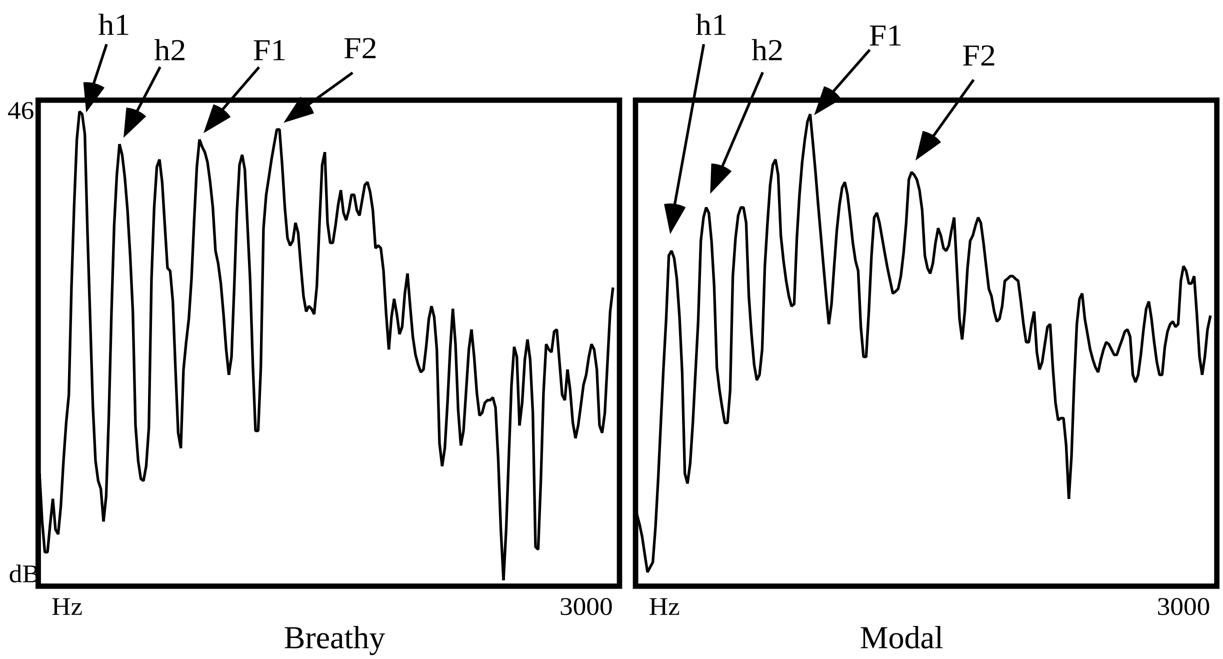


Figure 4. FFT spectra of breathy and modal /a/ in the Hupa word /tʃ’ahl̥/ ‘frog’ (female speaker)

During the breathy phase of the vowel, the most intense component in the signal is the first harmonic, while h2, F1 and F2 are roughly equivalent in intensity. During the modal portion of the vowel, there is a clear increase in intensity (though not as great as during a creaky vowel) as one moves from h1 to h2 to F1, with a slight drop-off in intensity going from F1 to F2, though F2 still is more intense than either of the first two harmonics.

3. Linguistic functions and timing of phonation events

3.1. Creaky voiced sonorants

Within the Athabaskan family, voice quality is only used to differentiate creaky and modal voiced sonorants in certain languages in root-final position and also across morpheme boundaries (where one might reanalyze them as glottal stop + sonorant clusters). The contrast between creaky and modal voiced sonorants in root-final position is found in Pacific Coast Athabaskan languages and certain Northern Athabaskan languages (see Krauss and Leer 1981 for discussion of Athabaskan sonorants). Pacific Coast Athabaskan languages like Hupa are particularly interesting with respect to creaky voiced sonorants (often referred to as glottalized sonorants), since an aspectual contrast between heavy and light stems (Golla 1970, 1977) is signaled by differences in the timing of the creak relative to the sonorant. Thus, in light stems, which convey a semantic sense of lesser definiteness relative to heavy stems, root-final creaky voiced nasals realize their creak on the end of the nasal (i.e. as post-glottalized nasals) while, in heavy stems, the creak is realized at the beginning of the nasal (i.e. as pre-glottalized nasals). This situation is unusual cross-linguistically, as the timing of creaky voice associated with sonorants is typically non-contrastive and is either, depending on the language, consistently realized at the beginning of the sonorant or variably realized as a function of context (see Gordon and Ladefoged 2001). In languages with allophonic variation in the timing of creak, the typical scenario is for creak to be realized at the beginning of the sonorant when it precedes a vowel and otherwise at the end of the sonorant (Gordon and Ladefoged 2001). In fact, the contrastive use of timing differences associated with creaky voiced nasals in Hupa originated as contextual variation of this sort: the root-final consonant in heavy stems was originally followed by another vowel (and still is when a consonant-initial suffix follows the stem), while the root-final consonant in light stems was not (Golla 1970, 1977).

Both pre and post-glottalized nasals in Hupa may be realized phonetically in different ways, depending on the particular speaker, the larger context in which the nasal occurs, and the particular instance of a word containing a glottalized nasal. There is a particularly large range of variation in the phonetic realization of pre-glottalized nasals. Figures 5-7 illustrate different phonetic realizations of preglottalized nasals. In figure 5, which contains a spectrogram of the word /kʲ'ɪwɪnjan̰/ [ʔjuːnjan̰] 'unshelled acorns' (female speaker), creak is realized on the end of the final vowel culminating in a brief glottal stop before the /n/. In figure 6, which illustrates another token of the same word as in figure 5 uttered by the same speaker, the creaky phase of the final vowel is relatively short but this is more than compensated for by the lengthy glottal closure before the final nasal. Finally, in figure 7, which contains a spectrogram of the word /nɪtʃʷʰen̰/ [nɪtʃʷʰen̰] 'it is bad' (male speaker), creak is also realized on the end of the final vowel persisting through the nasal, though complete glottal closure is never achieved unlike in figures 5 and 6.

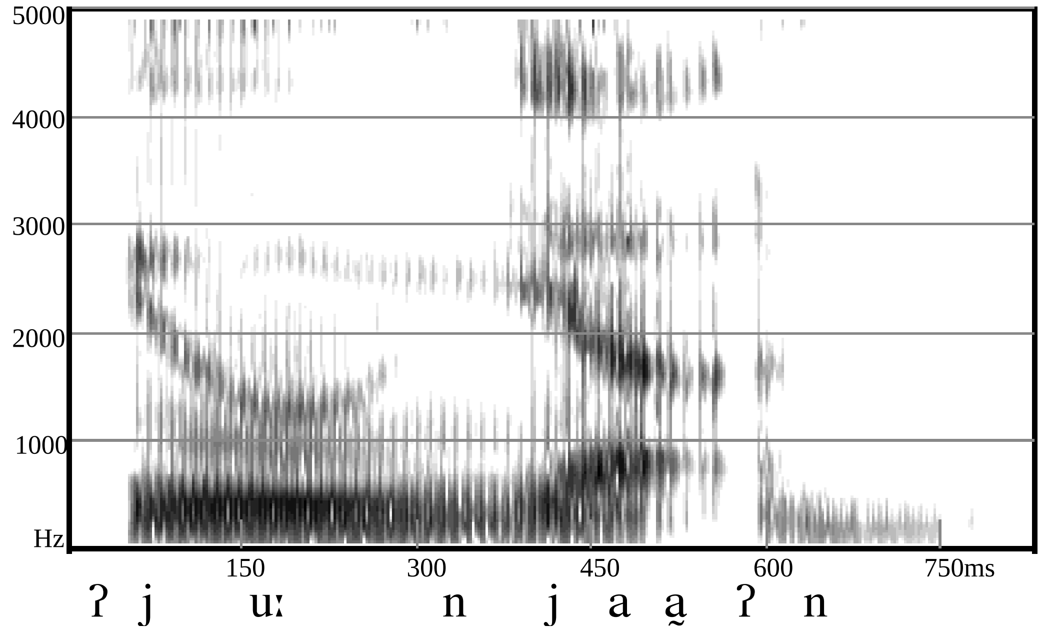


Figure 5. Waveform and spectrogram of the Hupa word /k^{j}’ɪwɪnjan̰/ [ʔjuːnjaʔn] ‘unshelled acorns’ (female speaker)

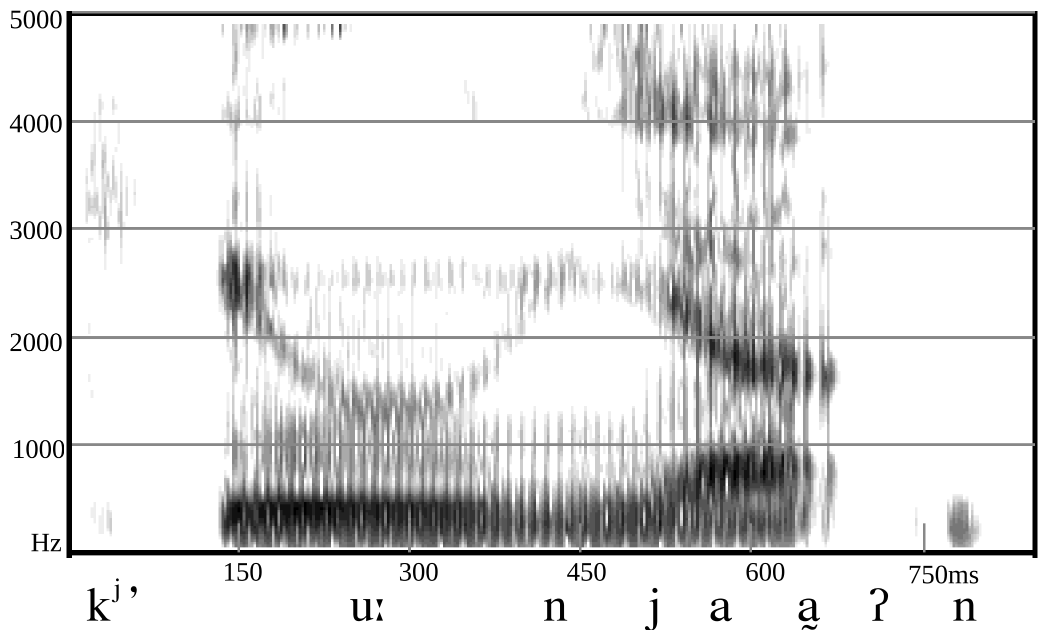


Figure 6. Waveform and spectrogram of the Hupa word /k^{j}’ɪwɪnjan̰/ [k^{j}’uːnjaʔn] ‘unshelled acorns’ (female speaker)

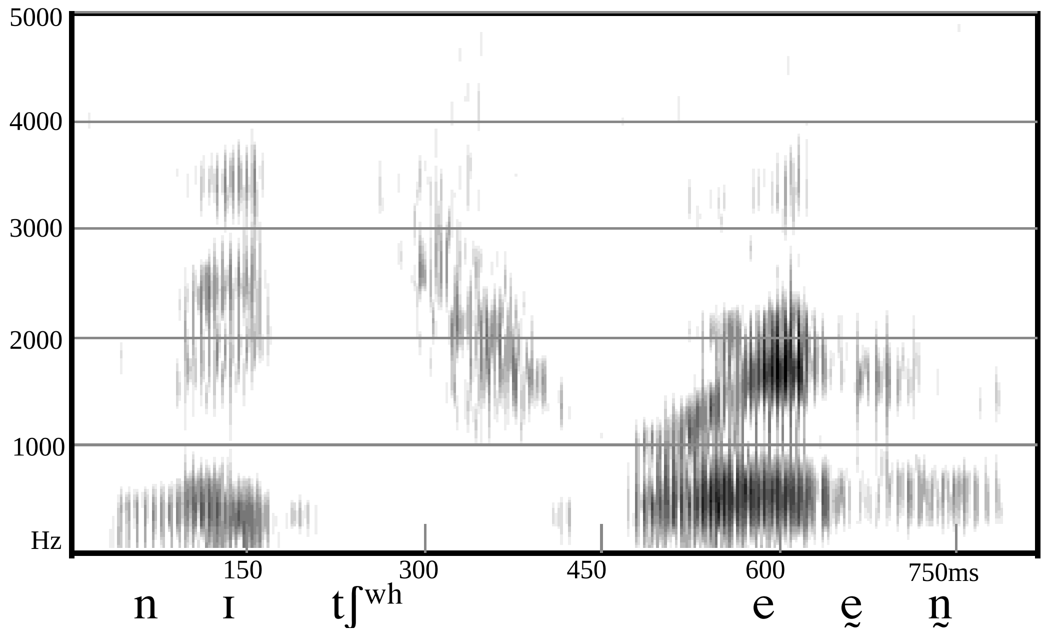


Figure 7. Waveform and spectrogram of the Hupa word /nɪtʃ^{wh}en̰/ [nɪtʃ̰^{wh}en̰] ‘it is bad’ (male speaker)

Postglottalized nasals are illustrated in Figures 8 and 9, which contain spectrograms of the word /maŋ̰/ ‘fly’ as uttered by the same female speaker. In figure 8, at the end of the nasal (which has a very approximant-like articulation) there is a brief period of creaky phonation culminating in a glottal stop. Figure 9 lacks noticeable creak on the vowel preceding the nasal, but has a lengthy glottal stop followed by an audible release as a /k/.

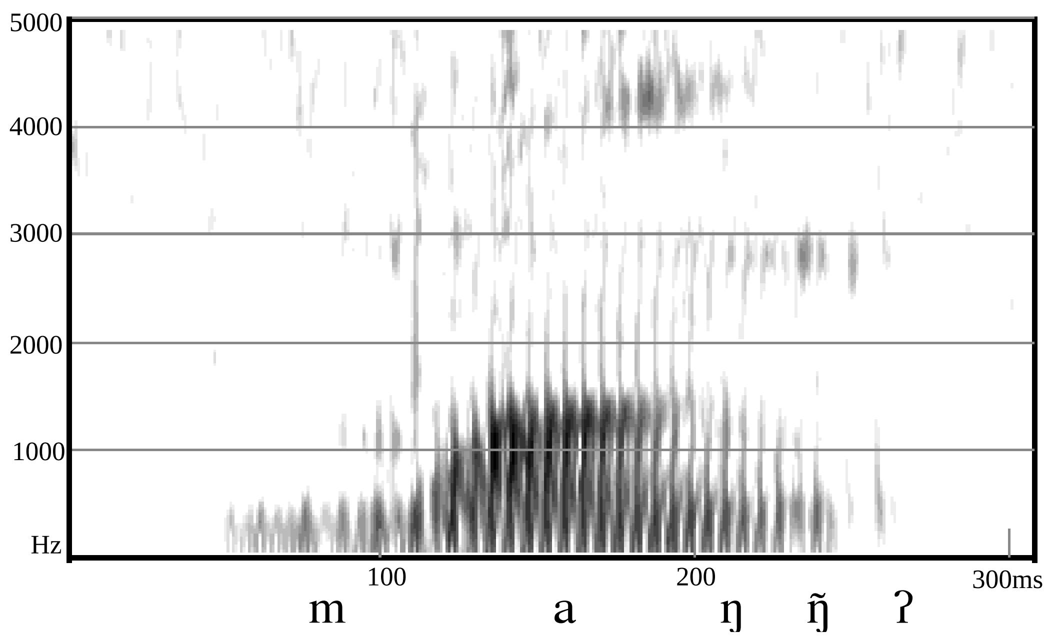


Figure 8. Waveform and spectrogram of the Hupa word /maŋ̰/ [maŋ̰ʔ]‘ ‘fly’ (female speaker)

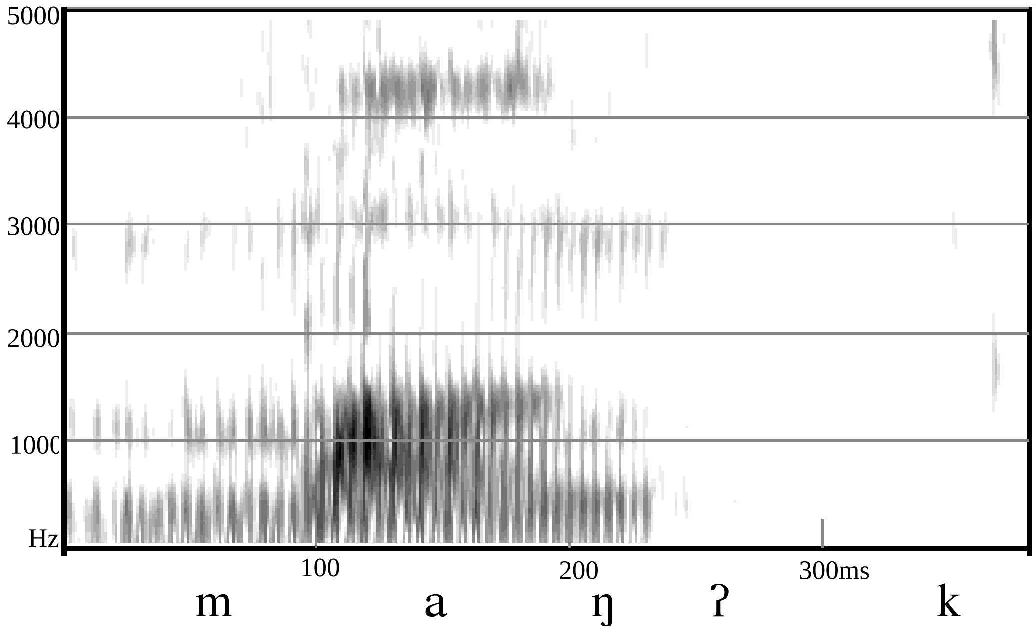


Figure 9. Waveform and spectrogram of the Hupa word /maŋ̃/ [maŋ̃ʔk]'fly' (female speaker)

3.2. Glottal stop and /h/

Another context in which non-modal voice qualities commonly arise in many languages, including Athabaskan languages, is in the vicinity of glottal stop and /h/. Frequently, the portion of vowels immediately adjacent to /h/, which is essentially a voiceless vowel, are breathy. This was seen earlier in the spectrogram of /tʃ'ahl̥/ in figure 3. Vowels immediately adjacent to glottal stop are often creaky, with the degree of creak decreasing as one moves away from the stop. Contextual creakiness on vowels adjacent to glottal stop can be seen in figure 10, which contains a spectrogram of the Hupa word /w̥ɪʔat/ [w̥aʔat] 'my wife' (male speaker), in which there is a full glottal stop in intervocalic position.

In many cases, creakiness on an adjacent sound is the only clue to the presence of a phonemic glottal stop, as it is not uncommon for full glottal closure not to be achieved, particularly in positions that are non-final. The realization of glottal stop as creaky voice was seen earlier in Figure 3, where the first glottal stop is realized as creaky phonation rather than as a full glottal stop.

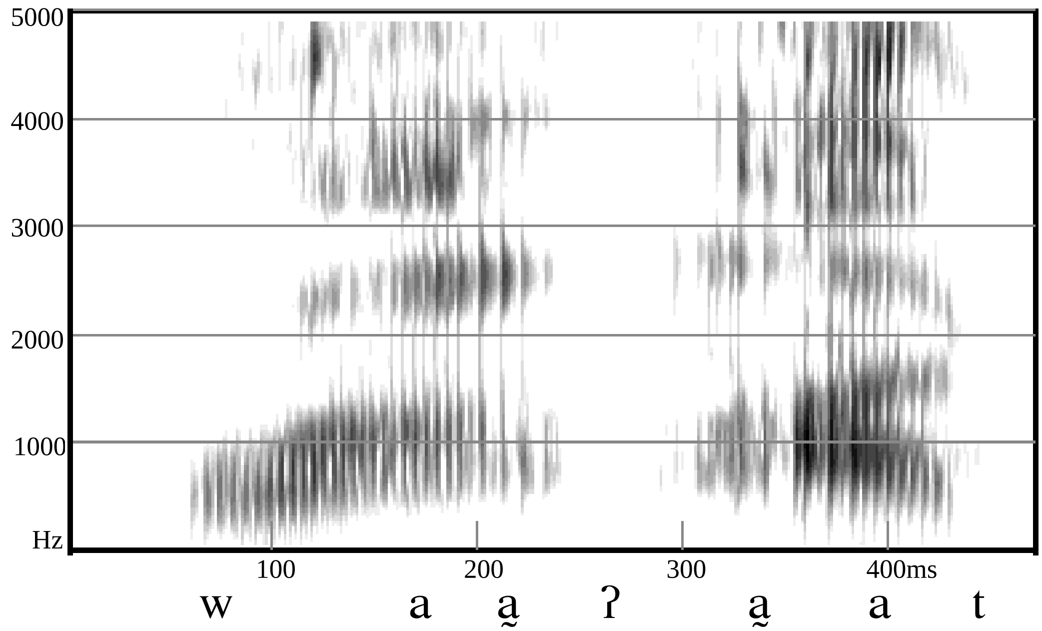


Figure 10. Waveform and spectrogram of the Hupa word /w̥ɪʔat/ [w̥aʔat] ‘my wife’ (male speaker)

3.3. Ejectives and creak

Another context where one might expect contextual creakiness is on a vowel immediately following an ejective. Although ejectives found in Athabaskan languages typically have fairly long voicing lags following the release (see, for example, McDonough and Ladefoged 1993 on Navajo, Gordon 1996 on Hupa, Potter et al. 1999 on Western Apache), there are instances in which the vowel immediately following an ejective is realized with noticeable creakiness at the beginning. For example, Figure 11 depicts an ejective followed by a creaky voiced vowel from the Western Apache word /ɪk’ah/ ‘fat’ as produced by a female speaker.

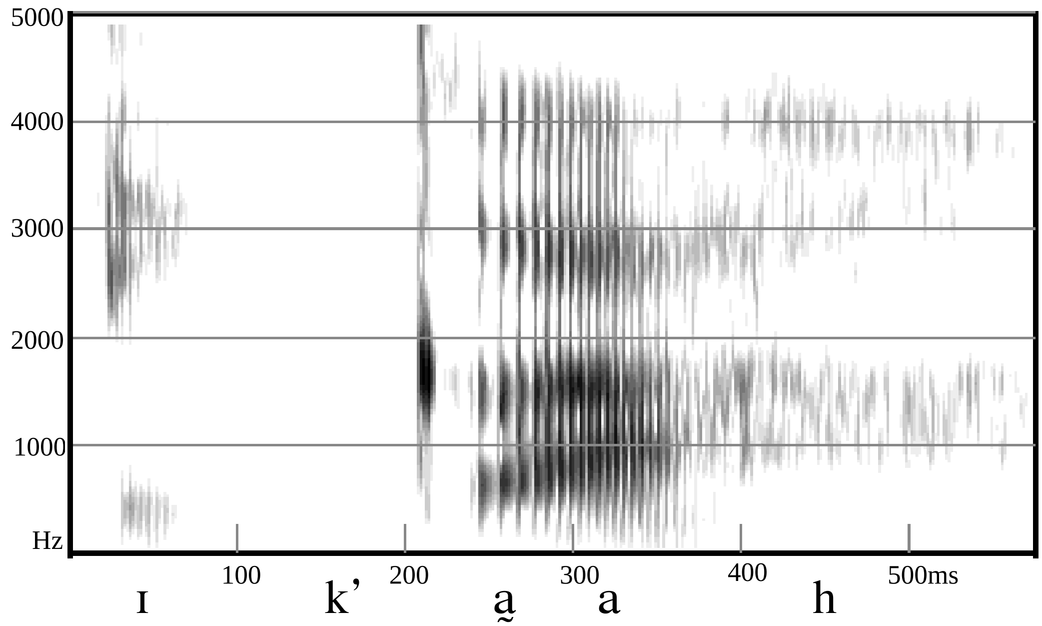


Figure 11. Waveform and spectrogram of the Western Apache word /ɪk’ah/ ‘fat’ (female speaker)

In this token, there are several pitch periods (lasting over 50 milliseconds in total) at the onset of the vowel which are noticeably creaky (between 240 and 290 milliseconds). Based on observations of ejectives uttered by several Western Apache speakers (see Potter et al. 1999) for discussion of the phonetics of Western Apache), tokens like that in figure 11 displaying noticeable creakiness for a lengthy portion of the vowel following an ejective seem to be relatively uncommon. Rather it is more typical for phonation to appear modal throughout virtually their entire duration following an ejective, as illustrated in the example in Figure 12 of the same word as in Figure 11, as uttered by another speaker.

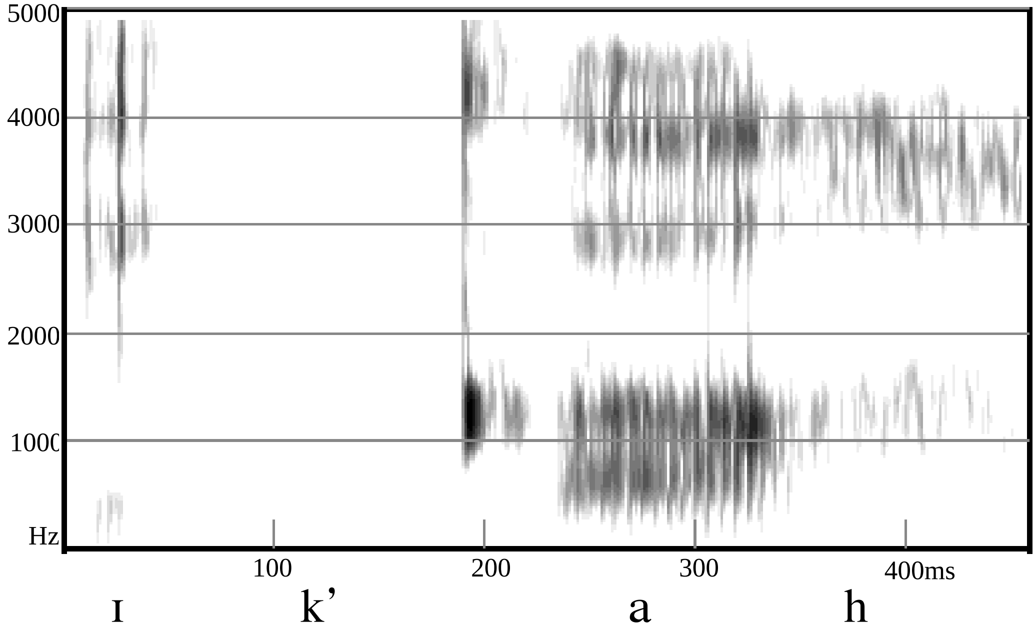


Figure 12. Waveform and spectrogram of the Western Apache word /ɪk’ah/ ‘fat’ (female speaker)

The absence of noticeable creak on vowels following ejectives also is characteristic of Hupa (see Gordon 1996 for discussion of Hupa stop consonants), a Pacific Coast Athabaskan language, and also Navajo (see McDonough and Ladefoged 1993 for discussion of Navajo stop consonants), another Apachean Athabaskan language closely related to Western Apache. Nevertheless, despite visual appearances to the contrary, it is still possible that vowels following ejective stops are characterized by a different phonation setting than vowels following non-ejective stops. It may thus be the case that the spectral tilt measurements discussed in section 2.1 reveal that vowels following ejectives are creaky for at least some portion of their duration, and that this contextual creakiness serves as a secondary cue to the ejective nature of the stop, complementing the burst and voice-onset-time properties differentiating ejectives from other stops.

3.4. Contextual creakiness in Western Apache and Hupa: a phonetic study

In order to investigate the potential role of contextual creakiness in differentiating ejectives from other stops, a small study was conducted using data on Hupa and Western Apache. The vowel /a/ immediately following ejectives were compared with vowels following unaspirated stops to see whether they differed from each other in their voice quality. The target vowels appeared following consonants at two places of articulation: dental/alveolar and a backer articulation, velar in Western Apache and uvular/back velar in Hupa. (Both languages, not surprisingly from an Athabaskan perspective, lack bilabial ejectives). Data from seven speakers (two females and five males) of Western Apache and two speakers (one female and one male) of Hupa were investigated. The words in which the vowels were measured in the two languages appear in Tables 1 (Western Apache) and 2 (Hupa).

Table 1. Words used to measure voice quality in Western Apache. (Transcriptions in IPA; measured vowels are underlined; high tone is marked)

Stop	Word	Gloss
t	pɪtá̲ʔjú	at its edge
t’	pɪt’a̲h	near him/her
k	pɪka̲t	her/his cedar
k’	ɪk’a̲h	fat

Table 2. Words used to measure voice quality in Hupa. (Transcriptions in IPA; measured vowels are underlined.)

Stop	Word	Gloss
t	w̥ɪta̲ʔ	my mouth
t’	w̥ɪt’a̲h	my pocket
q	qa̲t	tree root
q’	q’a̲t	now, already

The words in Tables 1 and 2, each of which was repeated twice by individual speakers, were digitized at 16kHz using Kay Elemetrics CSL as a part of independent phonetic studies reported on elsewhere. For this study, an FFT spectrum was computed for each of the target vowels over a window starting at the beginning of the vowel (as diagnosed through the first appearance of the second formant in an accompanying spectrogram) and lasting 32 milliseconds (512 sample points). From the spectrum, three intensity measurements of spectral tilt were taken: h2-h1, F1-h1, and F2-h1. In addition, the frequency of the fundamental (first harmonic) and the first and second formant were also measured from each spectrum.

Results for both Hupa and Western Apache were similar and confirmed that voice quality differs between vowels following ejectives and those following non-ejective stops. In particular, many spectral measures characteristic of creaky voiced vowels in other positions (vowels adjacent to glottal stops) also characterize the portion of vowels immediately following ejectives in Hupa and Western Apache.

3.4.1 Western Apache

Looking first at Western Apache, F1-h1 values were greater for vowels following ejectives than for vowels following unaspirated stops by 5.25 dB averaged over all seven speakers, a difference which was significant according to an analysis of variance (ANOVA): $F(1, 41) = 9.35$, $p=.0039$. Six of the seven speakers displayed this pattern of greater F1-h1 values for post-ejective vowels, suggesting a greater increase in intensity at higher frequencies and thus greater creakiness for vowels following ejectives than for vowels following non-ejective stops. In addition, F2-h1 values were also significantly larger for vowels after ejectives: 5.87 dB averaged over all speakers, $F(1, 41) = 10.29$, $p=.0026$. Six of seven speakers displayed this pattern; the only speaker who showed the opposite pattern was the same speaker who behaved exceptionally with respect to the F2-h1 results. The final spectral tilt measure, h2-h1, was less definitive in differentiating vowels following ejectives and those following unaspirated stops. Averaged over all seven speakers, ejectives had marginally lower h2-h1 values, .29 dB, yielding a non-significant effect according to an ANOVA: $F(1, 41) = .06$, $p=.8070$. Two speakers had larger h2-h1 values for post-ejective vowels, three displayed a reversal of this pattern, and two had virtually no difference in h2-h1 values between vowels following ejectives and those following unaspirated stops.

Vowels following ejectives also had lower fundamental frequency (h1) values than vowels following unaspirated stops. This difference was 12.64 Hz averaged over all speakers and was significant according to an ANOVA: $F(1, 41) = 8.829$, $p=.0049$. An analysis separating vowels according to the place of articulation of the preceding consonant revealed a similar result for vowels following dental/alveolars and those following velars. This separation according to place of articulation was important, since the vowel following the unaspirated dental/alveolar stop is high-toned, whereas its counterpart adjacent to the dental/alveolar ejective does not bear high tone. Thus, any lowering effect of the dental/alveolar ejective on the fundamental of the following vowel could potentially be attributed to the high tone on vowel rather than to the ejective itself. This potential confound does not interfere with comparison of the vowels following velars. In fact, vowels following velar ejectives had lower fundamental frequency values for four of seven speakers (a 13.43 Hz difference [averaged over all speakers) than vowels following velar unaspirated stops, indicating that ejectives tend to lower the fundamental of following vowels (at least for certain speakers) independent of the tonal specification of the vowels.

Another result was that first formant frequency values were higher and second formant values were lower on average for vowels following ejectives than for vowels following unaspirated stops. Thus, F1 values were 44 Hz higher (averaged over all speakers) and F2 values were 146 Hz lower for vowels after ejectives than for vowels after unaspirated stops. Although I am not aware of other studies indicating that creakiness is associated with lowering of second formant values, researchers working on other languages have discovered a raising of first formant values similar to those found in Western Apache. For example, in their study of the Otomanguean language Jalapa Mazatec, which contrasts creaky (as well as breathy) voice with modal voice, Kirk et al. (1993) found that frequency values for the first formant were higher during creaky phonation than during modal (and breathy) phonation. They speculate that this difference is due to a raising of the larynx and concomitant shortening of the vocal tract during creaky voice. Similarly, Maddieson and Ladefoged (1985) also report raised first formant values for tense vowels, which are similar in certain respects to creaky vowels, in Haoni, a Sino-Tibetan language of China.

3.4.2. Hupa

Results for Hupa were quite similar to those for Western Apache. Both F1-h1 and F2-h1 values were greater for vowels following ejectives than for those following unaspirated stops: F1-h1 was 10.43 dB higher and F2-h1 was 11.75 dB higher for post-ejective vowels than for vowels following unaspirated stops averaged over both speakers. The effect of the laryngeal feature of the preceding consonant on both F1-h1 and F2-h1 was significant according to ANOVAs: $F(1, 11) = 8.731$, $p=.0131$ for F1-h1; $F(1, 11) = 6.969$, $p=.0230$ for F2-h1. The difference between h2-h1 values as a function of the preceding consonant did not reach statistical significance according to an ANOVA: h2-h1 was only 2.80 dB greater for vowels following ejectives than for vowels following unaspirated stops (averaged over both speakers); $F(1, 11) = 2.216$, $p=.1647$. Both speakers did, however, show the same trend for h2-h1 to be greater after ejectives than after unaspirated stops, 4 dB for the male speaker and 2.4 dB for the female speaker. It is thus conceivable that more data would indicate that this third measure of spectral tilt would also point to increased creakiness in vowels following ejectives.

Fundamental frequency values did not reliably differentiate vowels following ejectives from those following unaspirated stops. For one speaker, ejectives triggered a raising of the fundamental (f0 was 20 Hz higher following ejectives), whereas the other speaker displayed the opposite pattern (f0 was 31 Hz lower following ejectives), though there is probably too little data to attach much importance to this discrepancy between speakers. Interestingly, as in Western Apache, first formant frequency values were higher and second formant values were lower for vowels following ejectives. F1 was 19 Hz higher and F2 was 260 Hz lower after ejectives (averaged over both speakers).

4. Conclusions

In summary, voice quality distinctions play an important role in a number of languages, including Athabaskan languages, where phonation differences both contrast in sonorants in certain languages as well as aid in the signaling of other linguistic contrasts in many languages. Differences in voice quality are visually apparent in basic acoustic displays and can be quantified through different measures taken from these displays. Finally, there is considerable variation in the phonetic realization of non-modal phonation, as we have seen in the case of creaky voiced sonorants.

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