An Acoustic Analysis of Stress in the Na-Dene Languages of Ahtna and Dena'ina

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Abstract

This study measures and analyzes the acoustic factors that contribute to the assignment of stress in non-tonal Na-Dene languages. Ahtna and Dena'ina are examined, and each language is represented by three archival audio recordings taken from the Alaskan Native Language Archive (ANLA). This paper studies the duration, intensity, and pitch of the vowel /a/ in stressed and unstressed environments. Through Praat and statistical analysis, a significant correlation is found between stress and duration where the token /a/ was longer in stressed environments compared to its unstressed counterparts. Pitch and intensity show no significant correlation to stress. This suggests that duration is the primary acoustic cue of stress placement in toneless Na-Dene languages.

1. Introduction

1.1 Stress in Linguistics

Stress, referring to the relative prominence of a syllable in a word, is a central concept in the study of phonology. The most prominent syllable of a word is labeled to have *primary stress*. Stress is crucial to language as it is required for lexical contrast and emphasis, which are essential for overall intelligibility. The main theory behind stress is the binary relationship between strong and weak syllables, coined by Liberman and Prince (1977) as Metrical Theory of Stress. They presented a new theory (at the time) where they proposed that stress patterns are in hierarchical structures instead of cyclic rules, which thus indicates that stress levels are not arbitrary (Liberman and Prince, 1997). Metrical Theory allows linguists to predict stress levels in a language which is now known as metrical stress.

It is important to note that metrical stress is different from lexical stress. Lexical stress is the degree of emphasis of the syllables of a word spoken in isolation, where the location of primary stress can differentiate segmentally equivalent words (Mousikou et al, 2024). Research has shown that lexical stress is typically cued cross linguistically with some combination of three factors: duration, volume, and pitch. For example, some languages may only use duration to denote stress while others use a combination of pitch and volume. Another area that complicates stress and stress assignment is the existence of tone in a language. Tone can greatly contribute to a language's stress assignment since tone can carry prosodic load, and thus, might change the location for phonetic cues for stress (Kidder, 2008). As de Lacy (2002) explains in his research, tone is the manifestation of pitch on the syllable and can override pitch-based (and potentially duration and volume based) stress cues. The overlap of tone and phonetic cues of stress can make it complicated for linguists to identify the effects of duration, volume, and pitch on stress for languages with rich tonal inventories.

1.2 Stress in Na-Dene

As stress occurs cross-linguistically, it is realized in many forms and cued differently depending on the language. Na-Dene languages also undergo stress computation by the speaker; however, not much work has gone into what causes stress to be detected by the listener. This research will focus on stress specifically in the Na-Dene language family. The Na-Dene language family is made up of around fifty distinct languages that are spoken across Alaska, the Yukon, the North West Territories, British Columbia, Alberta, and all the way down the west coast to California. Navajo and its related languages are also included in the Na-Dene language family and are currently located in Southern America mainly in Texas, New Mexico, and Arizona (Dryer & Martin, 2013).

1.2.1 Phonological Approach to Na-Dene Stress

Previous work that has been done into Na-Dene stress patterns has primarily focused on tonal languages in the family such as Tahltan, Tetsǫ́ t’ıné, and Tanana. Before delving into the research that has been conducted on stress and tonal Na-Dene languages, it is important to discuss the work of Leer (1999) on *tonogenesis* in the Na-Dene family. In his paper, Leer discusses the tone contrast between tonal Na-Dene languages to Proto-Na-Dene which has been theorized to be toneless (Krauss, 1964). Leer argues that phonemic tone developed in Na-Dene languages through the process of tonogenesis and through the conditioning of word-final glottal stops. Leer noticed that in Na-Dene languages that developed tone, the glottal stop at the end of the stem played an essential role in triggering the tonal distinctions. He explains how from a toneless Proto language, contrasting high and low tones appeared in Na-Dene languages depending on how the language applied the glottal features to the preceding vowel in the stem. As discussed in section 1.1, the presence of tone in a language can contribute to the assignment of stress in a language.

Alderete and Bob (2002) built off earlier work that was conducted by Cook (1972) on stress in Tahltan. Both papers confirmed that stress typically appears on the stem syllable and is conditioned by the weight of the syllable (long vowel or moraic coda). Cook initiated this inquiry by comparing stress, pitch, and vocalic quality, and found that these three factors were not randomly distributed but were in fact predictable. Alderete and Bob sought to refine this by analyzing a corpus of data in Tahtlan utilizing Metrical Stress Theory. They replicated Cook's finding that stress was predictable, and in fact, almost always fell on the stem syllable and was affected by the weight of the syllable. Furthermore, they supported Leer (1999) and briefly discussed the functional load of tone and how that affects stress assignment.

1.2.2 Acoustic Approach to Na-Dene Stress

Adding to the phonological approach, there have been studies that have applied phonetic methods to theories of phonological stress patterns to identify how stress is acoustically realized. As discussed in section 1.1, acoustic analysis of duration, pitch, and intensity can be used to discuss the perception of lexical stress (Mousikou et al, 2024). Tuttle (2000) conducted an acoustic analysis of vowel duration, fundamental frequency, and amplitude of stress between two lower Tanana dialects: tonal Minto and toneless Salcha. They noted that there was a difference in the acoustic features that assign stress between the tonal dialect and the toneless dialect. For Minto, pitch is dominant in signaling stress, while in Salcha, stress is marked by intensity and duration. They make the important note that since Salcha has no native speakers left, the use of instrumental measures impacts the validity of judgements made about the phonology of Salcha. Another acoustic study of Na-Dene by Jaker and Howson (2022) investigated the interaction of stress, the four-way tone system, and contrastive vowel length in Tetsǫ́t'ıné. This study explored how stress manifests according to the Functional Load Hypothesis and the Iambic-Trochaic Law. The Functional Load Hypothesis states that languages avoid using a single phonetic feature like duration to mark multiple contrasts, such as both tone and stress (Berinstein 1979). The Iambic Trochaic Law states that in languages with predictable iambic stress, it is usually duration that marks stress (Hayes, 1995). Jaker and Howson showed that in Tetsǫ́t'ıné, duration was the most prevalent cue for primary stress. This finding goes against the Functional Load Hypothesis as duration can be used to mark stress even in a tonal language.

1.3 Literature Gap

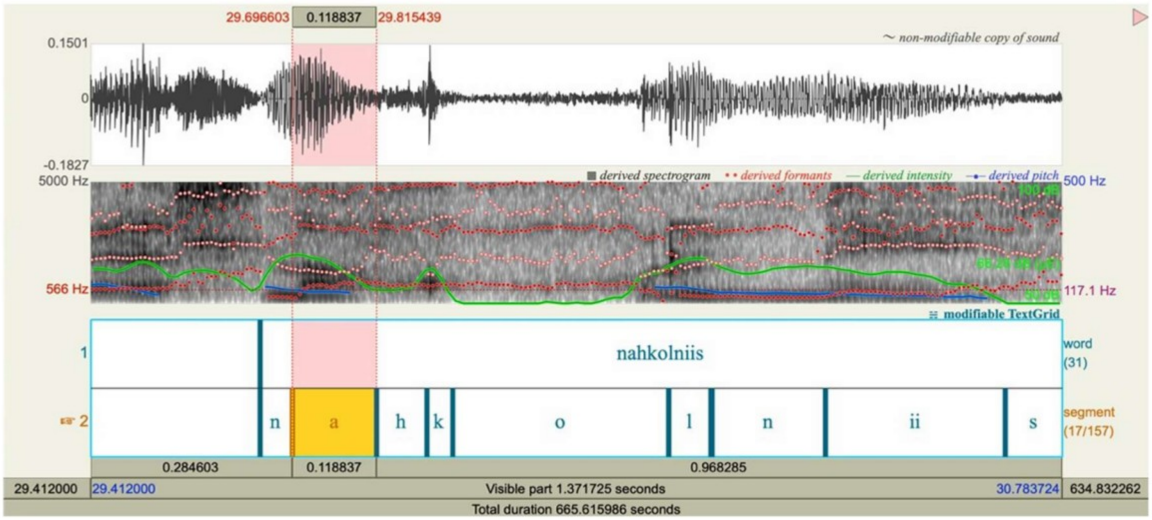
The literature contained in section 1.2 covers the vast majority of research that exists that focuses on stress assignment in Na-Dene languages. This is a deeply understudied area of linguistics, especially due to the historical silencing and underrepresentation of Indigenous languages. Within the literature that does exist around stress in Na-Dene, there have been no studies that focus on only toneless Na-Dene languages and how stress is phonetically realized in these languages. The lack of phonetic tone in toneless Na-Dene languages allows for a clearer look at how vowel length, intensity, and pitch affect stress assignment. While stress is not consistently marked in Na-Dene orthography, the work done by Shanks (2023) on syllable structure and moraic theory in Southern Tutchone points to a weight-based system in Na-Dene languages. Thus, this paper will aim to build on these insights by using an acoustic analysis to determine which features indicate weighted stress in toneless Na-Dene languages.

2. Methodology

2.1 Overview of Project

This project seeks to answer the question of how stress is realized in non-tonal Na-Dene languages. Specifically, how does duration, volume, and pitch vary in stressed versus unstressed environments in non-tonal Na-Dene languages? These questions will be explored through analyzing audio recordings of people speaking non-tonal Na-Dene languages. The recordings have been taken from the Alaskan Native Language Archive (ALNA) and manually matched up with transcriptions, also found on the ALNA. Most of these recordings are from the 1990s or earlier and as a result are not of high quality, nor do they have matching transcriptions. Subsequently, only the recordings that are intelligible and have a transcription on the ALNA will be presented here. The amount of data is limited due to the difficult nature of this matching process. Once the recordings and transcriptions were located, they were taken into Praat, and the transcription was manually aligned to the audio. The audio was then analyzed to see if the difference between stressed and unstressed environments results in a significant difference in duration, volume, and/or pitch. In analyzing the data, it was important to consider the possibility that multiple factors could contribute to the phonetic realization of stress in toneless Na-Dene languages, or that another factor that was not measured in this project could be the main contributing factor.

Figure 1: Example of Praat Analysis Showing Duration (s), Volume (dB), and Pitch (Hz)



To control this experiment, I selected a specific segment that occurs in both stressed and unstressed environments, and I recorded the duration in seconds, the volume in decibels, and the pitch in hertz for each environment. The values were taken directly from Praat where the duration is highlighted in red (0.118837 seconds in Figure 1), the volume is the green line (66.28 dB in Figure 1), and the pitch is the blue line (566 Hz in Figure 1). To collect the value for each of these lines, it is necessary to select the point on the spectrogram that one wishes to investigate. To remain consistent, I always selected the highest value for both volume and pitch. The specific environment that was selected was the /a/ vowel as it occurs in both selected languages of Ahtna and Dena'ina, and it occurs in both stressed and unstressed positions in both languages. For each recording, three words where /a/ is stressed and three words where /a/ is unstressed were selected for analysis.

2.2 Languages

The two languages chosen for this project were Ahtna and Dena'ina. Both languages are a part of the Na-Dene family and are traditionally and currently located in Alaska. The two languages of Ahtna and Dena'ina are closely related as they are both quite conservative; that is, they appear to preserve features from their theoretical ancestor parent language, Proto-Na-Dene. One of these features shared between these two languages is tonelessness, whereas most other Na-Dene languages are tonal. As discussed in section 1.2 regarding Leer (1999), tonogenesis is believed to have occurred in many Na-Dene languages from the toneless parent Proto-Na-Dene. Both Ahtna and Dena'ina did not undergo tonogenesis and thus still resemble the Proto language. It is because of their toneless nature that these two languages were selected to analyze how stress is realized in the absence of tone in the Na-Dene family.

2.2.1 Ahtna

The Ahtna live in the ‘Headwaters Country’ in Alaska that consists of complex mountain passes and is a crucial resource of salmon and other game (Kari, 1986). The Ahtna language is spoken in and around Copper River and consists of four dialects: Upper, Central, Lower, and Western Ahtna, with all but Lower Ahtna still being spoken today. The language is classified as nearly extinct on the World Atlas of Language Structure (WALS) and Glottalog (Campbell et al, 2022). Ahtna, like its other Na-Dene languages, has complex phonetics and phonology with a large consonant inventory, including plain, aspirated, and ejective plosives and affricates. Ahtna also has a large vowel inventory with contrastive long and short vowels. The full consonant and vowel charts for Ahtna can be seen in Tables 1 and 2. The recordings taken from ANLA are specifically of speakers of the Upper Ahtna dialect. Most of the information regarding the language is sourced from James Kari’s 1990 grammar of Ahtna; however, the transcription of the stories is from Kari’s earlier work titled *Tatl’ahwt’aenn Nenn’ (The Headwaters People’s Country): Narratives of the Upper Ahtna Athabaskans* (Kari, 1986).

Table 1: Ahtna Consonant Inventory (Kari 1990)

		Labial	Alveolar	Lateral	Velar	Uvular	Glottal
Nasals		m	n		ŋ		
Plosives/ Affricates	Plain	p	t ts	tɬ	k	q	ʔ
	Aspirated	p^h	t^h ts^h	tɬ^h	k^h	q^h	
	Ejective		t' ts '	tɬ'	k'	q'	
Fricatives		v	s z	ɬ	x ɣ	χ ʁ	h
Approximant		h^w		l			

Table 2: Ahtna Vowel Inventory (Kari 1990)

	Front		Back	
	Short	Long	Short	Long
High	ɪ	iː	ʊ	uː
Mid	ɛ		ɔ	oː
Low	ɐ	æ		ɑː

2.2.2 Dena'ina

The Dena'ina language sometimes referred to as Tanaina, is spoken in Cook Inlet in Alaska and consists of four dialects: Upper Inlet, Outer Inlet (sometimes called the *Kenai* dialect), Iliamna, and Inland (Boraas, 2009). The recordings taken from ALNA are all of Peter Kalifornsky who speaks the Kenai dialect. Like Ahtna, Dena'ina is also classified as nearly extinct by Glottalog, the Kenai dialect being the most endangered. In 2009, there were only around 10 speakers of the dialect, including Peter Kalifornsky. (Campbell et al, 2022; Boraas, 2009). In line with the Na-Dene family, Dena'ina has a rich consonant system with plain, aspirated, and ejective stops and affricates, as seen in Table 3. The vowel inventory for Dena'ina is not as complex as Ahtna as it does not have contrastive vowel length and only has four vowels as seen in Table 4. The grammatical and morphological information for Dena'ina is sourced from Boraas' (2009) grammar of Kenai Dena'ina titled *An Introduction into Dena'ina grammar: the Kenai (Outer Inlet) Dialect*. The transcriptions and recordings all come from Peter Kalifornsky's award winning book titled *K'tl'egh'i Suku* (Remaining Stories) where he wrote traditional Dena'ina stories which were translated with the help of Kari.

Table 3: Dena'ina Consonant Inventory (Boraas, 2009)

		Labial	Alveolar	Lateral	Palatal	Velar	Uvular	Glottal
Nasals		m	n			ŋ		
Plosives/ Affricates	Plain	p	t ts	tɬ	tʃ	k	q	ʔ
	Aspirated	p^{h}	t^{h} ts^{h}	$tɬ^{h}$	$tʃ_{h}$	k^{h}	q^{h}	
	Ejective		t' ts'	tɬ'	tʃ"	k'	q'	
Fricatives		f v	s z	ɬ	ʃ ʒ	x ɣ	χ ʁ	h
Approximant				l	j	w		

Table 4: Dena'ina Vowel Inventory (Boraas, 2009)

	Front	Central	Back
High	i		u
Mid		ə	
Low		a	

2.3 Data Selection

When performing data analysis, it is important to restrict the bounds of the inquiry to ensure accurate results. The first restriction was selecting the /a/ as the segment of interest in stressed and unstressed environments, as mentioned in section 2.1. Another crucial restriction concerns the amount of data collected. For each language it was important to have three different recordings to provide enough data and to ensure that the results do not occur due to random error. For the audio clip being analyzed, it must contain only the selected word and have a matching transcription to locate /a/. Furthermore, the sound cannot be produced in isolation as stress is often affected by the preceding and following segments, as discussed in section 1.1. Additionally, since I am not a speaker of Ahtna or Dena'ina, I do not have native intuitions on the phonology of these languages, and thus consulted with other listeners to more accurately determine where the primary stress of the word was. To avoid bias about where the primary stress is in the word based on the spectrogram, I would gather the opinions of non-linguists and from people not looking at the spectrogram. The last criteria I imposed on this research project is that the word must be polysyllabic. This is important to get the unstressed /a/ environments, it assumes that another vowel in the word is stressed and thus cannot be monosyllabic. As well, most of the research conducted on Na-Dene languages has specifically been done with monosyllabic or disyllabic words (e.g., Krauss (1964); Leer (1979)). As a result, not much work has been done on stress in polysyllabic words in Na-Dene, so I believe that it was especially significant to pursue here.

3 Results

For each of the statistical analyses performed below, an alpha value of 0.05 (confidence interval of 95%) was assumed. For Figure 2-6, each of the columns of duration, volume, and pitch of Tables 5-10 were compared in group with an independent samples t-test. This test compared the variance between stressed ('yes') and unstressed ('no') values in each column. The results of the one-sided and two-sided t-tests are shown in the significance column of the figures. The independent t-test calculates the significance for equal variance assumed and for equal variances not assumed, and for this project I will only be looking at the equal variances not assumed values. Furthermore, since I am looking for an increase in one of duration, volume, or pitch from unstressed to stressed syllables, I will be looking at the one-tailed tests. Thus, the hypotheses for this project are made with the two-group t-test structure of a null hypothesis and an alternative hypothesis. The hypotheses are as follows:

$$H_0 = \mu_{stressed} \leq \mu_{unstressed}$$

$$H_a = \mu_{stressed} > \mu_{unstressed}$$

3.1 Ahtna Results

Three stories were able to be matched to the transcriptions from *Tatl'ahwt'aenn Nenn' (The Headwaters People's Country): Narratives of the Upper Ahtna Athabaskans* by James Kari.The three chapters that were matched was “Chapter 4: Dae’ Ts’atk’aats (How We Were Trained)” which corresponds to ANLC5030B, “Chapter 8: Tsaał K’aas C’eghaan T’ił’aen’de (When ‘He Trains the Chinook Wind’ Made War)” (ANLC5030A), and “Chapter 17: C’uka Ts’ul’aen’i gha Nen’ Ta’stedeł dze’ (How We Went Hunting Out in the Country)” (AT973K2010). Because each of these stories is spoken by a different person, I will not compare the pitch and volume across samples, since the sex of the speaker can affect these factors (Chen et al, 2010). Thus, duration was compared both across samples and within-sample, while pitch and volume were only compared for each story.

Table 5: Huston Sanford Reading “Chapter 4: Dae’ Ts’atk’aats (How We Were Trained)”

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
neniłdaagga'en	yes	0.187966	64.46	403.9
nicdalzes	yes	0.087683	66.09	538.9
nek'ehwtedax	yes	0.118368	66.95	640.2
nahwnedełi'eł	no	0.160754	68.93	606.4
nakakolniis	no	0.094798	62.33	505.2
nadaexi'en	no	0.155596	64.99	572.7

Figure 2: One-Tailed and Two-Tailed T-Test for Huston Sanford’s Ahtna Data

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
LENGTH	Equal variances assumed	.419	.553	-.157	4	.442	.883	-.0057103	.0364504	-.1069128	.0954921
	Equal variances not assumed			-.157	3.618	.442	.884	-.0057103	.0364504	-.1112671	.0998464
LOUDNESS	Equal variances assumed	1.945	.236	.203	4	.424	.849	.41667	2.05150	-5.27921	6.11255
	Equal variances not assumed			.203	2.568	.427	.854	.41667	2.05150	-6.77916	7.61249
PITCH	Equal variances assumed	1.385	.304	-.452	4	.337	.674	-33.76667	74.63160	-240.97720	173.44387
	Equal variances not assumed			-.452	2.730	.342	.684	-33.76667	74.63160	-285.14992	217.61658

Table 5 shows the data collected for Huston Sanford reading Chapter 4 and for each highlighted vowel (/a/) in the chart's word column. By looking at the significance values in the unequal variance and one-sided t-test rows and columns in Figure 2, length (duration), loudness (volume), and pitch are not significant. This is because when these p-values are compared to the alpha value of 0.05, they are not lower than the alpha, and the null hypothesis is not rejected. Since none of this data is significant, no conclusions can be drawn from only looking at Huston Sanford's data.

Table 6: Katie John Reading "Chapter 8: Tsaał K'aas C'eghaan T'ił'aen'de (When 'He Trains the Chinook Wind' Made War)"

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
stanad**aa**s	yes	0.265884	64.40	851.3
ts'ilgh**a**n	yes	0.126750	63.59	783.4
sk'etl'**aa**ze'	yes	0.225314	66.39	953.2
n**a**hwogholnigi	no	0.111882	63.11	817.4
st**a**nadaas	no	0.083615	62.37	919.3
stan**a**daas	no	0.179850	62.51	885.3
st**a**natkaes	no	0.090535	59.56	817.4

Figure 3: One-Tailed and Two-Tailed T-Test for Katie John's Ahtna Data

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
LENGTH	Equal variances assumed	1.051	.352	2.070	5	.047	.093	.0895122	.0432452	-.0216532	.2006775
	Equal variances not assumed			1.913	3.124	.074	.148	.0895122	.0467881	-.0560926	.2351169
LOUDNESS	Equal variances assumed	.029	.870	2.489	5	.028	.055	2.90583	1.16754	-.09542	5.90709
	Equal variances not assumed			2.530	4.697	.028	.056	2.90583	1.14878	-.10537	5.91703
PITCH	Equal variances assumed	.648	.457	.054	5	.479	.959	2.78333	51.11472	-128.61124	134.17790
	Equal variances not assumed			.050	3.063	.482	.963	2.78333	55.53031	-171.90149	177.46815

Table 6 shows the data collected for Katie John reading Chapter 8, and the data collected is for each of the highlighted vowels (/a/) in the word column of the chart. The procedure was the same as mentioned for Figure 2, so the significance can be found in the significance column of Figure 3. Unlike Huston Sanford's data, volume is significant for the one-sided t-test with unequal variances. The value is 0.028, which is less than the alpha of 0.05, making this data significant at the 95% confidence interval. With a $p = 0.028$, a $t = 2.489$, and a mean difference of 2.91 dB, I can reject the null hypothesis and conclude that stressed syllables are louder than unstressed syllables in Katie John's speech. The significance values for length duration and pitch show no significant variance between stressed and unstressed syllables in Figure 3, thus the null hypothesis cannot be rejected, and no conclusion can be drawn.

Table 7: Adam Sanford Reading "Chapter 17: C'uka Ts'ul'aen'i gha Nen' Ta'stedeł dze' (How We Went Hunting Out in the Country)"

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
sesyaane'yaen	yes	0.138925	79.04	1210
nadaeggi	yes	0.168357	74.92	769.4
ts'eghaax	yes	0.186860	80.60	735.5
kats'enaes	no	0.129134	77.50	701.6
naxaelts'eldeli'el	no	0.079288	82.94	735.5
nats'idaetl	no	0.142137	80.94	803.2

Figure 4: One-Tailed and Two-Tailed T-Test for Adam Sanford's Ahtna Data

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
LENGTH	Equal variances assumed	.615	.477	2.019	4	.057	.114	.0478610	.0236996	-.0179396	.1136616
	Equal variances not assumed			2.019	3.657	.060	.120	.0478610	.0236996	-.0204483	.1161703
LOUDNESS	Equal variances assumed	.039	.853	-.979	4	.192	.383	-2.27333	2.32257	-8.72181	4.17514
	Equal variances not assumed			-.979	3.984	.192	.383	-2.27333	2.32257	-8.73234	4.18567
PITCH	Equal variances assumed	9.589	.036	1.016	4	.184	.367	158.20000	155.72106	-274.15098	590.55098
	Equal variances not assumed			1.016	2.153	.205	.410	158.20000	155.72106	-468.31159	784.71159

Table 7 shows the data collected for Adam Sanford reading Chapter 17, and the data collected is for each of the highlighted vowels (/a/) in the word column of the chart. The independent sample test for length (duration), loudness (volume), and pitch for this data is shown in Figure 4. By looking at the significance values for the unequal variances row, no p-values are below the threshold of 0.05, and thus this data is not significant. Therefore, the null hypothesis cannot be rejected, and I cannot make any conclusions regarding the effect of duration, volume, or pitch on Adam Sanford's syllable stress.

Figure 5: One-Tailed and Two-Tailed T-Test for All Ahtna Duration Data

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
LENGTH	Equal variances assumed	1.425	.249	2.090	17	.026	.052	.0445863	.0213297	-.0004153	.0895880
	Equal variances not assumed			2.042	13.371	.031	.061	.0445863	.0218340	-.0024505	.0916231

As mentioned at the beginning of the analysis of the Ahtna data, only the length of the vowel /a/ can be compared across the data since volume and pitch are dependent on the speaker and their sex and vocal cord length (Chen et al, 2010). Within each individual's speech, the length of the vowel did not prove to be significant. However, comparing the results across the samples yields a value of $p = 0.031$, $t = 2.042$, and a mean difference of 0.446 for the one-tailed t-test with unequal variances. Since this p-value of 0.031 is smaller than the alpha of 0.05, I can conclude that these results are significant at the 95% confidence level. As such, I am able to draw the conclusion that stressed syllables are longer than unstressed syllables in Ahtna.

3.2 Dena'ina Results

I was able to match three transcriptions to three separate recordings of Peter Kalifornsky reading Kenai Dena'ina. Two of the transcriptions came from Kalifornsky's book *K'tl'egh'i Sukdu*, specifically "K'uch' Qinseshi Suduk II (Supernatural Story II)" (the beginning of ANLC1318B) and "Unhshcheyakda Sukt'a (My Great Great-Grandfather's Story)" (21:31 of the same recording). The other transcription is the “Naq’eltanich’ Bahdach’nelneshi (The Lord's Prayer)”, which was found in *Kalifornsky Songs and Stories* (identifier TI 972 Kl, K1972b) and corresponds to 35:00 in ANLC1378. I have separated the three stories into different tables with the data collected depending on the story. Since all the stories are by the same speaker, I can analyze duration, volume, and pitch across the samples as seen in Figure 6.

Table 8: Peter Kalifornsky Reading K’uch’ Qinseshi Suduk II (Supernatural Story II)

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
Dena'ina	yes	0.155632	69.56	904.9
yahghuhdnil'ih	yes	0.116030	71.16	1074
ghetazhchedi	yes	0.233743	74.81	1142
k'qestlagh	yes	0.241510	66.35	873.1
q'aghnudnul'ih	no	0.078957	63.96	769.4
qaqyedenish	no	0.130473	74.68	1210
qahdełtl'it'h	no	0.088307	71.77	1040

Table 9: Peter Kalifornsky Reading Unhshcheyakda Sukt’a (My Great Great-Grandfather's Story)

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
nach'anildush	yes	0.114609	74.51	972.7
Naqan'ijut	yes	0.110655	73.14	871.0

Qadanalchen	yes	0.095204	70.72	701.6
q'anqeydul'uk	no	0.107701	72.15	972.7
taqiynin'un	no	0.080313	74.44	938.8
Qadanalchen	no	0.081144	71.53	803.2
Qadanalchen	no	0.074466	75.57	873.1

Table 10: Peter Kalifornsky Reading Naq’eltanich’ Bahdach’nelneshi (The Lord's Prayer)

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
yuyanq'	yes	0.192437	77.46	701.6
ch'adlkidi	yes	0.135499	83.47	904.9
qtułahqech'	yes	0.100123	73.34	701.6
Natukda	no	0.153106	85.64	837.1
taqech't'htunił	no	0.072236	73.73	667.7
nak'uch'inłkit	no	0.120439	79.38	938.8

Figure 6: One-Tailed and Two-Tailed T-Tests for Dena'ina Data

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means							
						Significance				95% Confidence Interval of the Difference	
		F	Sig.	t	df	One-Sided p	Two-Sided p	Mean Difference	Std. Error Difference	Lower	Upper
LOUDNESS	Equal variances assumed	.051	.823	-.361	18	.361	.722	-.83300	2.30920	-5.68444	4.01844
	Equal variances not assumed			-.361	17.461	.361	.723	-.83300	2.30920	-5.69519	4.02919
LENGTH	Equal variances assumed	5.220	.035	2.622	18	.009	.017	.0508300	.0193878	.0100978	.0915622
	Equal variances not assumed			2.622	13.368	.010	.021	.0508300	.0193878	.0090620	.0925980
PITCH	Equal variances assumed	.000	1.000	-.298	18	.385	.769	-20.34000	68.33780	-163.91239	123.23239
	Equal variances not assumed			-.298	17.999	.385	.769	-20.34000	68.33780	-163.91281	123.23281

From Figure 6, the p-value for length for the one-tailed and unequal variance is p = 0.010, which is less than the alpha value of 0.05. This means the value is significant, and the null hypothesis can be rejected to support the alternative hypothesis. Since t = 2.622 which is a positive value, the positive correlation of the alternative hypothesis is accepted, thus I conclude that the vowel /a/ is longer in stressed syllables than in unstressed syllables. The p-values for pitch and loudness are not significant at the alpha value of 0.05, thus no conclusions can be drawn from that data. These results mirror the results that were seen in Ahtna.

4 Discussion

In the following section, I discuss the results provided in section 3 and situate them within the broader literature. This section will address the individual results from both Ahtna and Dena'ina before comparing them to each other. The implications of this research for the Na-Dene language family and suggestions for further research will also be discussed.

4.1 Ahtna Conclusions

From the comparison of duration, volume, and pitch in Ahtna, only duration proved to be statistically significant. This led me to conclude that the duration of the vowel /a/ is longer in stressed syllables than unstressed syllables. It is important to note that some of the values included for duration are for long vowels, since Ahtna has both the long vowel [æ] and the short vowel [ɐ]. For all the words that were taken into consideration for Ahtna, the long vowels only appeared in the stressed position, which does support the hypothesis that longer duration is what phonetically indicates stressed syllables, and sometimes, that arises as long vowels in Ahtna. However, I also want to point out that not every long vowel is stressed in Ahtna. For example, with "Nakakolniis" in Table 5, the long vowel of [iː] does not attract the primary stress which is actually realized on the /o/. For all three speakers of Ahtna that were collected in section 3, pitch did not show significant difference between the stressed and unstressed. This is surprising, since I had expected pitch to be involved in stress determination since other Na-Dene languages have prosodic pitch (tone), which can play a role in stress assignment. If Ahtna and Dena'ina, the more conservative languages of the Na-Dene family, had pitch influenced the assignment of stress, this research could phonetically support Leer (1999) and the theory of tonogenesis. However, pitch did not come into play, so this project makes no claims about tonogenesis and the assignment of stress in Na-Dene.

Lastly, with volume in the Ahtna data, only Katie John's speech was significant at the 0.05 level for having a difference between stressed and unstressed syllables. Since this pattern did not show up in any other Ahtna speech, it could be a unique characteristic of Katie John's speech. Alternatively, this pattern could be indicative of the role volume plays in the perception of stress in Ahtna. In order to further understand this pattern, I investigated the difference in volume between the vowel /a/ in three different positions of a polysyllabic word. Given the limited data, only the word "Stanadaas" was able to be researched in this study, as seen in Table 11 below. The word "Stanadaas" allows me to investigate the vowel /a/ in three separate environments: two unstressed and one stressed. There is not enough data to run a robust statistical analysis on the data in Table 11, but by visual analysis, the volume of the stressed /a/ is roughly 2 dB higher than that of the unstressed /a/. More data needs to be collected to draw conclusions on whether this finding is significant, but regardless, it is interesting that only Katie John's speech showed this pattern.

Table 11: Analysis of the Ahtna Word Stanadaas

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
stanad**aa**s	yes	0.265884	64.40	851.3
st**a**nadaas	no	0.083615	62.37	919.3
stan**a**daas	no	0.179850	62.51	885.3

4.2 Dena'ina Conclusions

From the comparison of duration, volume, and pitch for Dena'ina, like Ahtna, only duration proved to be statistically significant. Similarly to Ahtna, I was able to conclude that the duration of the vowel /a/ is longer in stressed syllables than unstressed syllables in Dena'ina. Unlike Ahtna, Dena'ina does not have contrastive vowel length and thus does not have the long vowel /aa/. The lack of the moraic long vowel syllable in Dena'ina helps emphasize the significance of duration affecting the location of stress since a long-short vowel contrast cannot be the cause of this significant observation. As such, the data from Dena'ina is crucial to the understanding of phonetic realization of stress in Na-Dene, as this finding does not result from the existence of long vowels or from tone, but purely from the duration of /a/. On the other hand, pitch and volume did not show any significant effects on stress in Dena'ina. Similar to what was discussed in 4.1, it was surprising that pitch did not play a role in Dena'ina, since tone later developed in other Na-Dene languages (Leer, 1999).

In terms of the volume data for Dena'ina, there was no significant variance between the stressed and unstressed environments across the data collected from Peter Kalifornsky's speech. Due to the pattern found in Katie John's Ahtna speech, I investigated whether there was a similar pattern in Dena'ina by looking at the word "Qadanalchen". This word was chosen as it allowed me to investigate the vowel /a/ in three separate environments: two unstressed and one stressed. Since only one word was investigated, there is not enough data for significant analysis, but the volume information can be observed visually. The stressed /a/ vowel in "Qadanalchen" is quieter by around 2-5 dB compared to the unstressed /a/ vowel. This observation would not support the idea that volume increases on the stressed syllable in a polysyllabic word in Dena'ina. Interestingly, by visual observation, I noticed that the first syllable is typically the loudest in Dena'ina. However, I did not collect data on this specifically.

Table 12: Analysis of the Dena'ina Word Qadanalchen

Word	Stressed	Duration (s)	Volume (dB)	Pitch (Hz)
Qadan**a**lchen	yes	0.095204	70.72	701.6
Qad**a**nalchen	no	0.081144	71.53	803.2
Q**a**danalchen	no	0.074466	75.57	873.1

4.3 Implications for Na-Dene Languages

The results discussed above correspond with the literature discussed in section 1.1.2, especially with the study conducted by Jaker and Howson (2022). Even in tonal Na-Dene languages like Tetsǫ́t'ıné, duration was found to be the cue for the location of primary stress. It is interesting to see that both toneless Na-Dene languages of Ahtna and Dena'ina share these results. This would suggest that, fundamentally, duration is the cue used in Na-Dene languages to indicate stress.

While this cannot be concluded with certainty, it can be posited to be likely since both toneless and tonal Na-Dene languages exhibit duration-induced stress assignment. According to both grammars for Ahtna and Dena'ina, stress is predictable in both languages and typically falls stem-initially (Kari, 1990; Boraas, 2009). Neither language has been classified as iambic or trochaic, however, following the Iambic-Trochaic Law stated in Hayes (1995), it is possible to identify the foot pattern of these languages. Jaker and Howson (2022) found that Tetsǫ́t'ıné is dependent on heavy moraic syllables (long vowels or moraic codas), and they concluded that it was iambic due to its heavy foot-initial stress.

My research found that stress is cued with vowel duration in Ahtna and Dena'ina, and both are known to have stem-initial stress (Kari, 1990; Boraas, 2009). Therefore, it could be the case that these two languages are also iambic, as was found for Tetsǫ́ t'ıné (Jaker & Howson, 2022). However, despite finding that duration plays a significant role in the phonetic realization of stress, it may not be the sole determinant of stress in the Na-Dene family. This specifically relates to the volume pattern found in Katie John's Ahtna speech, where the stressed syllable appears to be louder than the other syllables. Since vowels of the same quality must be compared and there is a lack of data, nothing conclusive can be drawn, however, this observation aligns with lexical stress cues cross-linguistically (Mousikou et al, 2024). As well, it was noted that not all long vowels are stressed, which suggests that Ahtna (and potentially Dena'ina by association) are not entirely governed by duration. It could be the case that stress is also influenced by additional prosodic features (like volume mentioned above). This aligns with Metrical Stress Theory, which allows for stressed heavy syllables but does not require all heavy syllables to be stressed (Hayes, 1995). Thus, while duration was found to be a key acoustic cue in stress assignment in Ahtna and Dena'ina, it must also be understood in conjunction with the specific phonological systems of the languages.

4.4 Further Research and Limitations

This study lends itself many avenues for further research. One area that I wish to investigate further is the potential effect of volume on the assignment of stress. Since there was some significant data in Ahtna with Katie John's speech, it would be interesting to gather more data and see if this result is an isolated case or is part of a larger pattern. Building on this, I would investigate the volume of the vowel /a/ in different positions within one word, as seen in Table 11. This would allow for the comparison between stressed and unstressed /a/ in a word to see if stressed syllables are significantly louder than unstressed syllables in Ahtna. It would also be interesting to extend this research to Dena'ina. However, I expect that Dena'ina would show a different pattern, based off the data and analysis of Table 12 in section 4.2.

Additionally, further investigation into stress in polysyllabic words should be done. This research was one of the first to look at polysyllabic words specifically and due to this, the foot assignment of syllables has not been studied in depth. I would like to expand on this research to see if conclusions can be drawn regarding whether Ahtna and Dena'ina form iambic or trochaic feet like Jaker and Howson (2022) did for Tetsǫ́ t'ıné. The final area of further research I will mention is connecting this study to the information known about Proto-Na-Dene. We currently know that Proto-Na-Dene would have been toneless and thus Ahtna and Dena'ina are the two Na-Dene languages that closely resemble it due to their conservative nature. It would be interesting to see if this research could provide insight into how stress would have been cued in Proto-Na-Dene. Since Proto-Na Dene is purely theoretical and cannot be spoken, researching the current spoken languages that most resemble it is the only way to obtain information regarding stress in the Proto language.

I would also like to address the many factors that limited the study. Firstly, I am a white non Indigenous researcher who does not speak any Na-Dene language. Not being able to speak or understand the languages I was investigating could have affected my judgement regarding the place of stress within the words, along with the process of lining up the transcription with the audio file. Another limitation is the lack of data collected for this research. Due to poorly managed archives, there was a lot of difficulty finding audio-transcription matches thus only three recordings for each language were analyzed. While this was enough data to pull significant results, with more time and manpower, much more data could be collected for further research. The last limitation is the degree of error that comes with using Praat to get the values for duration, volume, and pitch. All these values are dependent on the researcher, as to obtain the value, you must click on the point you wish to investigate, and as such, different researchers will have different methods. As mentioned in section 2.1, I always selected the highest value for volume and pitch with the goal of mitigating as much error as possible. For further research, a more accurate tool could be utilized to collect these values.

5 Conclusion

The goal of this paper was to investigate whether duration (s), volume (dB), and/or pitch (Hz) cued the phonetic realization of stress in toneless Na-Dene languages. This research focused on data collected from the Alaskan Native Language Archive (ANLA) for the Ahtna and Dena'ina languages, specifically looking at /a/ in both languages. After analyzing three different recordings for each language, I was able to conclude that duration played a significant role in the phonetic realization of stress in both Ahtna and Dena'ina. Since the data was significant for a one-tailed t test, I was able to reject my null hypothesis and conclude that the vowel /a/ is longer in stressed syllables compared to unstressed. These findings are instrumental to future work that could be conducted into stress and Na-Dene languages, as it is a historically understudied field.

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