PHONETIC STRUCTURES OF WESTERN APACHE

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1. Introduction

Western Apache is a Southern Athabaskan language spoken primarily on the San Carlos and White Mountain Apache Reservations in east central Arizona. Figure 1 illustrates the locations of these reservations.

Figure 1. Map indicating primary area in which Western Apache is spoken.

The first recorded use of the term ‘Apache’ is by Juan de Oñate at San Juan Pueblo on September 9, 1598. As discussed in Opler (1983), there are several hypotheses about the original source for this word including the Zuni and Yavapai words [ʔaapaču] and [ʔawáača], respectively, referring to the Southern Athabaskan people in general, as well as the Spanish word *mapache* ‘racoon’. The Western Apache people refer to themselves (in their practical orthography) as the ‘nnee’, ‘ndee’, or ‘inee’, depending on dialect.

The Southern Athabaskan languages, also known as the ‘Apachean’ languages, additionally include Navajo, and Mescalero, Chiricahua, Jicarilla, Lipan, and Plains Apache. The classification in Figure 2 combines the proposals in Hoijer (1938) and Hoijer (1971), and is compatible with that of Hardy (1979). Note that Chiricahua and Mescalero are considered to be distinct languages, although they are mutually intelligible. of one language.

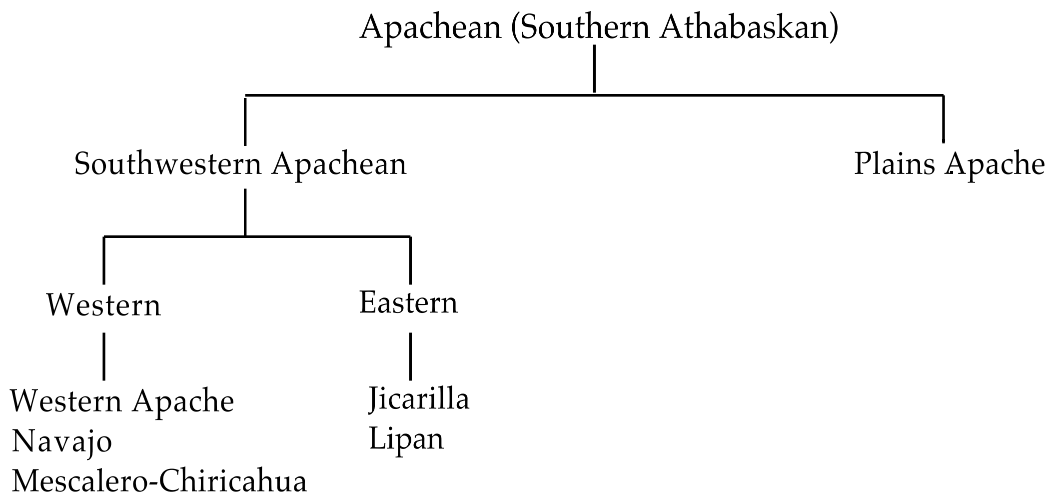

Figure 2. Classification of the Southern Athabaskan languages.

Hoijer identified the Apachean languages as ‘closely related’ (Hoijer 1963:6) but ‘mutually unintelligible dialect groups’ (Hoijer 1945:193, 1938). Western Apache is not mutually intelligible with Navajo, its geographically closest relative, but de Reuse (1993, 1994) notes that Western Apache and Navajo speakers understand much of each other’s languages, and that some speakers claim mutual intelligibility. Western Apache dialects spoken in regions close to the Navajo reservation exhibit a greater degree of mutual intelligibility with Navajo than do dialects spoken in regions farther from the Navajo reservation. The Tonto dialect of

Western Apache, spoken in and near Camp Verde and Payson, Arizona, is geographically and linguistically the closest dialect to Navajo, while the San Carlos dialect, the predominant dialect on the San Carlos Reservation, is geographically and linguistically the most distinct. Note that the predominant dialect on the White Mountain Apache reservation is White Mountain Apache.

The 1990 U.S. Census reports an estimated 12,390 speakers of ‘Apache’. It is unclear to what extent this figure accurately distinguishes Western, Mescalero-Chiricahua, Jicarilla, Plains, and Lipan Apache. An estimated 303 respondents also identified themselves specifically as ‘San Carlos’ speakers. Census estimates also indicate that over 17,000 respondents identified themselves as speakers of ‘Indian’ or ‘American Indian’, and approximately 1,500 respondents identified themselves as ‘Athabaskan’ speakers. The particular languages spoken by these individuals are not known. A fair estimate of the total number of Western Apache speakers at present is 14,000 - 15,000. The Census figures are listed with commentary by Broadwell (1995). The figures are from an unpublished Census report: Language Spoken at Home and Ability to Speak English for United States, Regions and States: 1990 (CPH-L-133).

Relatively few materials are presently available on Western Apache phonetics. There are two dissertations on Western Apache phonetics and/or phonology: Greenfeld (1972), a study of White Mountain phonetics and phonology, and Durbin (1964), a study of San Carlos phonology and morphology. De Reuse (1994) provides an introduction to Western Apache phonetics and Hill (1963) and de Reuse (1993) discuss dialect variation within Western Apache. Several works on Navajo phonetics are relevant to the present study including deJong & McDonough (1994), McDonough & Austin-Garrison (1994), McDonough & Ladefoged (1993), and McDonough, Ladefoged & George (1993). Additionally, there is discussion of Navajo sounds/orthography in Young & Morgan (1987) and of Western Apache sounds/orthography in White Mountain Apache Culture Center (1972a,b) and Bray (1998). (See de Reuse (1994) and Potter (1997) for more comprehensive discussion of Western Apache linguistic materials.)

2. Present study

The present study is based on a list of approximately 150 Western Apache words that was designed to illustrate several of the principal phonetic features of the language, including voice-onset-time and closure duration of the stops, spectral properties of the fricatives, and duration and quality of the vowels. The word list was checked and recorded by one male speaker, M1, in Los Angeles. The remainder of the fieldwork was conducted in Tucson, Arizona, and in the towns of Bylas, Peridot and San Carlos on the San Carlos reservation. The word list was elicited from a total of nine speakers, four women and five men. The speakers represented a number of different dialects within Western Apache including San Carlos, White Mountain, Cibecue, and two different varieties spoken in Bylas. Data from one of the female speakers could not be used; thus, this paper presents data from three female and five male speakers. Recordings were made using a headmounted noise-canceling microphone, which ensured an approximately 45 dB signal to noise ratio. Three speakers were recorded outdoors. Speakers repeated each word twice, while recordings were made on a Sony Digital Audio Tape

Recorder at a sampling rate of 48 kHz. Upon return to the UCLA Phonetics Laboratory, the data that were to be used for acoustic analyses were transferred to the Kay Computerized Speech Lab and down sampled to 16 kHz for analysis.

3. Consonants

The consonant phonemes of Western Apache are shown in Table 1. IPA symbols are used in the text, except for those delimited by angled brackets, which represent the orthographic conventions prevalent in the Athabaskan literature, shown in Table 2.

Table 1. The consonants of Western Apache as investigated in the present study.

	Bilabial	Alveolar	Palato-alveolar	Velar	Glottal
Stops	**p**	**tʰ t t'**		**kʰ k k'**	**ʔ**
Affricates		**tsʰ ts ts'**	**tʃʰ tʃ tʃ'**		
Nasals	**m**	**n**			
Fricatives		**s z**	**ʃ ʒ**	**x ɣ**	**h**
Laterals		**ɬ l**			
Lateral Affricates		**tɬ tl tɬ'**			
Approximants	**w**		**j**		

Table 2. Conventional Athabaskan orthography for the consonants of Western Apache.

	Bilabial	Alveolar	Palato-alveolar	Velar	Glottal
Stops	**b**	**t d t’**		**k g k’**	**’**
Affricates		**ts dz ts’**	**ch j ch’**		
Nasals	**m**	**n**			
Fricatives		**s z**	**sh zh**	**x, h gh**	**h**
Laterals		**… l**			
Lateral Affricates		**t… dl** **t…’**			
Approximants	**w**		**y**		

Note that several sounds and/or sound combinations present in Western Apache are not indicated in Table 1. Table 1 does not include the prenasalized voiced stops [mb] and [nd], which occur as variants of /m/ and /n/. Word initial glottal stop is not written in the orthography. Labialized [hw] and [kw] are considered as the equivalent of phonemes in the orthography, but we did not investigate them in the present project. Note also that while listed separately in Table 1, the phonemic distinction between /x/ and /h/ is of some debate (cf. de Reuse 1994), and [w] is possibly an allophone of /ɣ/ (Greenfeld 1972, de Reuse 1994). These sounds, which are distinguished in the Western Apache orthography, were included in the present study. The status of [p^h] (orthographic ‘p’) will be discussed in section 3.1. Finally, note that the release of the unaspirated affricates is typically voiceless although there may be some tokens with slight voicing during the fricative phase.

3.1. Unaffricated stops

Western Apache unaffricated stop consonants are produced at three places: bilabial, alveolar, and velar. At the alveolar and velar places of articulation there are three possibilities: aspirated, ejective and unaspirated. (The voiceless unaspirated alveolars are characteristically realized as taps in intervocalic environments other than in stem-initial position; an example of a tap appears later in Figure 18) The bilabial stops are more restricted. Ejective bilabial stops do not occur, and aspirated bilabial stops are rarely attested, surfacing primarily, if not exclusively, in borrowed words. Figures 3 - 5 illustrate the alveolar stop series for one speaker. The closure for the three alveolar stops is voiceless, as indicated by the absence of any energy in the spectrograms during the closure phase. The vowel following the unaspirated stop in Figure 3 commences almost instantaneously after the release of the stop. Another interesting feature of Figure 3 is the realization of the phonemic glottal stop as creaky phonation (indicated by increased distance between the vertical pitch striations in the spectrogram) on the transition into the glide. After the aspirated stop in Figure 4, there is a lengthy period of aspiration before voicing and the following vowel begins. Finally, the ejective in Figure 5 is followed by a long silent period (lacking aspiration) before the onset of voicing in the following vowel.

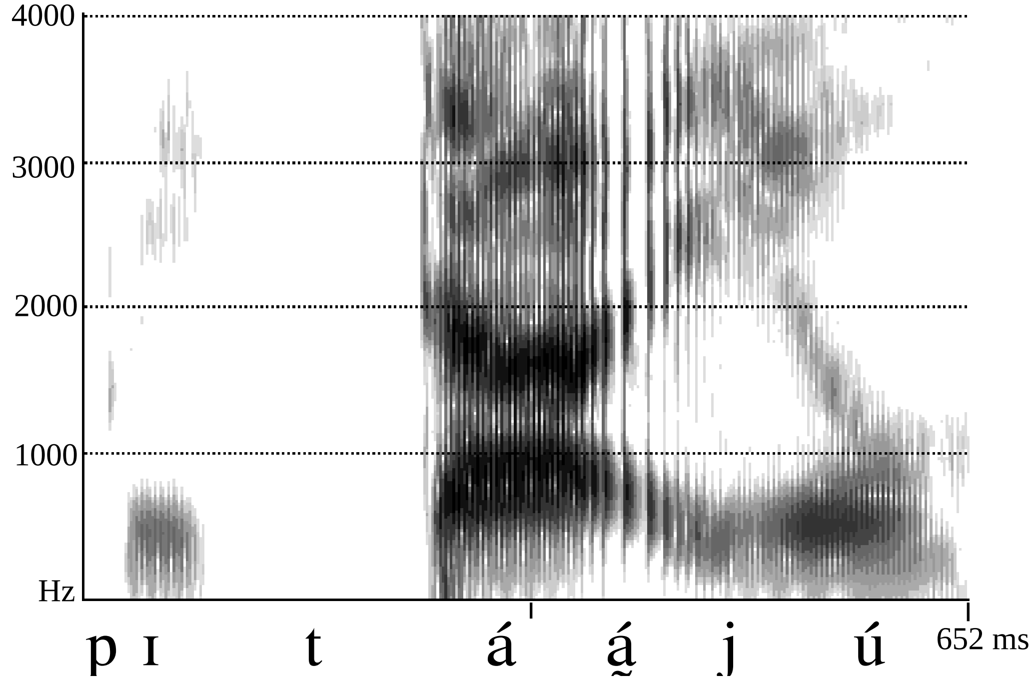

Figure 3. Voiceless unaspirated alveolar stop in the word /pi**t**áʔju/
'at its edge' as produced by speaker F1.

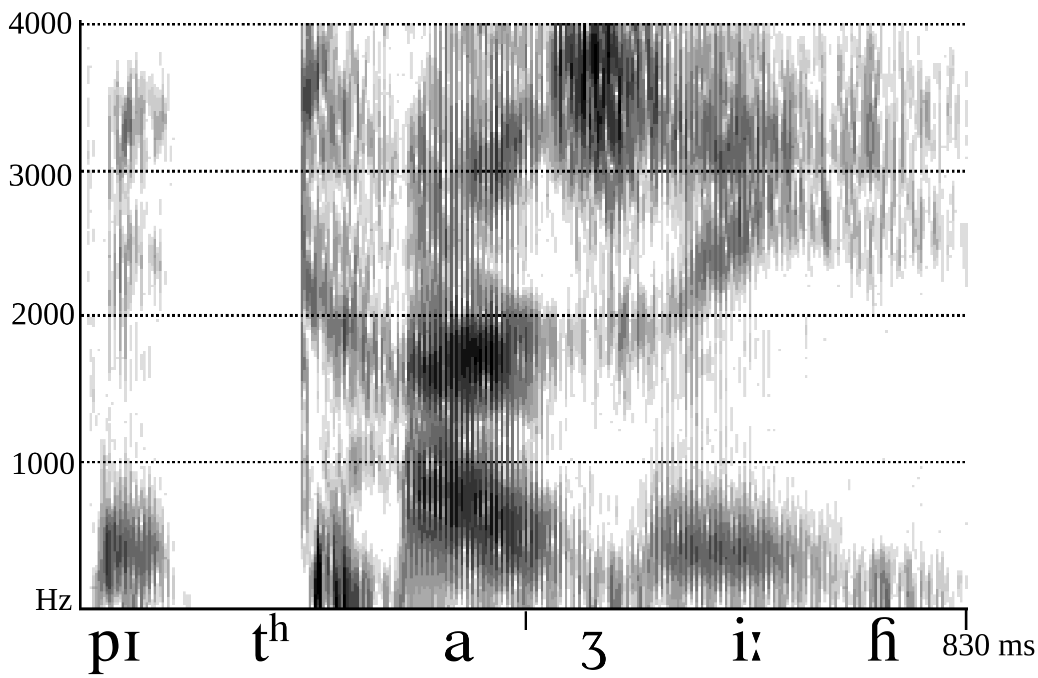

Figure 4. Voiceless aspirated alveolar stop in the word /pi**tʰ**aʒiːh/
'her/his turkey' as produced by speaker F1.

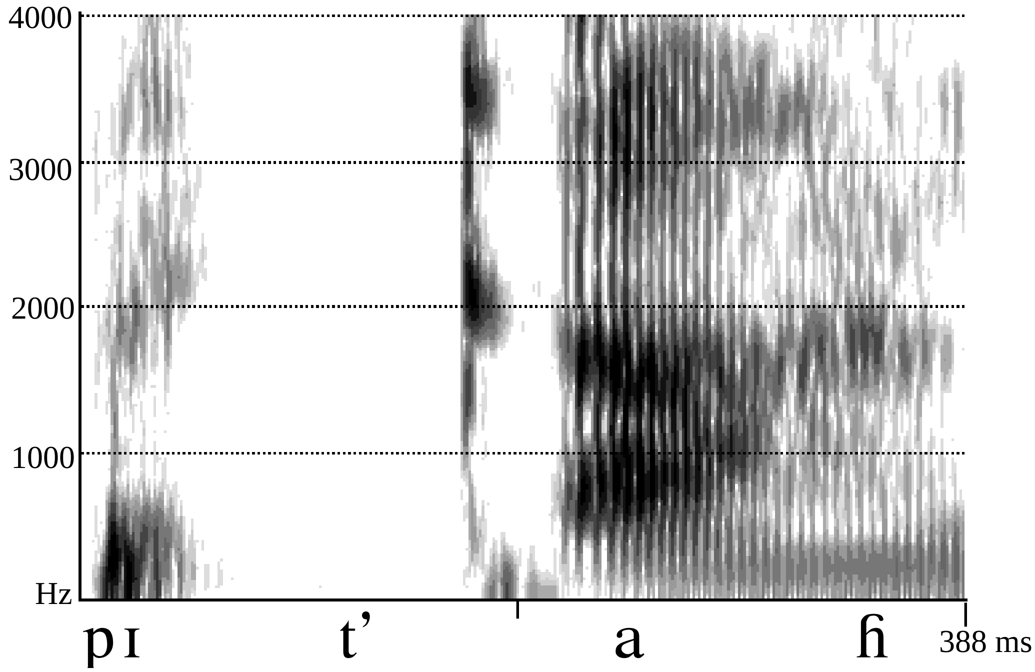

Figure 5. Ejective alveolar stop in the word /pit’ah/ ‘next to her/him’ as produced by speaker F1.

In addition, although not previously recognized for Western Apache, the present study investigates the possible presence of contrastively voiced stops in the language. As reported in Section 3.3, a voiced alveolar stop, contrasting with the unaspirated alveolar stop, was identified in the speech of two Western Apache speakers (see section 3.3 for discussion of the historical origins of this voiced stop).

3.1.1. Voice onset time (VOT)

Voice-onset-time (the period from consonant release to the onset of voicing of the following vowel, abbreviated VOT) was measured for the stops using the waveform in conjunction with a spectrogram. VOT measurements were made for the boldface consonants appearing in the words in Table 3. Consonants were measured in two intervocalic contexts, in both of which the stop occurred in stem-intial position and was preceded by the high front vowel [ɪ]. The contexts are distinguished by the vowel following the stop, high front [ɪ] or [i] versus low [a].

VOT values were found not to differ as a function of whether they appeared before low or before high vowels. Mean values averaged over all speakers and all consonants were in fact 43 ms in both environments. Nor did individual speakers show substantially different patterns. For this reason, the other analyses of VOT discussed below collapse results for all speakers and both contexts in which the target stop appeared.

Table 3. Words used to measure VOT and closure duration for unaffricated stops.

Stop Consonant	Before [i] / [ɪ]		Before [a]	
p	pɪ**p**ɪt	her/his stomach	ɪ**p**an	buckskin
t	pɪ**t**ɪɬ	her/his blood	pɪ**t**áʔjú	at its edge
k	pɪ**k**ɪʃ	her/his cane	pɪ**k**at	her/his cedar
t^h	pɪ**t**^{h}ɪsko	more so	pɪ**t**^{h}aʒi	her/his turkey
k^h	ɬɪ**k**^{h}ɪʒ	spotted	ɪ**k**^{h}aɬ	animal hide
t’	pɪ**t’** iːs	her/his cottonwood tree	pɪ**t’** ah	near him/her
k’	pɪ**k’** ɪsn̩	her/his brother	ɪ**k’** ah	fat

VOT for the three manners of stop consonants (aspirated, ejective, and unaspirated) appear graphically in Figure 6. Bilabials were omitted from this comparison, due to the lack of aspirated and ejective bilabials in the data set. Thus, data in Figure 6 includes only alveolar and velar stops. All three manner classes differ significantly from one another in terms of VOT. VOT is longest for the aspirated stops, intermediate in length for the ejective stops, and shortest for the unaspirated stops. The effect of manner of articulation on VOT was found to be highly significant at the p<.0001 level according to a two-factor analysis of variance with place of articulation and manner of articulation as independent variables: F (2, 185) = 97.831, p<.0001. Additionally, all of the pairwise differences between individual manners of articulation were found to be highly significant at the p<.0001 level according to Fisher's PLSD post hoc tests.

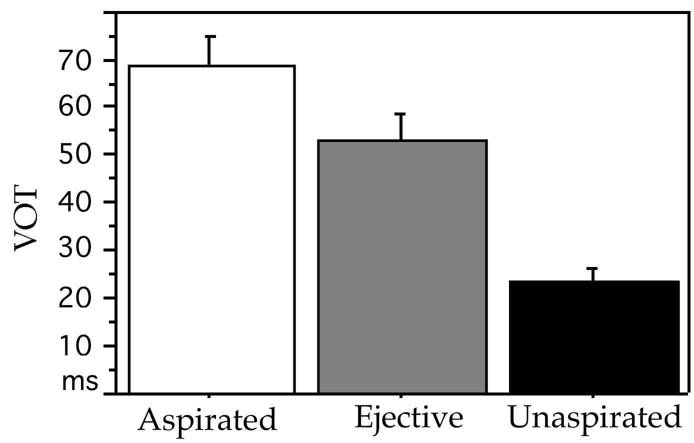

Figure 6. VOT values for aspirated, ejective, and unaspirated stops (velars and alveolars).

VOT was also highly influenced by place of articulation according to the analysis of variance: F(1, 185) = 41.485, p<.0001. In a series of unpaired t-tests, velars and alveolars were compared within the ejective and aspirated series, while velar, alveolar, and bilabial stops were compared within the unaspirated series. Results for all three manners of articulation were similar. According to Fisher's PLSD post hoc tests, velars had significantly longer VOT values than alveolars (p<.0001) for ejective, unaspirated, and aspirated stops, as shown in Figure 7.

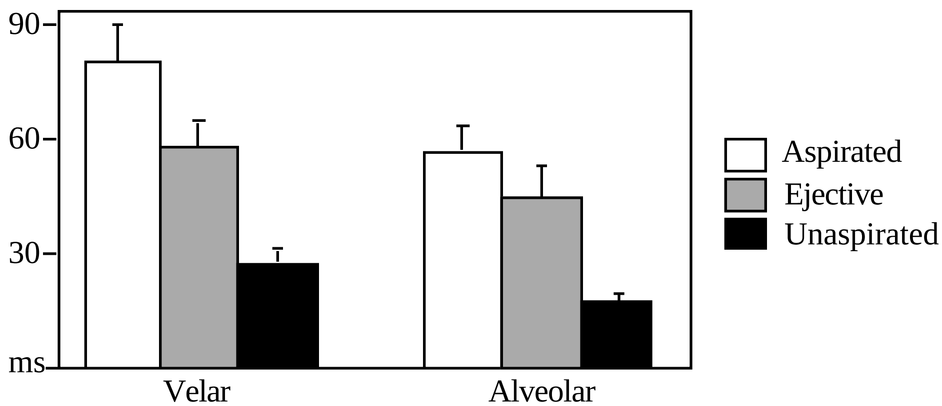

Figure 7. VOT for velar and alveolar stops classified by manner of articulation.

Alveolars, in turn, had significantly greater VOT values than bilabial stops (historically derived from proto-Athabaskan /w/ which had become a stop by the proto-Southern-Athabaskan period) in the unaspirated series (p=.0192), the only class of stops for which comparison could be made. Though statistically significant, this difference was quite small, only a few milliseconds. VOT values for the three places of articulation in the unaspirated stop series are shown in Figure 8.

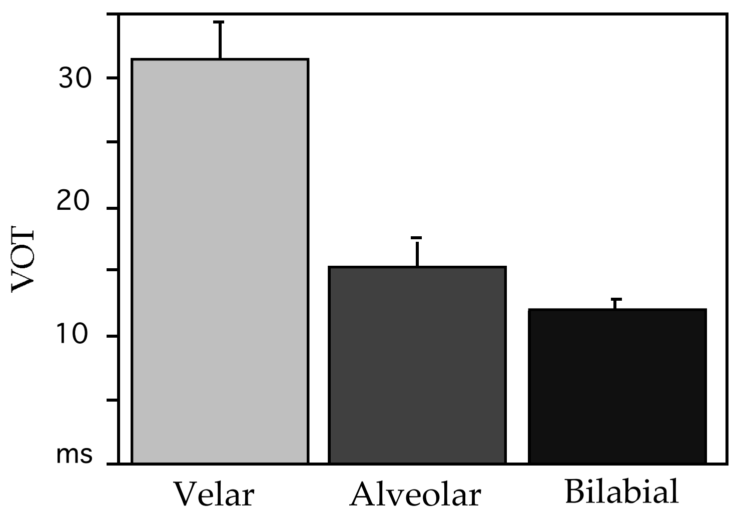

Figure 8. VOT values for velar, alveolar, and bilabial stops in the unaspirated stop series.

The VOT patterns found in Western Apache stops bear close resemblance to those found in other languages of the world (cf. Cho and Ladefoged 1999 for data on 18 languages). Figure 9 shows comparative data for coronal (alveolar/dental) and velar stops in Apache and three other languages in the Na-Dene phylum. All these languages were recorded and analyzed in the same way, as part of the UCLA endangered languages project. The pattern, aspirated stops having a longer VOT than ejectives, which are in turn longer than unaspirated stops is found in Navajo (McDonough and Ladefoged 1993) and Tlingit (Maddieson et al. 1996). In Hupa (Gordon 1996), however, VOT values for the dental ejectives are slightly longer than for the dental aspirates. Although the direction of the VOT difference between aspirated and ejective stops is not entirely consistent across these four languages, the fact that ejectives and aspirated stops consistently differ suggests that VOT is perhaps used as a perceptual cue to differentiate the two classes of stops. However, further research on a greater number of genetically diverse languages, in addition to perception experiments, would be necessary to substantiate this hypothesis.

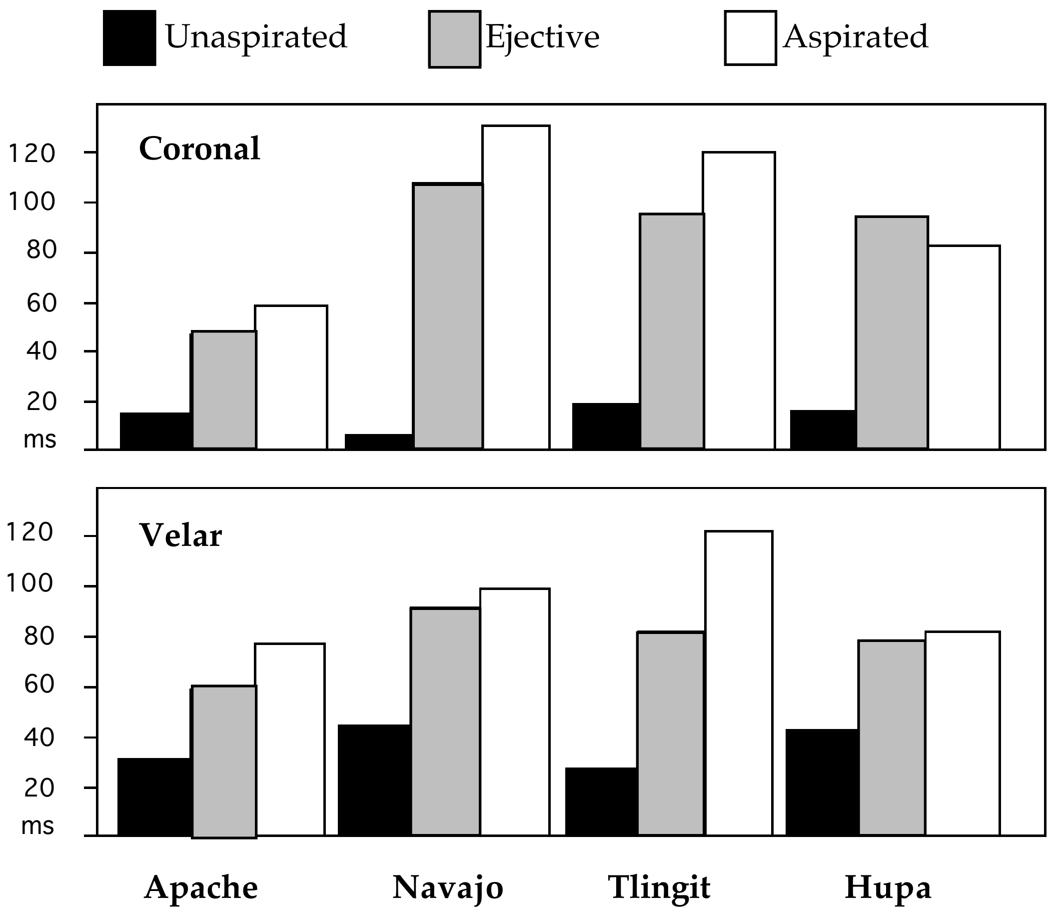

Figure 9. Comparative VOT for unaspirated, ejective and aspirated stops in four languages. Data from the present study, McDonough and Ladefoged (1993) for Navajo, Maddieson et al. (1996) for Tlingit, and Gordon (1996) for Hupa.

A further result of interest in the present study was that female speakers had significantly longer VOT values according to an unpaired t-test (p=.0003) than male speakers for both the ejective and aspirated stops: females 48 ms and males 40 ms, averaged over all places and manners of articulation. A gender dependent difference was not found in the unaspirated stops, probably because of the small range of VOT values for the unaspirated series which is involved in a phonemic contrast with the aspirated stop series. VOT values separated by gender appear in

Figure 10.

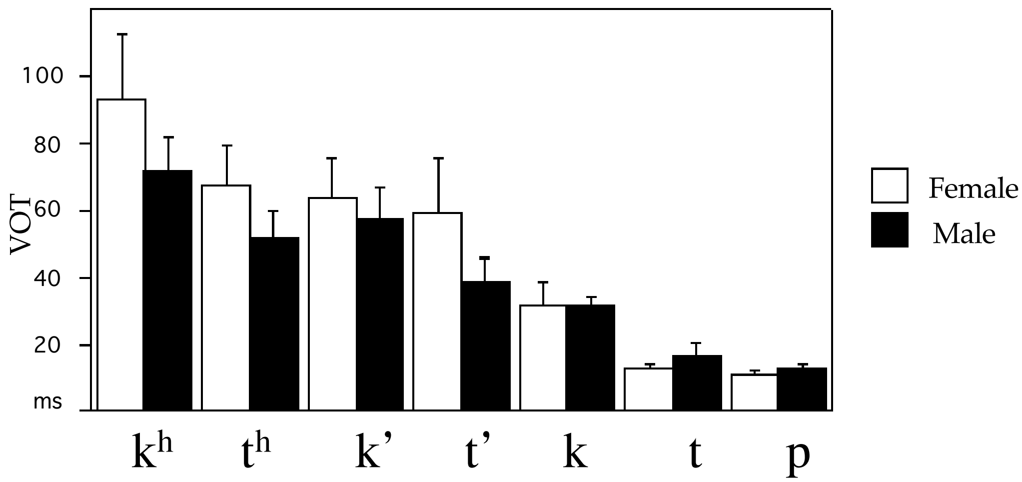

Figure 10. VOT values for all unaffricated stops divided by gender.

3.1.2. Closure duration

Closure duration values for the boldfaced stops in Table 2 were also measured from the waveforms. Measurements were taken from the onset of the stop closure to the point of the release.

An analysis of variance for closure duration of velars and alveolars (the only places of articulation attested for all manners of articulation) with manner and place of articulation as independent variables indicated a highly significant effect of manner ($F(2, 184) = 6.865$, $p=.0013$) and a weaker but significant effect of place ($F(1,184) = 5.161$, $p=.0243$) on closure values. Closure values (shown graphically in Figure 11) differed between all three manners of articulation according to Fisher's PLSD post hoc tests, though the only statistically significant difference was between aspirated and unaspirated stops ($p=.0003$), with the aspirated stops displaying shorter closure durations than the unaspirated stops.

Ejectives had closure durations which were intermediate between those of the aspirated and unaspirated stops, although these differences did not quite reach statistical significance: aspirated vs. ejective, p=.0784; ejective vs. unaspirated, p=.0583.

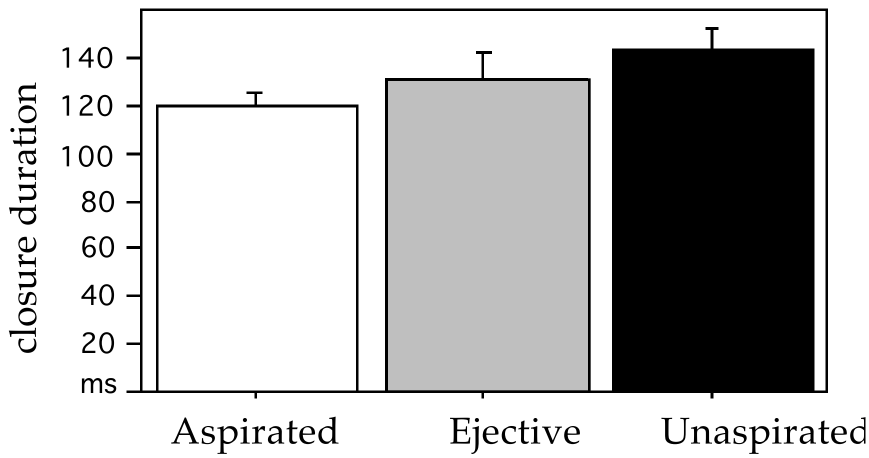

Figure 11. Closure duration for aspirated, ejective, and unaspirated stops (velar and alveolar places of articulation).

Turning to place of articulation, velars had significantly shorter closure duration values than alveolars (p=.0250), as shown in Figure 12 for all three manners of articulations.

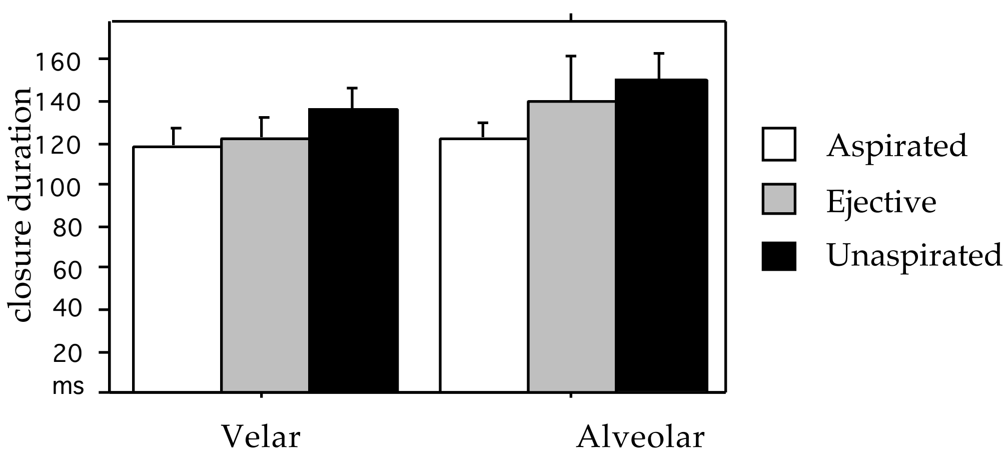

Figure 12. Closure durations for velar and alveolar stops classified by manner of articulation.

In the unaspirated stop series, the only stop series containing bilabials, the only significant difference due to place of articulation was between bilabial stops and velar stops, according to unpaired t-tests. Results for the unaspirated stops appear in Figure 13.

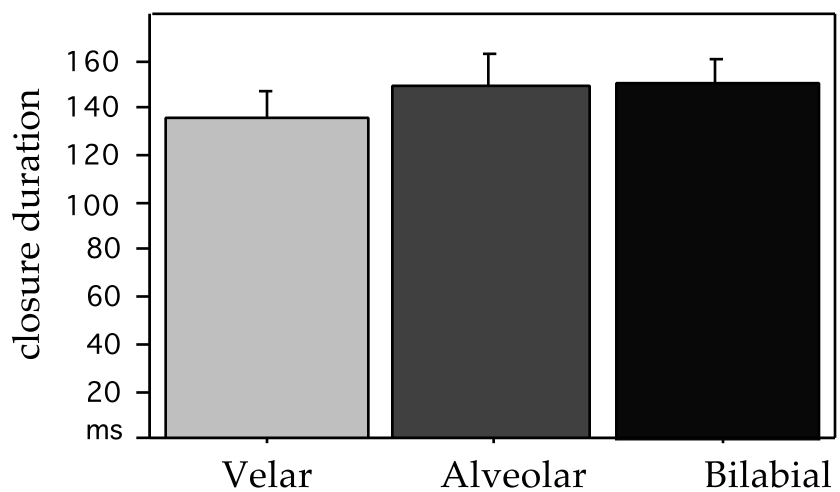

Figure 13. Closure durations for velar, alveolar, and bilabial stops in the unaspirated series.

As shown in Figures 14 and 15, if closure and VOT values are summed together for each place of articulation, the combined values for each of the three places (two in the case of ejectives and aspirated stops) of articulation turn out to be approximately the same. This is shown in Figure 14 for the velar and alveolar aspirated stops, and in Figure 15 for all three places of articulation in the unaspirated series. According to an analysis of variance for the unaspirated series (the series with all three places of articulation represented), there is statistically no effect of place of articulation on the sum of closure duration and VOT values, supporting the trading off relationship between closure duration and VOT. An analysis of variance for the aspirated stops revealed only a barely significant effect of place of articulation of the sum of closure and VOT values: ($F(1,62) = 4.058$, $p=.0483$).

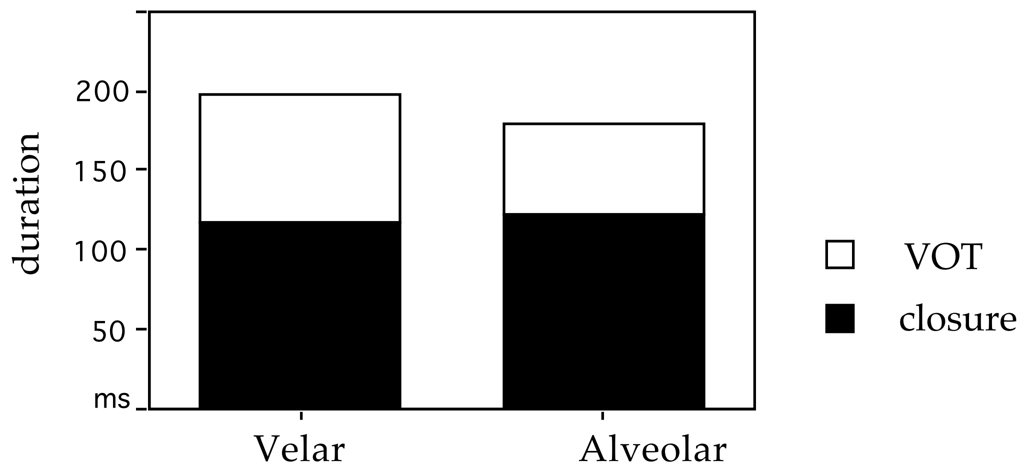

Figure 14. Closure duration and VOT values for velar and alveolar aspirated stops.

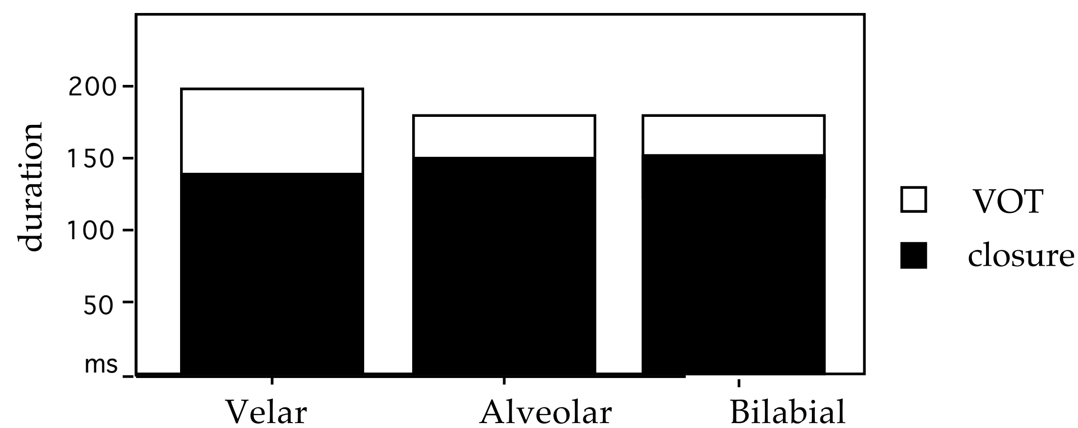

Figure 15. Combined closure duration and VOT values for unaspirated velar, alveolar, and bilabial stops.

The inverse correlation between VOT and closure duration for stops at different places of articulation appears to be a general cross-linguistic property attested in a large number of languages. Weismer (1980) offers a possible explanation of the place-dependent nature of both the closure duration and VOT suggesting that the duration of the vocal fold opening may be fixed, with different durations for aspirated and unaspirated stops. When the closure duration is relatively longer, the VOT becomes relatively shorter (and vice versa). As Maddieson (1997:621), summarizing Weismer's findings, puts it: "There is an abduction-adduction cycle of the vocal cords for voiceless stops which is longer in duration than the closure and has a constant time course, anchored to the onset of closure."

A possible reason for the shorter closure duration for the velar stop than both the alveolar and the labial stops is that the seal for more posterior stops may be more difficult to hold in the face of increased air pressure (Maddieson 1997). When the oral closure is further back, the cavity behind the closure is smaller, and the air pressure reaches a maximum more quickly. The faster the increase in pressure, the shorter the closure is held, perhaps due to a biomechanical feedback mechanism. Following this logic, the seal for a velar will be maintained for a shorter period of time than the closure for an alveolar stop which in turn will be held for a shorter period of time than the bilabial stop. The Western Apache data are compatible with this account, as velars show the shortest closures, whereas bilabials have the longest closures, though differences in both closure duration and VOT between the bilabial and alveolar stops are negligible in the language.

A weaker inverse correlation between closure duration and VOT is also found if different manners of articulation are compared, as shown in Figure 16. Those stops with the longest VOT values, the aspirated ones, have the shortest closure durations. Conversely, the stops with the shortest VOT values, the unaspirated ones, have the longest closure durations. Ejectives are intermediate in terms of both VOT and closure duration.

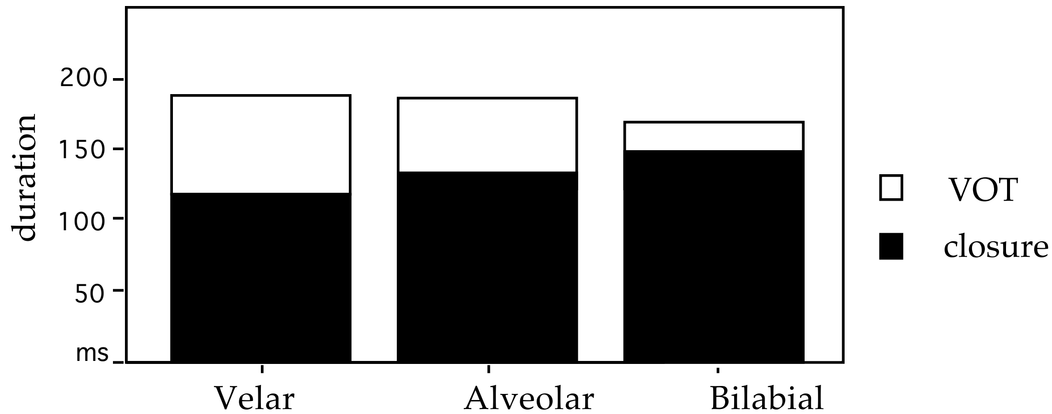

Figure 16. Combined closure duration and VOT values (ms) for aspirated, ejective, and unaspirated stops.

The manner dependent tendency for closure durations to be shortest when VOT values are longest also potentially finds an explanation similar to the one offered by Maddieson to account for the place-dependent inverse relationship between closure duration and VOT. The duration of the vocal fold opening may be fixed for each class of stops, so that lengthening the closure phase results in a compensatory shortening of the VOT phase.   Conversely, shortening the closure results in a longer VOT period.

This explanation, with slight modification, will account for the inverse relationship between closure duration and VOT for the ejective stops.   Ejectives require a closed glottis to be produced, unlike the aspirated and unaspirated stops which are fully voiceless in Western Apache and require an open glottis during production. If the duration of the glottal closure in ejectives is fixed, both the compensatory relationship between closure duration and VOT in the ejective series and the parallel between ejectives and voiceless stops are accounted for. Thus, it may be the case that not only is the duration of the glottal abduction-adduction cycle fixed, but that the adduction-abduction cycle is also fixed, with the cycles roughly equivalent to one another in duration.

Closure durations were found to be significantly longer at the p<.0001 level according to an unpaired t-test for the females than for the males: 147 ms for the females compared to 127 ms for the males. This result is similar to that found for VOT in section 3.1, which was also longer for female than for male speakers. Closure duration values are plotted in Figure 17 for all stop consonants separated according to the speaker gender.

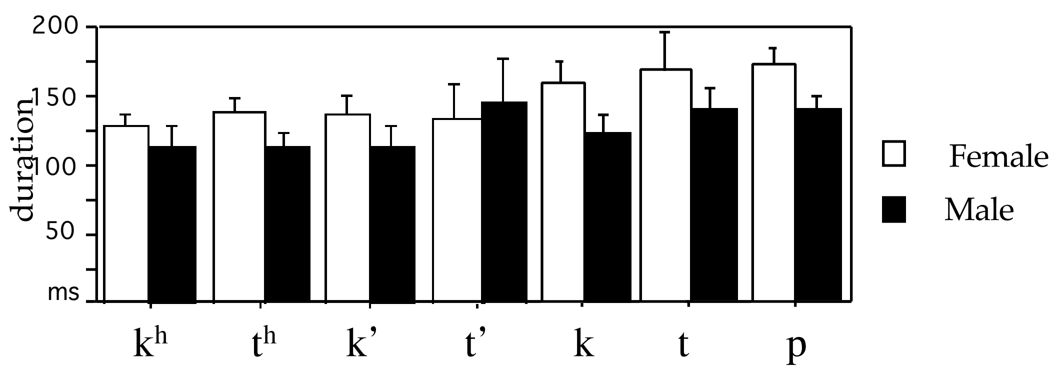

Figure 17. Closure duration values for all unaffricated stops divided by gender.

3.2. Affricated stops

The VOT and closure duration for affricated stops (also in stem-initial position) were measured using waveforms in conjunction with spectrograms. Measurements were made for the boldface consonants appearing in the words in Table 4. The affricates were measured in the same two intervocalic contexts as the unaffricated stops, with one exception. In the word [najɪɬ**tɬʰ**at] ‘he is greasing it’, the aspirated /tɬʰ/ occurs between a lateral fricative [ɬ]and [a].

Table 4. Words used to measure VOT and closure duration for affricated stops.

Affricate	Before [i] / [ɪ]		Before [a]	
ts	pɪ**ts**ɪɬ	her/his mountain	náʔtiː**ts**aː	she/he got up
tʃ	pɪ**tʃ**íʔɪ	her/his heart	pɪ**tʃ**at	her/his leg
tl	ɪk’ɛʔɪ**tl**ɪʃɛ́	stink bug	taɾɪ**tl**aʔ	lightning
tsʰ	pɪ**tsʰ**ɪʔ	her/his daughter	pɪ**tsʰ**aɬ	her/his needle
tʃʰ	pɪ**tʃʰ**ɪʒ	her/his firewood	pɪ**tʃʰ**an	its feces
tɬʰ	tɪ**tɬʰ**ɪd	shaky	najɪɬ**tɬʰ**at	she/he is greasing it
ts’	pɪ**ts’** ɪlɛ́	her/his cone	tɪ**ts’** ak	strong (hard but flexible)
tʃ’	pɪ**tʃ’** ɪt	her/his blanket	haɾɪ**tʃ’** aːt	it is oozing
tɬ’	pɪ**tɬ’** iːʃ	her/his snake	pɪ**tɬ’** akʰaɬ	her dress

Voicing for the unaspirated laterally released affricate typically commences approximately in the middle of the lateral, though sometimes even earlier, as in the exemplar in Figure 18, which also illustrates an alveolar tap allophone of /t/. The acoustic result is a stop followed by a lateral that is voiceless for its first half and voiced for its second half. The unaspirated laterally released affricate in Navajo has a similar realization (McDonough and Ladefoged 1993). The unaspirated laterally released affricate in Figure 18 can be compared with its aspirated counterpart in Figure 19. The lateral phase of the aspirated affricate is typically completely voiceless, as in Figure 19.

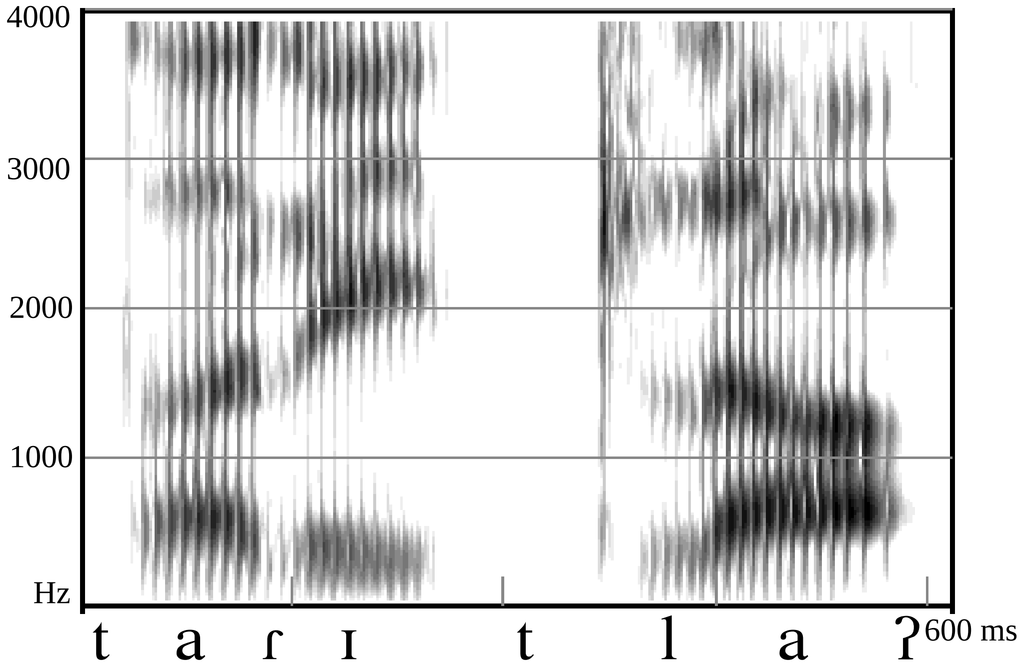

Figure 18. Unaspirated laterally released affricate in the word /tatɪtlaʔ/ ‘lightning’ as produced by speaker M1.

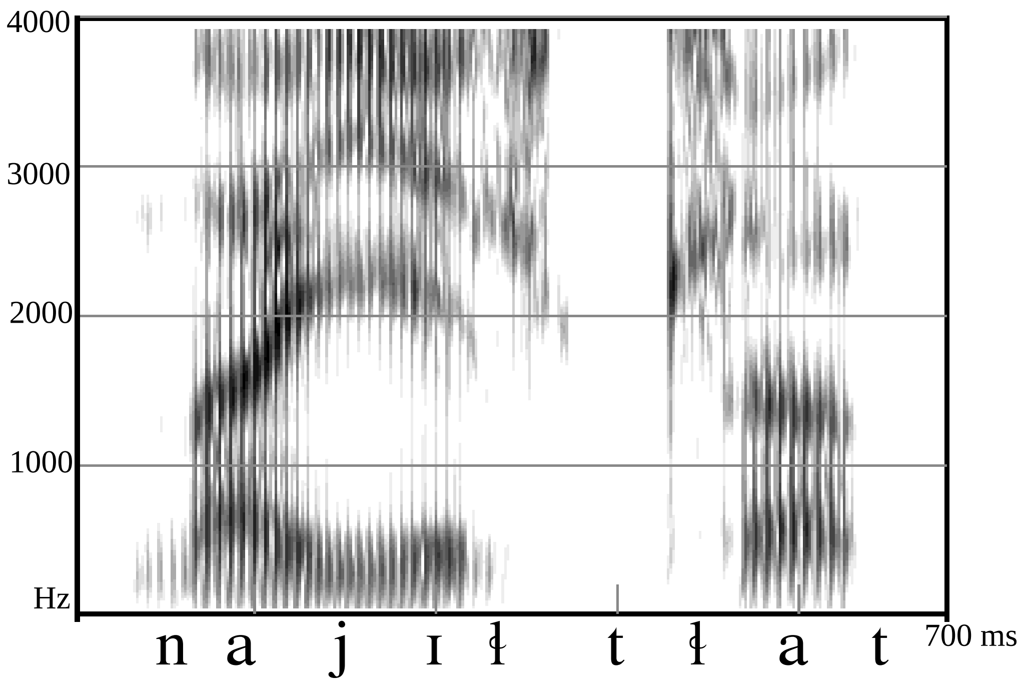

Figure 19. Aspirated laterally released affricate in the word /najɪɬtɬʰat ʔ/ ‘she/he is greasing it’ as produced by speaker M1.

3.2.1. VOT of the affricated stops

An analysis of variance of VOT was performed for the affricated stops, taking place of articulation, manner of articulation, the following vowel, gender of the speaker, and the repetition number as independent variables. Four of these five factors were found to exert a highly significant influence on VOT values: place of articulation, $F (2, 200) = 62.521$, $p<.0001$; manner of articulation, $F (2, 200) = 95.660$, $p<.0001$; the following vowel, $F (1, 100) = 21.933$, $p<.0001$; gender, $F (1, 200) = 26.056$, $p<.0001$. The remaining factor, the repetition number (i.e. the first or second repetition of each word uttered by a speaker), exerted only a negligible influence on VOT. None of the interactions between factors was statistically significant at the $p<.05$ level except for the interaction between manner and gender: $F (2, 200) = 4.882$, $p=.0085$.

Figure 20 graphically depicts the effect of manner of articulation on mean VOT values. Following the pattern of the unaffricated stops, the aspirated affricates are characterized by the longest VOT values on average, while the unaspirated affricates have the shortest average VOT values. The ejective is intermediate in terms of VOT. A Fisher’s PLSD post hoc test indicates that all manner of articulations are significantly different from one another in terms of VOT at the $p<.0001$ level.

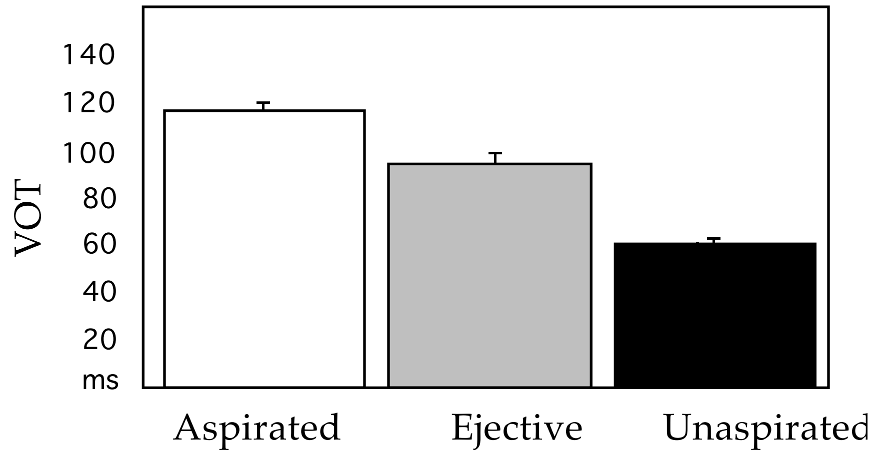

Figure 20. VOT for aspirated, ejective, and unaspirated affricates.

VOT values as a function of place of articulation are shown in Figure 21. As Figure 21 indicates, VOT is longest for the alveolar affricate, shorter for the palato-alveolar affricate, and still shorter for the laterally released affricate. All of these differences are statistically significant from one another at the $p<.0001$ level according to PLSD posthoc tests dependent on the ANOVA described above.

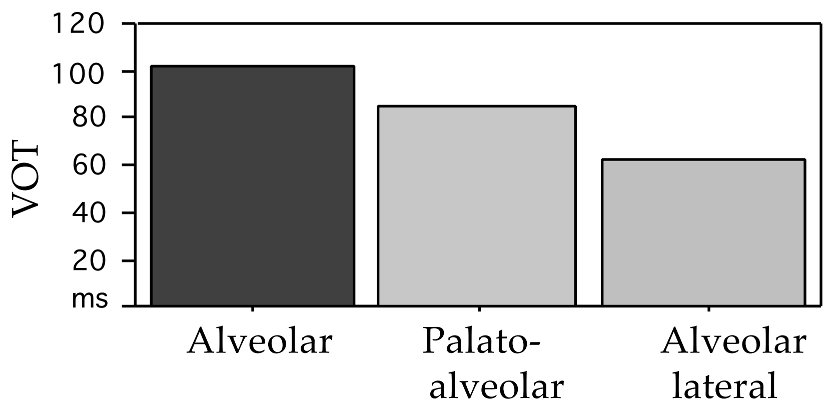

Figure 21. VOT for alveolar, palato-alveolar, and laterally released affricates.

The difference between the alveolar and the palato-alveolar is the opposite pattern from that seen in the unaffricated series, where the fronter articulation has shorter VOT values than the backer articulation. The VOT results for the Western Apache affricates are similar to those for the unaspirated series in Navajo (McDonough and Ladefoged 1993). Interestingly, the Navajo differences are most noticeable in the unaspirated series; neither the affricated nor the ejective series of affricates show reliable differences in VOT between the alveolar, the lateral, and the palato-alveolars in Navajo. In Apache, the same VOT pattern (alveolars longest followed by palato-alveolars followed by laterals) is found for all manners of articulation, as Figure 22 demonstrates.

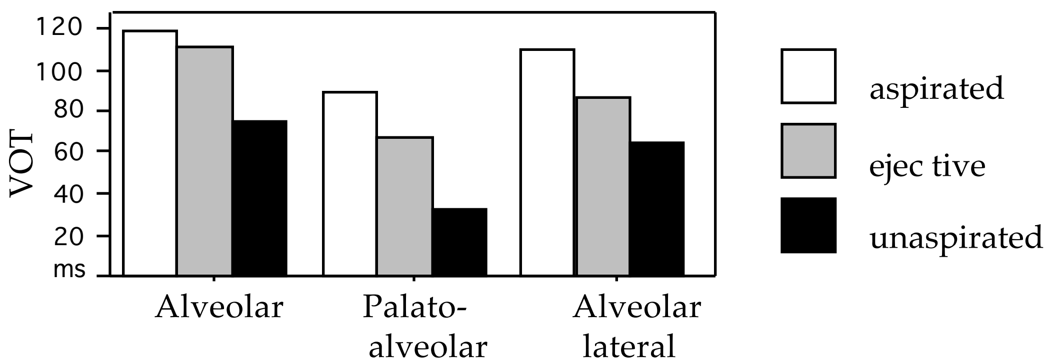

Figure 22. VOT for alveolar, laterally released, and palato-alveolar affricates classified by manner of articulation.

VOT values were slightly longer before high vowels than before low vowels, a difference of 15 ms averaged over all places and manners of articulation which was significant at $p<.0001$ according to a Fisher's PLSD posthoc test. VOT values were longer on average (17 ms) for female than for male speakers ($p<.0001$), a difference which was also seen in the unaffricated stop series in Figure 17. The first repetition was negligibly longer (6 ms) on average than the second repetition of each word. This difference was only barely significant according to a Fisher's PLSD posthoc test ($p=.0337$). Given the extremely small absolute difference in

VOT duration and the large number of tokens in the analysis, this result does not appear to be robust.

3.2.2. Closure

For closure duration, an ANOVA was performed with place of articulation, manner of articulation, the following vowel, gender of the speaker, and the repetition number as independent variables. The largest effect was exerted by gender: F (1, 196) = 19.428, p<.0001, with smaller effects exerted by the following vowel (F (1, 196) = 13.531, p<.0003), manner of articulation (F(2, 196) = 6.717, p=.0015), and place of articulation (F (2, 196) = 4.456, p=.0128). Repetition number had no reliable effect on closure duration (F (1, 196) = .568, p=.4520). None of the interactions between factors was statistically robust except for a three-way interaction between place of articulation, the following vowel, and manner of articulation. This difference was fairly weak statistically, p=.0126.

Mean closure duration values as a function of manner of articulation appear graphically in Figure 23. Exactly opposite to the VOT results in Figure 20, closure duration is longest for the unaspirated series and shortest for the aspirated affricates. Only the difference between the aspirated and unaspirated affricates reaches statistical significance, p=.0031. The inverse relationship between closure duration and VOT as a function of manner parallels the result for the unaffricated stops in section 3.1.2 and is similar to the result found for Navajo (McDonough and Ladefoged 1993).

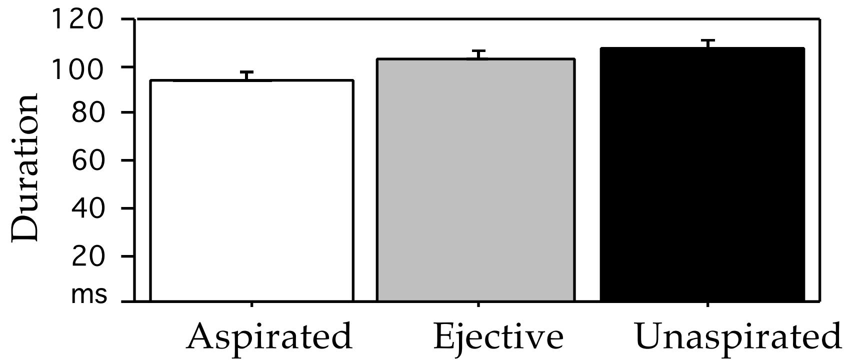

Figure 23. Closure duration for aspirated, ejective, and unaspirated affricates.

Closure durations for the palato-alveolar affricates were significantly shorter than those for both the alveolar and lateral affricates as Figure 24 shows: palato-alveolar vs. alveolar, p=.0088 according to a Fisher's PLSD post hoc test; palato-alveolar vs. lateral, p=.0028. The difference between alveolars and laterals was minuscule and statistically insignificant, p=.6434.

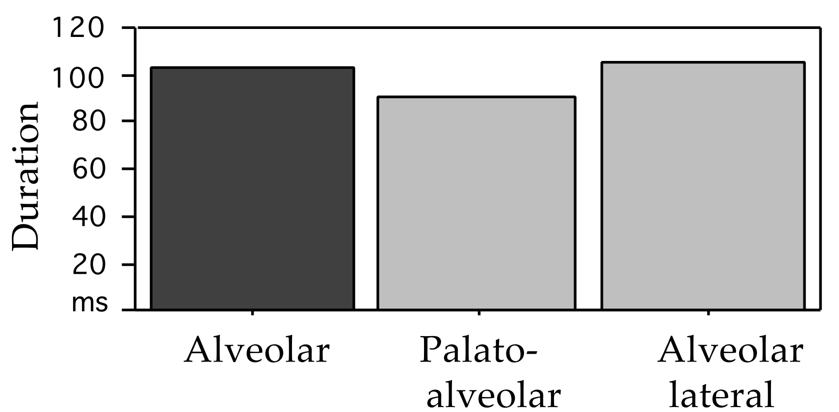

Figure 24. Closure duration for alveolar, palato-alveolar, and laterally released affricates.

These results for Western Apache differ from those for Navajo, where the laterally released affricate has much longer closure durations than both the alveolar and palato-alveolar affricates, at least in the unaspirated and aspirated series

(McDonough and Ladefoged 1993).

Closure duration was slightly longer before /i/ than before /a/ (11 ms, $p=.0028$ in a Fisher’s PLSD posthoc test), and closure duration was longer for females than for males (16 ms, $p<.0001$). Repetition number was shown to have no reliable effect on closure duration (2 ms, $p=.5173$).

3.3 Voiced Stops

Although not previously recognized for Western Apache (but see Tuttle 2000 for an overview of voiced stops in other Athabaskan languages and a phonetic study of voiced stops in Jicarilla Apache), the present project investigated the possible presence of contrastively voiced stops in root-initial position. The words in Table 5 were identified as containing potentially voiced bilabial and alveolar stops and were included in the word list recorded by the Western Apache speakers. No potentially voiced velar stops had been identified at the time the recordings were made.

Table 5. Words used to investigate the possible presence of voiced stops in Western Apache.

	Before [ɪ]		Before [a]	
Bilabial	pɪ**p**íʒ	his knife	ɬɪ**p**aːh	it is gray
Alveolar	sɪ**d**ɪl	they are in position	yaːyɪ**t**ah	he habitually forgets it

Of the words in Table 5, only <sidil> was found to contain a voiced stop. The labial stops were realized as voiceless stops in the analyzed data, though voiced labial stops have been heard on occasion. In the case of <sidil>, substantial dialect variation was observed. Two of the speakers pronounced the word as [sɪnɪl], the probable earliest common form (cf. Navajo <sinil>, Young & Morgan 1987), while one speaker pronounced it as [sındıl]. Of the five speakers who pronounced the word with a non-nasal alveolar stop, only two had a voiced [d]. For these two speakers, however, the contrast between the voiced and voiceless unaspirated alveolar stops is clear. Figures 25 and 26 illustrate the contrast for speaker F3, where the low frequency energy during the stop closure in Figure 25 but absent in Figure 26 is indicative of voicing.

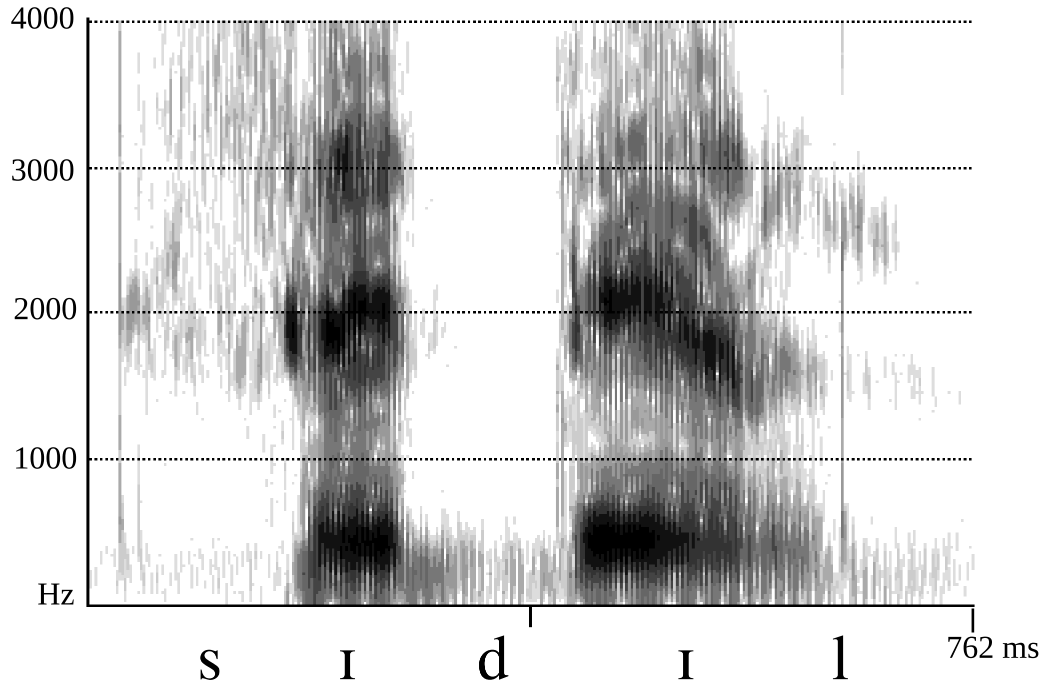

Figure 25. Voiced stop in the word /sɪdɪl/ ‘They (plural objects) are in position’ as produced by speaker F3.

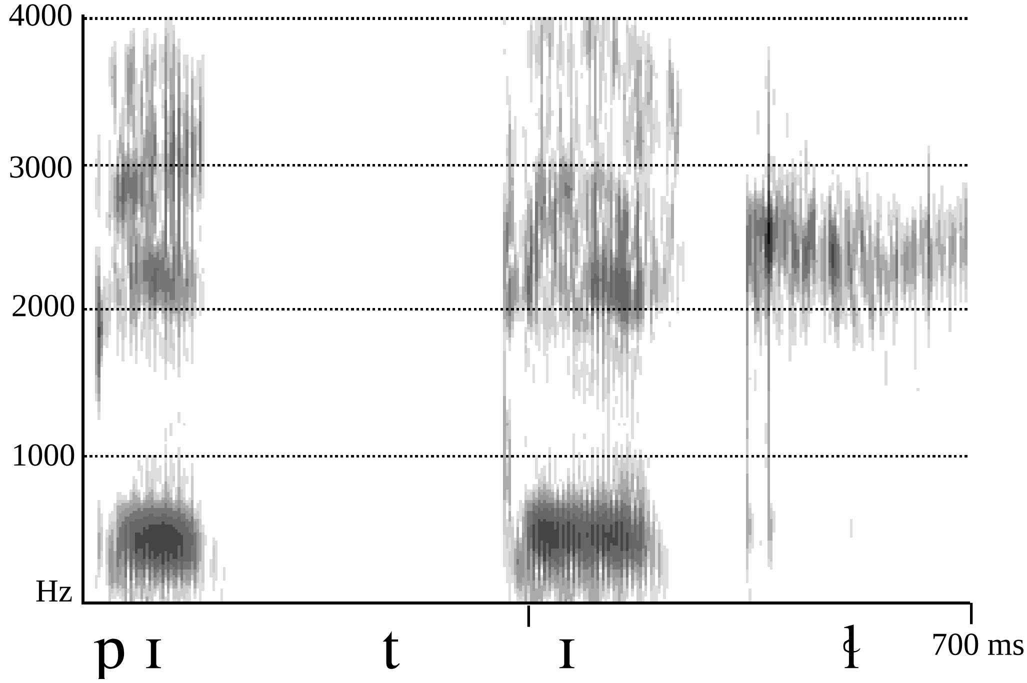

Figure 26. Voiceless unaspirated stop in the word /pɪtɪɬ/ 'his blood' as produced by speaker F3.

The possible development of a contrastively voiced alveolar stop may be presently confined to those stops that vary dialectally between [d] / [t], [n], and [nd], i.e. alveolar stops that are derived historically from proto-Athabaskan [n]. It must be noted, however, that the word [jaːjɪtah] shows this same pattern with dialectal variants [jaːjɪndah] and [jaːjɪnah], but was not pronounced with a voiced alveolar [d] by any of the recorded speakers.

3.4. Fricatives

Western Apache has four voiceless oral fricatives /ɬ/, /s/, /ʃ/, and /x/ (plus /h/, which will not be considered further.) The acoustic properties of these sounds were investigated in a set of words containing the fricatives in two intervocalic contexts, between a high front vowel and [a] and between two high front vowels.

These words were digitized at a sampling rate of 22,050Hz using Kay MultiSpeech. The measured fricatives appear in boldface in the words in Table 6. (Note that one of the environments in which /x/ was examined was between /s/ and the high front vowel.) A 1,024 point window (approximately 46 ms) was centered around the middle of each fricative and an FFT spectrum of this window was calculated. Numerical spectra were then averaged together over the two tokens of each fricative appearing in the same environment for a given speaker. Because visual inspection revealed consistency across speakers in their spectral properties, the spectra for all speakers of the same gender were averaged together for each fricative. These averaged spectra in the pre-[a] context appear in Figure 27 (female speakers) and Figure 28 (male speakers). (Spectra for the fricatives before the high front vowels were quite similar to those in the [a] context.)

Table 6. Words used to examine the spectral properties of Western Apache fricatives

Fricative	Before [ɪ]		Before [a]	
ɬ	pɪ**ɬ**ɪt	her/his smoke	tʃ’ɪʔkotɪ**ɬ**an	centipede
s	hɪ**s**iː	I will miss it	ʃɪ**s**ánɛ́	my old lady
ʃ	bɪ**ʃ**ɪʃ	It stung her/him	bɪ**ʃ**aʃ	her/his bear
x	jɪzɪs**x̃**ĩː	she/he killed it	bɪ**x**aɬ	her/his club

As Figures 27 and 28 indicate, the fricatives are for the most part well-differentiated in terms of their spectral characteristics. The strongest energy for /s/ occurs at frequencies above 4000Hz for the male speakers and above 6000Hz for the female speakers. The spectrum for /ʃ/ is characterized by a relatively sharp peak in energy at approximately 3500Hz for the males and 4000Hz for the females. /s/ and /ʃ/ are thus differentiated on the basis of the location of their strongest energy in the frequency domain: /s/ has more energy at higher frequencies than /ʃ/. /s/ also has a less sharp spectral peak than /ʃ/. /x/ is characterized by a very pronounced peak in energy below 2000Hz and then more diffuse peaks at about 4000 and 7000Hz. The spectral peak for /ɬ/ falls between that of /x/ and that of /ʃ/ at approximately 2500-3000Hz. In summary, the four oral fricatives of Western Apache can be distinguished from one another in terms of the location of their spectral peaks, and, to a lesser extent, in terms of the degree of sharpness of these spectral peaks. There is relatively little cross-linguistic data on the acoustic properties of fricatives. However, Jassem (1968) presents spectra from his speech of three of the four fricatives measured in Western Apache, /s/, /ʃ/, and /x/. The spectra of Jassem's fricatives bear close resemblance to those in Western Apache. /x/ has a sharp peak in energy below 2000Hz, /ʃ/ has an energy peak slightly higher at 3000-4000Hz, and /s/ has a peak at 4000Hz. Interestingly, Jassem also includes a spectrum of a dental fricative /s̪/ which actually bears closer resemblance to the Apache /s/ both in terms of location of spectral peak and degree of sharpness of the peak than Jassem's alveolar fricative /s/. Since Jassem's study is based on only a single speaker, however, we cannot infer with any certainty that the Western Apache /s/ is more dental than alveolar.

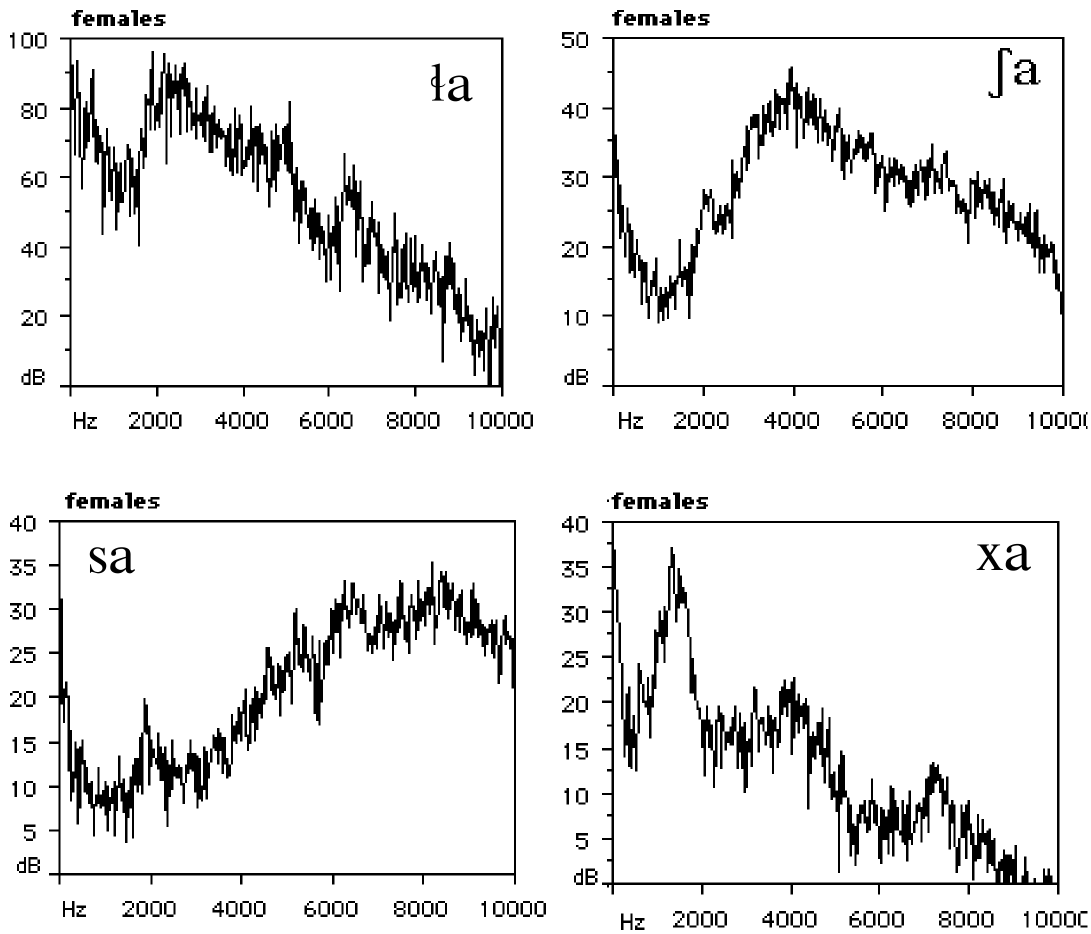

Figure 27. FFT power spectra of fricatives before [a] (female speakers)

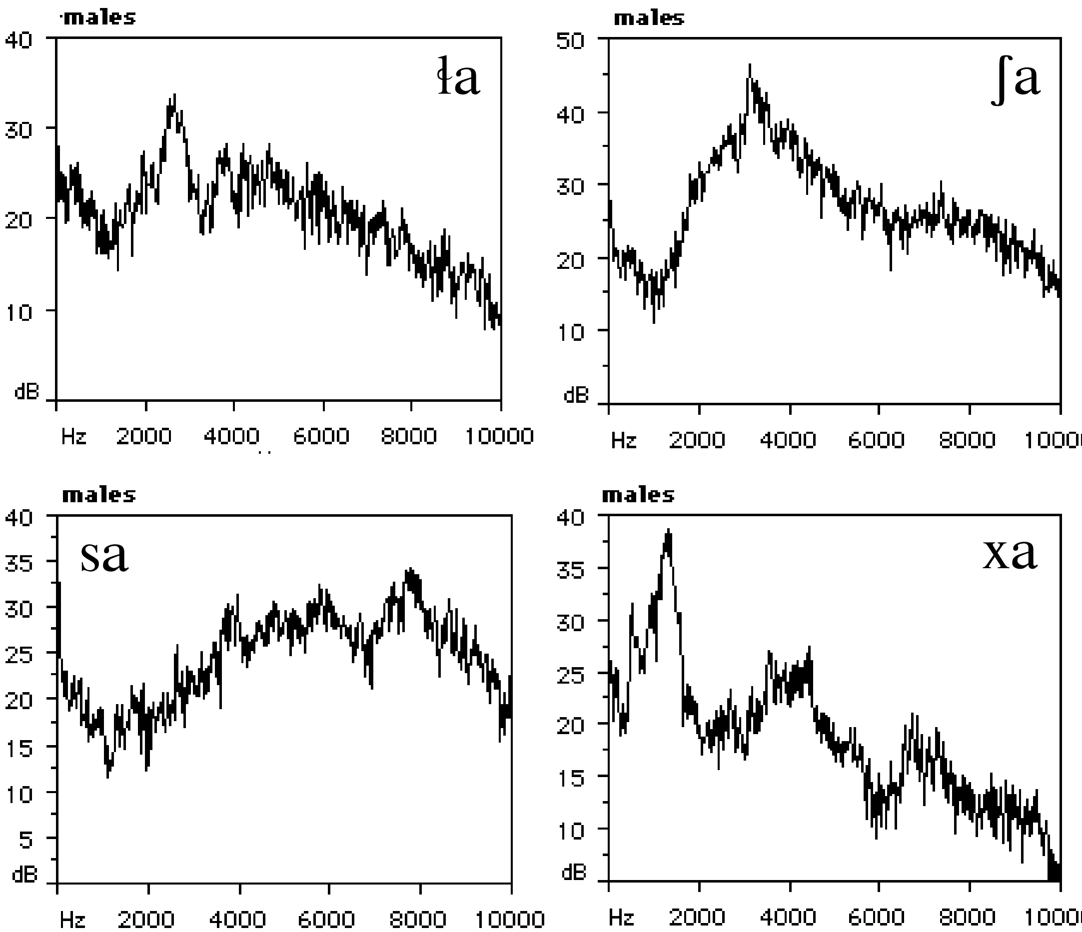

Figure 28. FFT power spectra of fricatives before [a] (male speakers)

4. Vowels

Like Navajo (cf. Hoijer 1945, McDonough & Austin-Garrison 1994), Western Apache has four phonemic vowel qualities: /i/, /e/, /o/, and /a/, each of which has two phonemic vowel lengths: short and long. Although the high back vowel [u] surfaces in several Western Apache words, Greenfeld (1972) demonstrates that [u] is an allophone of the phoneme /o/. /o/ is pronounced as [u] when preceding the vowel [i]. Long, high tone [óː] is pronounced as [úː] when preceded by [t^h], [k^h],

[s], or [j] (de Reuse 1994). The Western Apache vowels appear in Table 7.

Table 7. The vowels of Western Apache.

Short			Long		
i			iː		
	e	o		eː	oː
	a			aː	

In addition, every vowel may be either oral or nasalized and may carry either high tone or low tone. (Current research by de Reuse and Tuttle (forthcoming) indicates the possible presence of a contrastive mid tone as well.) The contrastive use of tone is a common feature of Southern Athabaskan languages, including Navajo and Western Apache, as well as many Northern Athabaskan languages. Long vowels in Western Apache may also carry contour tones consisting of a high tone followed by a low tone or vice versa. Contour tones in Western Apache are fairly rare, however, and almost exclusively limited to morphologically complex words. The words analyzed for this paper appear in Table 8. Words illustrating the nasal vowel series were also recorded, but are not included in the present analysis.

Table 8. Words used to examine the quality, fundamental frequency, and duration of Western Apache vowels. Entries in parentheses were not pronounced as expected (see text).

Vowel	Short - Low Tone		Short - High Tone	
i	tʃ**ɪ**k	blanket	ʔɪɬk’**ɪ́**koɾɛstɔ̃	to straighten it out
e	k’**ɛ**kowã	home, ruins	kotɛ’**ɛ́**ko	finally
o	bɛ́ːʃtɪst’**ɔ**k	arrowhead	(ʔɪk’án nást’**ó**ːk)	dough
a	jɪɾɪts’**a**k	he hears him	pɪts^{h}ɪt’**á**kɛː	top of his head
Vowel	Long - Low Tone		Long - High Tone	
i	nákonɛtʃ’**i**ːki	locust	na’ɪtɬ’**í**ːki	gopher
e	taɬɛ́ɬt’**ɛ**ːko	same way	ʧ́ijat’**ɛ́**ːko^{h}	awful
o	t^{h}ú hajɪɬt’**o**ːk	he pumps water	(nájɪɬt’**o**ːk)	he soaks it
a	haɾɪtʃ’**a**ːk	it oozes	hakon̩’**á**ːkɛ^{h}	corner

The goal of the list of words in Table 8 was to provide each oral vowel of the language in a minimally contrasting environment: between an ejective stop or glottal stop and the unaspirated velar stop. To the extent possible, words were chosen in which the vowel appeared as part of the root morpheme. The two entries in parentheses were not pronounced as expected from the list. The word selected to exhibit short, high tone /o/ was most typically pronounced with a long vowel, and the word selected to exhibit long, high tone /o/ was most typically pronounced with low tone. These items were excluded from the statistical analyses as appropriate. Note also that word final stops were unreleased, and stem final /k/ varied dialectally with /t/. This latter variation was present in the words for ‘blanket’, ‘he hears him’, ‘dough’, ‘locust’, ‘he pumps water’, ‘it oozes’, ‘gopher’, and ‘he soaks it’. Finally, short /e/ is rare in Western Apache and only five speakers recognized the word for ‘home, ruins’ and only three speakers recognized the word for ‘finally’.

4.1. Vowel duration

Vowel duration was measured from a waveform alongside a spectrogram. The duration of each vowel included the time from the onset of the first formant of the vowel to the offset of the first formant. Not surprisingly, phonemic long vowels were found to be significantly longer than phonemic short vowels ($p<.0001$). Long vowels averaged 187 ms collapsing all speakers and all vowel qualities, while short vowels averaged 89 ms. In terms of ratios, long vowels were thus 2.1 times longer than short vowels. This long-to-short ratio is smaller than the one found by McDonough and Austin-Garrison (1994) in their study of Navajo. They found that long vowels were 2.8 times as long as short vowels for monolingual speakers and 2.3 times as long as short vowels for bilingual speakers. (All the Western Apache speakers were bilingual.) Duration ratios between short and long vowels vary substantially across languages; the Western Apache ratio of approximately 2:1 falls squarely within the range of cross-linguistic variation (cf. Lehiste 1970 and Hubbard 1994 for representative values from other languages).

Figure 29 plots the duration of different vowel qualities, collapsing short and long vowels. The high vowels were found to be significantly shorter than all other vowel qualities, a familiar pattern from a number of languages (cf. Lehiste 1970 for a summary of the data). Neither of the mid vowels differed significantly from the low vowel in terms of duration, though /e/ was found to be significantly longer than /o/ ($p=.0028$).

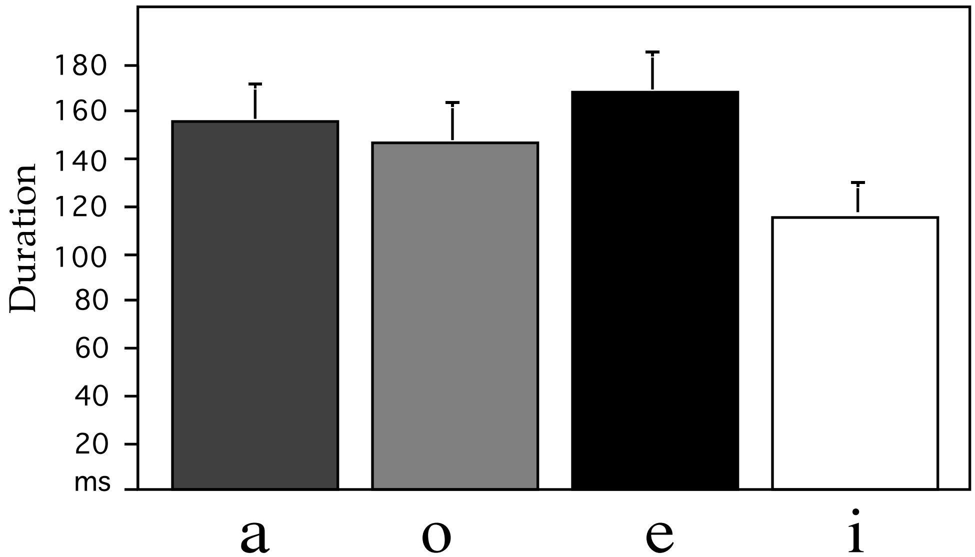

Figure 29. Duration of vowels of different qualities.

Vowels were also found to be significantly longer for the female speakers than for the male speakers (p=.0033). The significance of this result is due to the long vowels, which averaged 208 ms for the female speakers but only 174 ms for the male speakers. Short vowels were virtually identical in duration for the male and female speakers: 91 ms for the male speakers vs. 86 ms for the female speakers.

The confinement of the gender dependent length difference to the long vowels plausibly has similar motivations as the absence of gender dependent length differences among unaspirated stops. In both cases, it is the shorter phonemic category, unaspirated stops and phonemic short vowels, which fail to display duration differences as a function of gender. Manipulation of the length of the shorter category would potentially interfere with the perception of the phonemic length contrast, by making the shorter category more like the longer category. Lengthening the longer category (aspirated stops and long vowels), on the other hand, only enhances the percept of the phonemic length contrast.

4.2. Fundamental frequency

Fundamental frequency, the acoustic property defining tone, was measured using narrow band spectrograms. A measurement was taken from the tenth harmonic at a point with fairly level fundamental frequency and at approximately the mid point of each vowel. In cases where the tenth harmonic was not readily discernible, a measurement was taken from a lower harmonic. Measured values were divided by the number of the harmonic from which the measurement was taken, yielding a value for the first harmonic, i.e. the fundamental frequency. For male speakers, high tone vowels averaged 135 Hz, while low tone vowels averaged 118 Hz. For female speakers, high tone averaged 208 Hz, while low tone averaged 189 Hz.

Vowel quality did not have a statistically significant effect on fundamental frequency according to t-tests. /o/ had a slightly lower fundamental frequency (141 Hz) than /a/ (148 Hz) which in turn displayed a slightly lower mean value than /e/ (152 Hz) which in turn had a lower fundamental than /i/ (159 Hz). The only difference which reached statistical significance was the one between /o/ and /i/ ($p=.0254$). Dividing the tokens according to whether they had high or low tone did not yield any additional significant results.

4.3. Vowel quality

The first three vowel formants were measured using an LPC analysis calculated over a 30 ms window using 12 coefficients. An FFT spectrum was also consulted to ensure that the measurements taken from the LPC were accurate. A spectrogram provided further corroboration of the accuracy of the LPC measures.

The first two formants from all tokens produced by the female speakers are plotted in Figure 30. Formant values for the male speakers are plotted in Figure 31. Ellipses encircle all points falling within two standard deviations of the mean, which is plotted as a large vowel in the middle of the ellipse. Formant values for each of the individual speakers appear in Table 9. The first formant is inversely correlated with vowel height: higher vowels have lower first formant values. The second formant is largely a function of relative frontness of the vowel: fronter vowels have higher second formant values than backer vowels.

There is very little difference in the general form of the plots of the females' vowels and those of the males. The most salient difference between the two genders appears to be the location of long /iː/ relative to short /i/ in the vowel space. For the male speakers, long /iː/ is both much higher and much fronter than /i/. For the female speakers, the primary difference between /i/ and /iː/ lies in the front-back dimension, with /iː/ having a fronter articulation than /i/. There is a tendency for /iː/ to be slightly higher than /i/ for the female speakers, though this difference is much less striking than for the male speakers.

For the male speakers /iː/ is much higher than the long back vowels /o/ and /oː/. This difference is less apparent for the female speakers. For these speakers the difference between short /i/ and its short back counterpart /o/ is substantial, and in fact more salient than the corresponding difference for the male speakers. Whereas /o/ has first formant values approximately midway between those of /i/ and those of /e/ for the male speakers, /o/ has similar first formant values to /e/ for the female speakers.

Interestingly, similar to the male Apache speakers, in many languages with small vowel inventories, there is only a single back vowel which is realized as a mid rather than a high vowel, even though this realization fails to maximize the use of the vowel space. This is the case in Navajo (McDonough et al. 1993), which has a four vowel system /i, e, a, o/. Similarly Hupa (Golla 1970), another Athabaskan language, also lacks a high back vowel at least in its underlying phoneme inventory. In other language families the same situation is found. Banawá, an Arawakan language, spoken by about 75 speakers in northern Brazil (Ladefoged, Ladefoged and Everett 1997) has a four vowel system /i, e, a, o/, with qualities that are very similar to those of Apache. Wari' (Arawakan) has four vowels /i, e, a, o/ plus two front rounded vowels /y,ø/, but no high back vowel (MacEachern, Kern and Ladefoged 1997).

There are differences between the long and short vowels in Western Apache. The long back vowel /oː/ is backer and higher than its short counterpart /o/ for both female and male speakers, and the long low vowel /aː/ is slightly lower and backer than its short counterpart /a/. Comparison of short and long vowels thus indicates a general trend for the long vowels to be more peripheral in the vowel space than the short vowels. This is not the case, however, for the front mid vowel pair /e/ and /eː/. For most speakers, these vowels do not differ from one another in either front/back or height dimensions, as evidenced by the extensive overlap between their two ellipses and the close proximity of their means. Only two speakers (F3 and M2) do not display substantial overlap of short and long /e/ as shown in Table 9. For both of these speakers, short /e/ is backer than long /eː/, as reflected in the lower F2 values for /e/. First formant values for /e/ and /eː/ are virtually identical, however, suggesting that they do not differ in terms of tongue height.

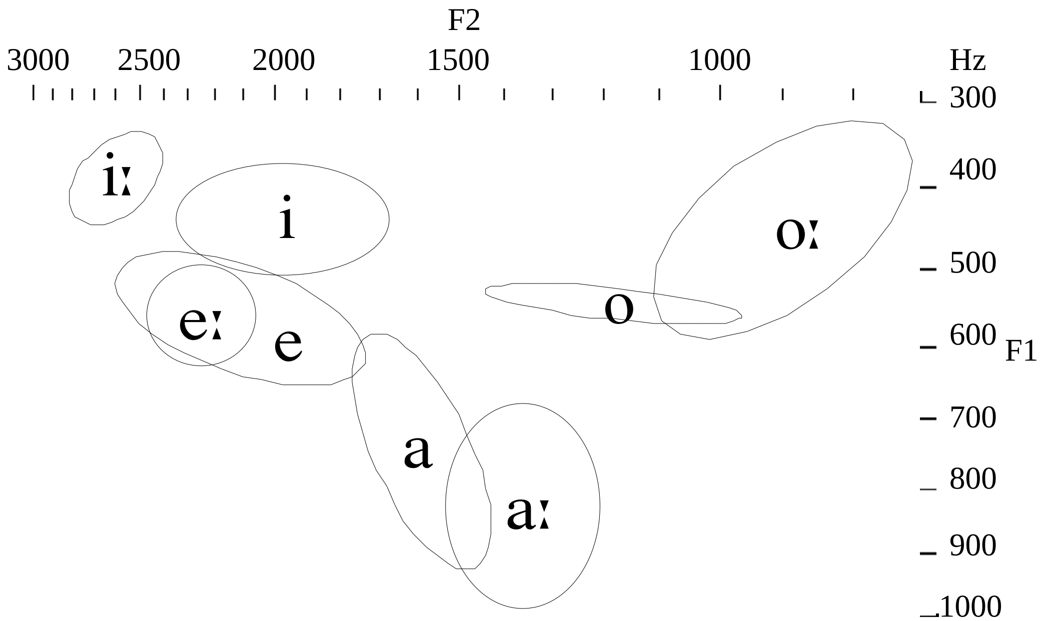

Figure 30. Plot of the first two formants for three female speakers.

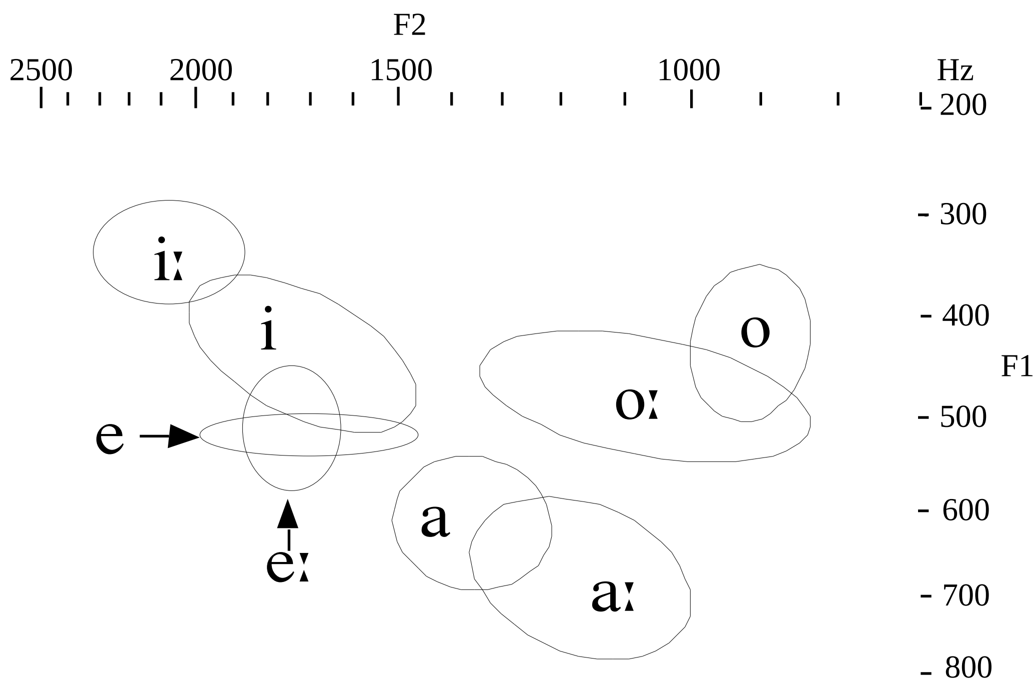

Figure 31. Plot of the first two formants for five male speakers.

Table 9. Mean values for the first three formants for five male and three female Western Apache speakers.

Spk	Short			Long			Spk	Short			Long		
	F1	F2	F3	F1	F2	F3		F1	F2	F3	F1	F2	F3
F1							**M2**						
i	463	1954	2812	413	2683	3367	i	468	1573	2412	362	2046	2440
e	536	2298	3183	551	2353	2853	e	518	1596	2114	532	1718	2281
a	858	1536	3041	913	1380	3078	a	582	1330	2091	674	1156	2302
o	556	1076	3168	436	821	3367	o	486	908	2201	468	940	2192
F2							**M3**						
i	426	1959	2788	408	2628	3087	i	376	1844	2284	316	1972	2289
e	----	----	----	559	2192	3013	e	----	----	----	486	1720	2133
a	669	1715	2926	819	1394	2807	a	614	1435	2729	624	1330	2367
o	541	1339	2532	422	908	2954	o	523	1009	2183	431	885	2174
F3							**M4**						
i	431	2078	2903	353	2550	3335	i	444	1779	2436	339	2092	2399
e	579	2003	2682	573	2247	2752	e	----	----	----	495	1711	2426
a	715	1583	2908	747	1371	3142	a	633	1348	2348	660	1105	2403
o	541	1220	2816	500	991	3027	o	495	1100	2238	385	945	2371
M1							**M5**						
i	458	1917	2550	339	2256	2518	i	445	1633	2417	339	2060	2578
e	523	1835	2385	532	1816	2473	e	523	1844	2366	514	1807	2376
a	601	1380	2509	679	1165	2619	a	651	1367	2477	711	1229	2573
o	431	1110	2431	413	935	2587	o	468	1257	2357	436	917	2509

6. Summary

In this paper, we have described several phonetic properties of Western Apache. The principal findings are as follows. For consonants, VOT was longer for aspirated stops than for unaspirated stops, whereas closure duration was longer for unaspirated stops than for aspirated stops. The ejectives had VOT and closure duration values intermediate between those of the aspirated and unaspirated stops. Place of articulation was also shown to affect both VOT and closure duration. VOT was longest for the velar stops, followed by the alveolars, followed in turn, by the bilabials. Conversely, closure duration was shortest for the velars, longer for the alveolars, and marginally still longer for the bilabials. There is some phonetic evidence for a four way manner contrast in the stop series between voiced, voiceless unaspirated, voiceless aspirated, and ejective stops, though voiced stops have a limited distribution relative to the other three categories. The four oral fricatives of Western Apache are well-differentiated in terms of the location of their spectral peaks in the frequency domain and their sharpness. /s/ has the greatest energy at frequencies above 4000Hz for the males and above 6000Hz for the females. /ʃ/ has a relatively sharp spectral peak at 3500Hz for the males 4000Hz for the females. /x/ has the most pronounced peak and the peak at the lowest frequency, about 1500Hz. /ɬ/ has a slightly flatter peak at frequencies intermediate between the peaks for /x/ and /ʃ/.

Concerning the vowels, long vowels tend to be slightly more peripheral than their short counterparts, except for the /e, eː/ pair which differed substantially in the first and second formant dimensions for only two speakers. As in other languages with small vowel inventories, the highest back vowel was more like [o] than [u]. Finally, female speakers differed from male speakers in having longer VOTs, closures, and vowel durations.

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