Performing Rhythm: Expressions of Meter in Two Yupik Languages

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

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Abstract

This dissertation is a series of studies that explore the acoustic production of stress, length, non-stress metrical phonology, and other syllable structure altering phenomena in Central Alaskan Yup'ik and Chugach Alutiiq. The intricate systems of weight, length, and stress that conspire to produce the notable rhythmic pattern in these languages have been the subject of much theoretical discussion, but little laboratory attention. The studies presented here apply laboratory phonological techniques of acoustic analysis to archival recordings of Yup'ik and Alutiiq. The first of these, which focuses on Yup'ik, examines gemination as a syllable-closing fortition process and addresses the relationship between stress and length. It shows a trichotomy of length among unstressed short, stressed short, and long vowels. The second study focuses on Alutiiq. In addition to a ternary stress-length distinction, Alutiiq metrical phonology also governs onset fortition, tone, and both binary and ternary feet. Moreover, Alutiiq also neutralizes vowel length, making an acoustical examination on metrical production especially interesting. The results show that, like Yup'ik, Alutiiq prefers to maintain a stress-length trichotomy, even where length is targeted for neutralization. They further show that the acoustic correlates of non-stress metrical phonology are considerably more complex than described in the literature. Lastly, the third study presents an exploration of culminativity in both languages. The findings do not provide evidence for word-level culminativity among stressed vowels in either language, which is typologically rare and leads to a discussion on the function of culminativity in metrical systems. The principal contributions of this dissertation include a detailed acoustical analysis of Yup'ik and Alutiiq metrical prosody, a discussion of the implications of this analysis on metrical stress theory, and a demonstration of the application of laboratory analytical methods on archival data.

Preface

Examining committee:

Anja Arnhold, Ph.D., Supervisor
Jorge Emilio Rosés Labrada, Ph.D., Supervisory Committee
Richard Compton, Ph.D., Supervisory Committee
Stephanie Archer, Ph.D., Examiner
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This dissertation is an original work by me, McKinley Alden. The University of Alberta Research Ethics Boards determined that the research project of which this dissertation is a part did not require ethics approval, as it did not involve human subjects and dealt entirely with publicly accessible archival data.

I was responsible for identifying usable Yup'ik and Alutiiq language materials in the Alaska Native Language Archive, as well as the phonetic transcription of all of the materials in Praat. The Praat script used to obtain the acoustical measurements was authored by Dr. Anja Arnhold. The literature reviews, data analyses, and discussions in Chapters 2, 3, and 4, as well as the discussion in Chapter 5, are my original work. A slightly different version of Chapter 2 of this dissertation is accepted for publication as Alden & Arnhold, 2023, "Acoustics of Stress and Weight in Central Alaskan Yup'ik," at the *Journal of Laboratory Phonology*. I was responsible for the manuscript composition. Dr. Anja Arnhold was the supervisory author and was involved with the development of the dissertation, assisted with data interpretation, and assisted with manuscript composition.

Acknowledgements

The planning and execution of a doctoral dissertation is rarely a fun process. The very first steps that I took in the pursuit of this dissertation happened during the early days of the COVID-19 pandemic. Unsurprisingly, the rapid change in research protocols, expectations, and priorities did not make the process any more fun. Despite the tragedy of the pandemic, its devastating effects on Alaska Native communities, and the strangeness of the remote graduate school environment, my department, the Alutiiq language community, and my family all came together to provide the comfort, care, knowledge, and perspective that I needed to bring this project to completion.

First and foremost, this dissertation would not have been possible without the guidance of my supervisor, Dr. Anja Arnhold. I have been fortunate to have worked alongside such a curious, patient, and enthusiastic researcher. I am also very grateful for the invaluable feedback of my committee members, Dr. Jorge Emilio Rosés Labrada and Dr. Richard Compton, as well as that of my external, Dr. Matthew Gordon. I would also like to thank Dr. Ksenia Bogomolets, for her important contributions during my candidacy.

A mere thanks is not enough to express my appreciation for the Department of Linguistics at the University of Alberta. When, in 2021, my home burned down and I lost all my research and back-ups, they came together to ensure that I was safe, well looked after, physically and mentally healthy, and financially secure enough to dust off the ashes and pick myself up again. Of course, I am grateful to the department as a funding body—but more importantly, I am grateful to the professors, instructors, staff, and fellow graduate students as people. Their humanity helped me to recover from my loss and complete this dissertation with dignity, and I will never forget it.

In addition to my supervisor, I have been blessed with a series of mentors throughout my academic journey. Dr. Vera Lee-Schoenfeld was the first professor to trust me with a research assistant position early in my undergraduate career and helped me to cement linguistics as a career path. Dr. Keith Langston instilled a true passion for language work and Slavic linguistics, which ultimately led to my study of Yup'ik and thus, this dissertation. Finally, I am proud to have been mentored by Dr. Siri Tuttle throughout my early graduate studies, who showed me a future in service to Alaska Native communities.

I also owe thanks to many Yup’ik and Alutiiq language scholars, knowledge bearers, organizers, and community members. Decades of Yup’ik scholarship have resulted in an impressive collection of language materials in the Alaska Native Language Archive, and the Alaska Native Language Center’s dedication to making those materials available to learners and researchers alike made this research possible in the first place. I would further like to acknowledge Ivana Qalirneq Ash for her contributions to this project as both a friend and consultant. Many others, among them Natalia Qangyuk Schneider and Peggy Arnangcuk Azuyak, have generously lent me their time and energy in Alutiiq language classes. I am an outsider in their community, and they have each met me with grace and understanding. I am keenly aware that without the contemporary Alutiiq language community, and without those who came before them, this work would not have been feasible.

Many more people deserve acknowledgement here, more than I have the space to write. My sister and my mother both deserve credit, as do a long line of friends and colleagues. Finally, I must thank my partner, Jesse, for his unwavering faith in me. I only ever dreamed that I would find a partner so supportive, gentle, and loving. Without him, I would have gone absolutely and irrevocably insane before ever nearing the completion of this dissertation. In light of that, I feel it is only fair that I dedicate this dissertation to him, as well as to our cats, Marco and Polo.

Table of Contents

List of Tables

List of Figures

1. Introduction

"(...) Now this is very profound, what rhythm is, and goes far deeper than words. A sight, an emotion, creates this wave in the mind, long before it makes words to fit it..."

-Virginia Woolf to Vita Sackville-West, 1926 (Woolf, 1978)

In the Alaska Native languages Central Alaskan Yup'ik (*Yugtun;* henceforth *Yup'ik*) and Chugach Alutiiq (*Sugt'stun, Sugcestun*; henceforth *Alutiiq*),[1] stress is the backbone of metrical expression. As sister languages in the Yupik branch of the Inuit-Yupik-Unangan language family, they share certain fundamental characteristics, including complex systems of vowel length and syllable weight, foot formation, and stress (Arnhold, forthcoming-a; Woodbury, 1984). Furthermore, both feature iterative iambic footing and a ternary stress-weight distinctions between long (obligatorily stressed), short stressed, and short unstressed vowels. Finally, though they are stress languages, both have been described as violating culminativity by featuring only one level of stress at the word level (see Jacobson, 1984, 1985; Jacobson & Jacobson, 1995; Mithun, 1996; Woodbury, 1987, 1995 on Yup'ik, and Leer, 1985a, 1985b, 1985d, 1990, 1994 on Alutiiq).

The ways in which the prosodic systems of Yup'ik and Alutiiq differ give both languages a unique rhythm resulting from overlapping systems of length, syllable closure, syllable weight, footing, and other phonology. Yup'ik, for instance, treats closed syllables differently than Alutiiq in terms of their weight, and its broad gemination environment leads to syllable closure becoming a key feature in the metrical system. Alutiiq, meanwhile, features unique ternary metrical feet, as well as length neutralizing phonology and several non-stress metrical behaviors that are absent in Yup'ik.

These divergent systems are particularly interesting to phonology as a field of linguistics, both in terms of the modelling of these complex systems and the little-studied acoustics of their expression. This dissertation seeks to review and evaluate descriptions of the stress systems of both languages, as well as examine the acoustic expressions of metrical structures in both

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[1] The autonyms for these two languages are *Yugtun* for Yup'ik, and *Sugt'stun/Sugcestun* for Alutiiq. However, the terms that Alaska Native people use to refer to themselves and their languages are often connected to the violent history of colonization across the region. As language suppression and alienation is a large part of colonial history, many community members do not have access to the language today, and the autonyms may not be widely known. In referring to the languages as *Yup'ik* and *Alutiiq* in this dissertation, the intention is to use the terms that are most accessible to both researchers and community members.

languages and the theoretical implications of their metrical behaviors. It further explores the extent to which stress in either language is observably culminative at the word level. In so doing, this research illustrates the value of digital archive collections and the use of archival materials in phonological research.

1.1. Background

This section is divided into several parts: a general outline of the two languages, including a description of their territory and dialectal distribution (1.1.1); an introduction to their word-internal morphosyntax (1.1.2); an overview of the Yup'ik phonemic inventory, orthography, and metrical behaviors (1.1.3); an overview of the Alutiiq inventory, orthography, and metrical behaviors (1.1.4); and a short introduction to claims surrounding culminativity in the two languages (1.1.5).

The theoretical framework for this analysis of prosodic behaviors is metrical stress theory. At its most basic, this theory proposes that stress is bound by metrical constituents (e.g. the metrical foot), and that the placement of stress is the result of parsing an utterance into such constituents (Hayes, 1995b; Liberman & Prince, 1977). Metrical theory is compelling for the purpose of describing Yup'ik and Alutiiq stress, as parametric metrical models have been shown to accurately diagnose the distribution of stress within prosodic words. Hence, the studies within this dissertation apply metrical theory for two purposes: as a means of predicting where stress will appear and explaining the acoustical behavior of syllables targeted for stress (or other metrical phonology).

1.1.1. Dialects and Populations

Yup'ik and Alutiiq are closely related members of the Yupik branch of the Inuit-Yupik Unangan[2] language family. There are no attested syntactic differences between the two (in part due to a relative dearth of Alutiiq morphosyntactic description), and speakers report mostly pronunciation and vocabulary differences. Emergent research suggests that Alutiiq features reduced polysynthesis compared to Yup'ik (Berge, forthcoming). They are often mutually

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[2] The names of both the branch and family are controversial within communities. The former names, the Eskimoan branch of the Eskimo-Aleut (Eskaleut), are offensive due to their inclusion of the term "Eskimo". Many groups, especially in Inuit communities against whom the word is leveraged, consider this word to be a racial slur. Out of respect, we have chosen to refer to the branch and family by the names that contain endonyms.

intelligible, leading to some debate regarding their typological relationship (Krauss, 1977; Leer, 1985a). Importantly, the two boast distinctive cultures, and the speaker communities self-identify as belonging to separate groups, with Alutiiq sharing many characteristics with other Pacific Coast traditions (see Berge, forthcoming). Alutiiq represents the southern end of a language continuum, with Siberian Yupik at the eastern end; Yup'ik lies in between the two, both geographically and linguistically (Alaska Native Language Center, n.d.-b; Woodbury, 1984). The traditional lands of their speakers in southwestern Alaska overlap, and historically there has been considerable bilingualism in speaker populations. Today, Central Alaskan Yup'ik has the most speakers of any Alaska Native language, with a speaker population of roughly 10,000 (Kaplan, forthcoming). The most populous dialect, and the dialect that this dissertation focuses on, is General Central Yup'ik, though there are four other dialects in Norton Sound, Hooper Bay-Chevak, Nunivak, and Egegik. There are roughly 400 speakers of Alutiiq, spread across two dialects: the Chugach dialect on the Kenai Peninsula, from Nanwalek and Port Graham to Prince William Sound, and the Kodiak dialect on Kodiak Island and the Alaska Peninsula (Berge, forthcoming). This dissertation focuses on the Chugach dialect. Henceforth, *Yup'ik* refers to General Central Yup'ik and *Alutiiq* refers to Chugach Alutiiq, unless otherwise specified.

Figure 1: Map of Inuit-Yupik-Unangan languages spoken in Alaska and across the Bering Strait (Noahedits, 2019)*; Central Yup'ik and Alutiiq can be seen in the southwest area of the state.*

1.1.2. Polysynthetic Word Structure

Both Yup'ik and Alutiiq are polysynthetic languages. Words in these languages can involve complex expressions made up of many morphemes, leading to long words with many syllables. In Yup'ik and Alutiiq, words are generally sorted into three lexical categories: nouns, verbs, and particles, the last of which contain any number of non-inflecting adverbs, demonstratives, conjunctions, and other such grammatical morphemes (Heinrich, 1979; Jacobson & Jacobson, 1995; Leer, 1978, 1990; Miyaoka, 2012). Words that would be considered adjectives in English generally behave as verbs (Jacobson & Jacobson, 1995; Leer, 1978, 1990; Reed et al., 1977; for a discussion on whether adjectival words actually are verbs or not, see Compton, 2012).

Verbs are minimally made up of a lexical root and an inflectional suffix (referred to in the literature an as 'ending') that encodes subject number and person. In transitive verb forms, the suffix also communicates information about the object number and person. The examples in (1) show the combination of three intransitive verb bases, *alinge-* 'to fear', *nere-* 'to eat', and *cali-* 'to work (Yup'ik), to do something (Alutiiq)', and the third person singular present tense suffix *-(t)uq*. All three forms in (1) are the same in both languages; in the examples in this section, the languages of each example are specified in the gloss where the example is not the same in both. All of the Yup'ik examples come from Jacobson & Jacobson (1995), and all of the Alutiiq examples (even where they are the same in both languages) come from Leer (1990).

(1) Simple verbs in Yup'ik and Alutiiq

a. *alinguq*
alinge-uq
fear-PRS.3SG
'he/she/it is afraid' (Jacobson & Jacobson, 1995:486, Leer 1990:53)

b. *ner'uq*
nere-uq
eat-PRS.3SG
'he/she/it is eating' (Jacobson & Jacobson, 1995:498, Leer, 1990:54)

c. *caliuq*
cali-uq
(Yup'ik) work-PRS.3SG
(Alutiiq) do-PRS.3SG
(Yup'ik) 'he/she/it is working'(Jacobson & Jacobson, 1995:489)
(Alutiiq) 'he/she/it is doing (something)' (Leer, 1990:43)

Similarly, nouns are made up of a lexical stem and any required inflection, including suffixes that specify case and number, and may also indicate possession. The simple paradigm in (2) demonstrates the same stem, *arnar-* 'woman', given in the (unpossessed) absolutive singular, dual, and plural forms. Again, for this example, all three forms are identical in both languages.

(2) Simple nouns in Yup'ik and Alutiiq

a. *arnaq*
arnaq-∅
woman-ABS.SG
'(one) woman' (Jacobson & Jacobson, 1995:488, Leer, 1990:147)

b. *arnak*
arnaq-k
woman-ABS.DU
'(two) women' (Jacobson & Jacobson, 1995:488, Leer, 1990:147)

c. *arnat*
arnaq-t
woman-ABS.PL
'(three or more) women' (Jacobson & Jacobson, 1995:488, Leer, 1990:147)

Words can be made more complex by the addition of (generally) non-inflectional suffixes, traditionally called *postbases* in the literature on Yupik languages. Some postbases are derivational, changing a verb to a noun or vice versa, while others simply add more information, such as tense and aspect, without changing the lexical category of the word. Some also act as adverbial and adjectival modifiers, restructuring verbs and modals (for a detailed morphosyntactic analysis of postbases, see Woodbury & Sadock, 1986 and Sadock, 1980). Example (3a) shows the postbase -*yug* 'to want to V', which attaches to a verb and yields a verb, while (3b) shows the postbase -*li* 'to make N', which attaches to a noun and yields a verb.

(3) Complex verbs in Yup’ik and Alutiiq

a. *caliyugtuq*
cali-yug-tuq
(Yup’ik) work-want-PRS.3SG
(Alutiiq) do-want-PRS.3SG
(Yup’ik) ‘he/she/it wants to work’(Jacobson & Jacobson, 1995:489)
(Alutiiq) ‘he/she/it wants to do (it)’ (Leer, 1990:43)

b. *kuuvvialiuten*[3]
kuuvviaq-li-uten
coffee-make-PRS.2SG
‘you are making coffee’ (Jacobson & Jacobson, 1995:495, Leer, 1990:83)

The ability of these languages to stack postbases leads to long words that are frequently analogous to English sentences. Example (4) demonstrates words with multiple postbases: (a) gives an example in Yup’ik, and (b) gives an example in Alutiiq.

(4) Words with multiple postbases

a. *ikamrapiangqellruuq*
ikamraq-piar-ngqerr-llru-(t)uq
sled-real-have-PST-PRS.3SG
‘he had a real dog sled’ (Yup’ik, Jacobson & Jacobson, 1995:238)

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[3] *kuugialiuten* in Alutiiq; the form for ‘coffee’ is *kuugiaq*. Also note that this is not a true transitive verb. It is a nominal root with a verbalizing postbase *-li*, as opposed to a transitive verb root. As such, it uses the non-transitive second person subject suffix *-(t)uten*, rather than the present tense second person subject to third person object suffix *-an*. The topic of transitivity is quite nuanced in these languages and deserves a dissertation of its own (see e.g. Miyaoka, 2015 for Yup’ik; for research on transitivity and related issues in the Inuit branch of the language family, see e.g. Bittner, 1987; Bourcier, 2016; Carrier, 2021; Sadock, 1980; Spreng, 2012; van Geenhoven, 1998; Yuan, 2018).

b. *agnguaruaqutartuanga*
agnguar-(r)uaq-kutar-tua(nga)
dance-fake-about.to-PRS.1SG
'I'm going to pretend to dance' (Alutiiq, Leer, 1985b:92)

In addition to the word-internal morphology described thus far, both Yup'ik and Alutiiq feature enclitics, adverbials, particles, conjunctions, and other morphemes that stand independent of the large noun and verb constructions. In both orthographies, enclitics are denoted by a separation from the word by a hyphen. Two common examples are the yes/no question enclitic *=qaa* and the nominal conjunctive enclitic *=llu*, exemplified in (5a). (5b) demonstrates how adverbials stand independently from, but still modify, verbs, with the word *akwaugaq* 'yesterday'. (5c) is an example of the particle *tuarpiaq* 'seems' in a sentence.

(5) Sentences with enclitics and particles

a. *Arnaq angun-llu quyauk.*
arnaq-∅ angun=llu quya-uk
woman-ABS.SG man=CONJ be.thankful-PRS.3DU
'The woman and the man are thankful.' (Yup'ik, Jacobson & Jacobson, 1995:46)

b. *Calillruuten-qaa kipusvigmi akwaugaq?*
cali-llru-(t)uten=qaa kipusvik-mi akwaugaq
do- PST-PRS.2SG=INT store-LOC yesterday-ABS.SG
'Were you working in the store yesterday? (Yup'ik, Jacobson & Jacobson, 1995:47)

c. *Tuarpiaq nuna'ilnguten.*
Tuarpiaq nuna-il-ngu-ten
seems place-PRV-PTP-2SG
'It seems you (sg.) have no place (to stay).' (Yup'ik, Miyaoka, 2012:1336)

This section has provided a very abbreviated overview of the morphosyntax of Yup'ik and Alutiiq (see Miyaoka, 2012 for a more detailed overview). The primary goal is to illustrate how words in these languages are constructed, in order to better inform the discussion of stress. Naturally, as morphemes stack and words grow longer, the number of stresses per word similarly increases. The following two sections illustrate the distribution of stress and other metrical behaviors in Yup'ik and Alutiiq. They are intended only to provide adequate context to inform the research questions; for a full review of the literature and discussion of the complexities of the prosody of each language, see Chapter 2 for Yup'ik and Chapter 3 for Alutiiq.

1.1.3. Yup'ik Phonology and Orthography

In Yup'ik, the prototypical syllable is (C)V(V)(C) (Jacobson & Jacobson, 1995:9). The phonemic inventory of Yup'ik is given in Table 1. The IPA form of the phoneme is listed on the top of each row, while the orthographic representation is given in angle brackets <> below.[4] As described in Jacobson (1995), Yup'ik stops and affricates are voiceless and unaspirated: they are generally impressionistically described as sounding 'between' voiced and voiceless. Voicing is contrastive for fricatives, laterals, and nasals (but see Compton, 2009); /z/ and /j/ share a voiceless counterpart in /s/. The velar and uvular fricatives further have rounded allophones that are given their own orthographic conventions, with <u͡g> representing the rounded /ɣ/, <w> for rounded /x/, and <u͡r> for rounded /ʁ/ (while Jacobson affirms that rounded /χ/ is possible, it is very rare and shares a grapheme with rounded /ʁ/).

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[4] The orthographic systems in use for both Yup'ik and Alutiiq were developed in the latter half of the 20th century, undergoing many changes and evolutions before arriving to their contemporary forms. Today, some spellings are influenced by dialectal, sociopolitical, and stylistic choices as well. As such, there may be some inconsistencies between the orthographies represented here and in-language texts. The writing system given here, and the corresponding Alutiiq system given in Section 1.1.4, are from common educational texts used to teach literacy in either language, and so will be accessible to most learners and speakers.

Table 1: Phonemic inventory of Yup'ik, adapted from Jacobson & Jacobson (1995:1-16).

Consonants	labial	alveolar	palatal	velar	uvular
plosive	p <p>	t <t>		k <k>	q <q>
affricate		tʃ <c>			
fricative	f v <vv> <v>	s z <ss> <s>	j <y>	x ɣ <gg> <g>	χ ʁ <rr> <r>
lateral		ł l <ll> <l>			
nasal	m̥ m <ḿ> <m>	n̥ n <ń> <n>		ŋ̊ ŋ <ńg> <ng>	

Vowels	front	central	back
high	i <i>		u <u>
mid		ə <e>	
low		a <a>	

Vowel length is contrastive, such that there is a contrast between the underlyingly long /aː/, /iː/ and /uː/ and short /a/, /i/, and /u/ vowels. Schwas only appear as short. Short vowels are written with a single character, as in <a>, while homogenous long vowels are written double <aa>. The spelling represents the underlying form: where short vowels are lengthened by stress (see below), they are still written as short. /a/, /i/, and /u/ are considered full vowels; in Yup'ik, every sequence of full vowels makes acceptable diphthongs. /ə/ is a weak vowel. It is often weakened or deleted altogether, although it is still written in the word due to the metrical effects of the underlying vowel.

In terms of punctuation, Yup'ik utilizes two essential marks: the hyphen and the apostrophe. Hyphens are used to separate enclitics from the rest of the word, as in *kuigpagmi-llu-*

gguq ‘also in the river, it is said’, where the enclitics *-llu* ‘and, also’ and *-gguq* ‘it is said’ are divided by hyphens.

The apostrophe serves many functions in Yup’ik. When written immediately following a consonant, as in *kuv’uq* ‘it is spilling’, it indicates that that consonant, here <v>, is geminated. This apostrophe-marked gemination is lexical. Gemination can also be phonological, called *automatic gemination*, where consonants in a V.CVV environment are lengthened (for more information on gemination and its metrical consequences, see Chapter 2). Where an apostrophe is written between the two vowels in the second syllable of this environment, it indicates that gemination does not happen. For example, in the word *tekiituq* /tə.kiː.tuq/, /k/ geminates to create [təkː.iː.tuq]. In *pika’antuq* /pi.kaːn.tuq/ ‘it is up there’, the presence of the apostrophe indicates that the /k/ does not geminate. Furthermore, the apostrophe can be used to break up consonant clusters. This can be to avoid confusion between monographs and digraphs, for example differentiating the /ng/ sequence from /ŋ/. The former would be written as <n’g>, as in *tan’gurraq* ‘boy’. The apostrophe can also indicate that automatic devoicing, which happens when a voiced fricative or nasal is devoiced by a preceding voiceless consonant, does not occur. For example, in *tep’lek* ‘one with odor’, the apostrophe indicates that the /p/ does not devoice the following /l/. Lastly, the apostrophe can indicate a dropped or missing segment, such as the shortening of *qaillun* ‘how’ to *qaill’*.

Yup’ik stress behaviors are described in Gabas, (1996), Halle (1990), Hayes (1995), Heinrich, (1979), Jacobson, (1984, 1985, 1990), Jacobson & Jacobson (1995), Leer (1985a, 1985d), Lipscomb (1992), Mithun (1996), Miyaoka (1985, 2012), Reed (1977), and Woodbury (1987, 1995). In an environment of only short, open syllables, stress alternates from left to right, starting at the second syllable, as in *nalluyagucaqunaku* ‘don’t forget it’ [na.ˈɬu.ja.ˈɣu.ʧa.ˈqu.na.ˈku] (Jacobson & Jacobson, 1995:10). Weight considerations interrupt the otherwise binary alternation of stresses. Stress is quantity-sensitive: short vowels are lengthened via iambic lengthening in order to become heavy when stressed, and syllables with long vowels, by nature of their weight, are obligatorily stressed. Closed syllables, however, present a complication, as syllables with codas appear to sometimes behave as heavy, and other times as light. (C)VC syllables are always considered heavy word-initially, and may behave as heavy elsewhere, but do not do so consistently: compare *aturyugtuten-qaa* ‘do you want to use (it)’ [a.ˈtuʁ.ˈjuɣ.tu.ˈten.ˈqaː] and *alingenrituq* ‘he/she/it is not scared (of it)’ [a.ˈli.ŋen.ˈʁi.tuq] (Jacobson & Jacobson, 1995:33), which, when compared, demonstrate the disparate treatment of

(C)VC syllables in terms of stress. Specifically, these examples show that while some (C)VC syllables are treated as heavy, such as [juɣ] in the former example, they are not always, as in the syllables [ŋen] or [tuq] in the latter.

Despite the thorough documentation of stress and syllable weight in Yup'ik, there has to date been only one acoustic study of stress correlates. Gabas (1996) demonstrated a correlate hierarchy wherein F0 is the primary means of expressing stress, duration is secondary, and intensity is tertiary. He further reports that "short" words (six syllables or less) are prosodically different from "long" words (seven syllables or more). Short words begin high in intensity and exhibit the highest pitch on the right-most stressed syllable. Long words, meanwhile, begin with high intensity and pitch, and the right-most stressed syllable is slightly higher in pitch but considerably louder than its neighboring syllables. While these results are interesting and corroborate claims made in Miyaoka (1971), the study reported a very small sample size (135 words, total number of syllables not reported), and some effects, such as intonational finality, were not accounted for.

Furthermore, the acoustic differentiation of phonemic length (short vs. long vowels) from metrical length (stressed vs. unstressed vowels) has yet to be addressed in Central Alaskan Yup'ik. While studies such as Koo & Badten (1974) on Central Siberian Yupik have reported on iambic lengthening in other members of the language family, it is unclear what the phonetic result of iambic lengthening is in Yup'ik: to what degree lengthened vowels are longer, and whether the resultant length is the same as for phonemically long vowels.

1.1.4. Alutiiq Phonology and Orthography

Similar to Yup'ik, the prototypical Alutiiq syllable has the form (C)V(V)(C) (Leer, 1985a, 1990, 1994). The Alutiiq phonemic inventory and orthography are outlined in Counceller & Leer (2012), which offers the most contemporary version of the Alutiiq spelling system. Although it specifically focuses on the Kodiak dialect, *The Alutiiq Orthography* also details ways in which the Kodiak dialect's sound and spelling systems differ from other dialects, and so it provides a thorough overview of the diversity within the language. Table 2 provides the phonemic inventory of Chugach Alutiiq. The IPA form of the phoneme is listed on the top of each row, while the orthographic representation is given in angle brackets <> below. The entries marked with an asterisk are not phonemically distinct in the Kodiak dialect, but are distinct in other dialects, and may or may not be represented in orthography.

Table 2: Phonemic inventory of Alutiiq, adapted from Counceller & Leer (2012); Leer, (1978, 1990).

Consonants	labial	alveolar	palatal	velar	rounded velar	uvular
plosive	p <p>	t <t>		k <k>	kʷ <kw>	q <q>
affricate		tʃ <c>				
fricative	f <f>	s <s>	j <y>	x ɣ <g> <gg*>	xʷ ɣʷ <gw> <ggw*>	χ ʁ <r> <rr*>
lateral		ɬ l <ll> <l>				
nasal	m̥ m <hm> <m>	n̥ n <hn> <n>		ŋ̊ ŋ <hng> <ng>		

Vowels	front	central	back
high	i <i>		u <u>
mid		ə <e>	
low		a <a>	

The Alutiiq sound inventory is similar to Yup'ik, although Alutiiq ostensibly makes fewer phonemic voicing distinctions. Like Yup'ik, voiceless stops and affricates are unaspirated, and have been described as sounding between voiced and voiceless (Leer, 1985b, 1994). The four vowels can be organized into two groups: the schwa /ə/ and the prime vowels /a, i, u/. Vowel length is also contrastive for prime vowels in Alutiiq, following the same orthographic conventions as Yup'ik in distinguishing a short vowel, written single, from a long vowel, written as two identical characters. Similarly, all combinations of prime vowels (ai, au, ui, ua, ia, iu) are acceptable diphthongs. Some diphthongs have been adopted into the language via Russian loan-words, for example *ungairtuq* ‘he is shaving’, in which the sequence <ai> represents the Russian diphthong /ei/, or *skauluq* ‘school’, where <au> represents /ou/.

The apostrophe and hyphen in the Alutiiq orthography share the functions of the Yup’ik apostrophe and hyphen, with several notable differences. In Alutiiq, like in Yup’ik, apostrophes are often used to break up digraphs, especially to indicate that vowel sequences are not diphthongs. However, the sequences *i’a, *i’u, *u’a, and *u’i are not permitted, instead repaired by the epenthetic glides <y> and <w>, often called ‘prothetic’ in the literature. This results in the sequences <iya>, <iyu>, <uwa>, and <uwi>. Furthermore, Alutiiq permits more complex consonant clusters than Yup’ik, and so uses the apostrophe to mark syllable boundaries in instances of complex onsets, as in *pat’snartuq* /pat.snaχ.tuq/ ‘it is cold’. The only exception to this is word-initially, where complex onsets are sometimes allowed (especially in English and Russian borrowings), as in *skʀiip’kaaq* /skɹip.kaːq/ ‘violin’.[5] Apostrophes can also be used to divide diphthongs from single vowels in sequence, and vowel pairs and single vowels: for example, in *guutai’ista* /xuː.tai.i.sta/ ‘dentist’ and *macuu’uq* /ma.tʃuː.uq/ ‘it is wet’, the apostrophe indicates a syllable boundary. Note that in instances of three vowel letters, the apostrophe will always occur between the second and third vowel, as in <V_1V_2’V_3>.

Alutiiq metrical behaviors are described in Counceller & Leer (2012), Hewitt (1994), Hewitt & Ann (1991), Leer (1978, 1985b, 1985a, 1985d, 1990, 1994), Martínez-Paricio & Kager (2017), and Rice (1988). Of these, Leer (1985a, b, d) represent the core literature that offers the most complete description of Alutiiq prosody as a whole, and are the foundational documentary works from which all other authors derive their analyses. In general, in a sequence of light, open syllables, Alutiiq stress alternates in an iterative iambic pattern starting from the left edge of the word (Hayes, 1995a; Leer, 1985b, 1985c). This stress, like in Yup’ik, is weight sensitive, such that heavy syllables (i.e., syllables with underlyingly long nuclei) are always stressed. Unlike in Yup’ik, syllable closure only contributes to weight word-initially in Alutiiq; similarly, automatic gemination only targets #(C)V.CVV sequences.

Table 3 shows examples of stress alternation based on this basic pattern.

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[5] The letter used to represent /ɹ/ is <ʀ>. It is only used in Russian borrowings and is referred to colloquially as the ‘Russian r’, despite its production as an approximant.

Table 3: Examples of stress distribution in Alutiiq words.

Example	Transcription	Source: (Leer, 1985b)
penaq ‘cliff’	[pə̥.ˈnaq]	p. 104
akutaq ‘a food’	[a.ˈku.taq]	p. 84
akutamek ‘a food (ABLATIVE SG)’	[a.ˈku.ta.ˈmək]	p. 84
taataqa ‘my father’	[ˈtaː.ta.ˈqa]	p. 86
ulua ‘its tongue’	[ˈul.ˈlua]	p. 87

While stressed short vowels are targeted for iambic lengthening, Alutiiq features compression on both underlyingly long vowels and vowels that are lengthened by stress. This compression has been described as a neutralizing process that targets stressed vowels in closed syllables or word-finally (Leer, 1985b, 1994). As a result, while length is still phonemically contrastive, Leer claims that the expression of vowel length in Alutiiq has become redundant, predictable by stress, closure, and syllable position (Leer, 1985b:88).

One of the most notable characteristics of Alutiiq stress is that stress alternation appears to regularly ‘skip’ a syllable. Hayes (1995:334-335) describes the basic Chugach Alutiiq pattern of syllable skipping as occurring in words with all light, open syllables: the second syllable is stressed, and additional stresses fall on every third syllable thereafter, as in *pisuqutaquni* ‘if he is going to hunt’ (**p**i.ˈsu).*qu*.(**t**a.ˈqu).*ni* (Leer, 1985b, p. 113). Various analyses have been proposed for this phenomenon (Hayes, 1995; Hewitt, 1994; Kager, 1994; Leer 1985a, 1985c, 1994; Martínez-Paricio, 2013, Martínez-Paricio & Kager, 2017). In the Internally Layered Ternary (ILT) foot model, which is adopted in this dissertation (see Chapter 3), Alutiiq distinguishes between minimal (binary) feet, composed of a dependent and a (rightmost) head, and maximal (ternary) feet, composed of a binary foot and an adjunct (skipped) syllable to the right of its head (Martínez-Paricio, 2013, Martínez-Paricio & Kager, 2017).

In addition to stress, Alutiiq features three additional phonological and prosodic processes that appear to behave metrically. These include onset fortition, tone, and additional lengthening. Firstly, onset fortition targets foot-initial consonants. Specifically, Leer (1985a) describes onset fortition as affecting the first segment of a binary iamb, excluding the skipped syllables: in *pisutaquni* ‘if he is going to hunt’, the fortified onsets (here marked in bold) would be (**p**i.ˈsu).*qu*.(**t**a.ˈqu).*ni*. The acoustic correlates of onset fortition are not clear; see Chapter 2 for an examination and discussion of onset fortition and gemination in Yup'ik.

Secondly, in Chugach Alutiiq, high (H) and low (L) tones alternate, appearing to correspond to metrical structures. Leer describes tone as conditioned by foot position, with stressed syllables always being H and ILT adjuncts always being L (Martínez-Paricio & Kager, 2017; Leer 1985d:164). In sequences of H tones with no intervening L, the second H tone is upstepped, which, according to Leer (1985b, 1994) and Martínez-Paricio & Kager (2017), results in a slightly higher H tone (¡H). Upstepping will not occur, however, if the preceding H is already upstepped.

Lastly, Leer describes additional lengthening as a process that appears to affect some, but not all, foot heads. It targets specifically open, stressed syllables of disyllabic feet, which are generally foot heads that immediately precede skipped syllables. In this case, that syllable will be produced distinctively from another stress. In the Internally-Layered Ternary foot model, the syllables targeted by additional lengthening are the heads of maximal feet, and this phenomenon contrasts them with binary foot heads.

While Leer (1985a, b, d) provides very thorough documentation of metrical behaviors in Alutiiq, all extant descriptions of the acoustic expression of these behaviors are impressionistic. There have to date been no acoustic studies of Alutiiq: no literature has established how phonemic length distinctions are expressed; whether compression is fully neutralizing; the acoustic correlates of stress, tone, and additional lengthening; or corroborated Leer's claims about the distribution of onset fortition.

1.1.5. The Culminativity Question

Typologically speaking, both Yup'ik and Alutiiq are considered stress languages. Hyman (2009) offers a foundational definition of stress systems, where stress languages have two inviolable properties: obligatoriness (every prosodic word has at least one stress) and culminativity (every prosodic word has maximally one primary stress, and all other stresses in the word are secondary) (see also Hayes, 1995 and Jun, 2014). These properties are definitional of stress, such that any language that is claimed to have stress should exhibit both within some domain no larger than the prosodic word. Despite having clear and demonstrable stress patterns and metrical structures, both Yup'ik and Alutiiq have been attested to be non-culminative: that is, there is no distinction between primary and secondary stresses within the word domain (Hewitt & Ann, 1991; Jacobson, 1990; Jacobson & Jacobson, 1995; Leer, 1985b, 1994; Martínez-Paricio & Kager, 2016; Mithun, 1996; Rice, 1988; Woodbury, 1995).

While most authors acknowledge Yup'ik stress as non-culminative, there is one notable claim surrounding Yup'ik culminativity. Miyaoka (1971, 1985, 2012) claims that the rightmost stress, as in the final stress of the word, closest to the right edge, in a Yup'ik word is the most prominent. However, no other authors repeat or otherwise investigate this claim. Alutiiq stress, meanwhile, has only ever been described as non-culminative (Leer, 1985a, b, d; 1994). To date, no acoustic study has explored how culminativity may surface among stressed syllables in the word domain in either language, and while emergent conceptions of culminativity allow for it to be expressed in domains smaller than the word (Bogomolets, 2020; Hyman, 2006, 2009), it is not clear how Yup'ik and Alutiiq fit into this typology.

1.2. Research Questions

The metrical systems of Yup'ik and Alutiiq are both well-documented. Existing literature establishes where stress appears, as well as what other phonological phenomena it interacts with. Furthermore, descriptions of phrasal phonology, such as IP-final destressing or HL% boundary tones, demonstrate how stress is affected by higher-order prosody (Woodbury, 1987). However, outside of a limited study of Yup'ik stress in Gabas (1996), all claims regarding the distribution and expression of metrical prosody in these two languages are either impressionistic accounts or analyses derived from impressionistic accounts.

In approaching stress from an acoustic angle, the goal of this dissertation is to both evaluate the accuracy of extant phonological accounts and to explore the relationship between the metrical phonology and phonetic performance of rhythm (and rhythm-adjacent phonology) in Yup'ik and Alutiiq. The research questions addressed in this dissertation are given in (6)-(8) below. They are organized by their order of presentation in the manuscript.

(6) Yup’ik research questions (see Chapter 2)
   a. For the purposes of describing syllable weight, what is the relationship between gemination and foot boundaries?
   b. In acoustic terms, how do speakers differentiate a stressed vowel from an unstressed vowel?
   c. How are long vowels distinguished from short vowels? Is this distinction maintained when short vowels are stressed?

(7) Alutiiq research questions (see Chapter 3)
   a. In acoustic terms, how do speakers differentiate a stressed vowel from an unstressed vowel?
   b. How are long vowels distinguished from short vowels? Is this distinction maintained when short vowels are stressed?
   c. How do other metrically-bound phonological phenomena, including length neutralization (compression), additional lengthening, tone, and onset fortition, affect the segments of the syllables they target? Does their acoustic expression align with descriptions of their functions and behaviors (e.g. compression neutralizing length distinctions, additional lengthening implying a duration effect, and tone implying an F0 effect)?

(8) Culminativity research questions (see Chapter 4)
   a. Is any given stress in the Yup’ik or Alutiiq word produced distinctly from other stresses within the domain of the prosodic word?
   b. If so, what are the acoustic correlates that encode this distinction?
   c. If not, what are the implications of non-culminativity in the context of polysynthetic words and metrical stress theory?

1.3. Dissertation Contributions

The relationship between length and stress forms the prosodic backbone of the Yupik language family. While the metrical systems themselves are well-described in the literature, how speakers perform the rhythm that these systems prescribe is yet unclear. This dissertation seeks to examine the expression of stress and other phonological phenomena that either directly affect stress derivation or expression (Yup'ik: gemination, Alutiiq: length neutralization), or are themselves attested to be metrical (Alutiiq: tone, maximal head distinctions, and foot-initial onset fortition). In doing so, it makes several important contributions, both to the description of prosodic performance in each language and to phonological theory.

In terms of structure, Chapter 2, *Acoustics of stress and weight in Central Alaskan Yup'ik* (and its companion document *User's Guide to Central Alaskan Yup'ik Stress Derivation*, see Appendix A), presents an examination of metrical performance in the Central Alaskan dialect of Yup'ik, including measurements of gemination and onset length, and the effects of stress and phonemic length distinctions on vowels. Chapter 2 addresses the research questions in (6a-c). Chapter 3, *Metrical Performance in Chugach Alutiiq*, discusses the metrical system of Alutiiq and presents measurements of stress, including an exploration of stress/length neutralization. It also presents measures of other metrical phenomena, such as the lengthening of ternary foot heads, tone, and foot-initial onset fortition. It addresses the research questions in (7a-c). Chapter 4, *Is Stress in Chugach Alutiiq and Central Alaskan Yup'ik Actually Non-Culminative?*, explores the degree to which stress is culminative in each language, following up on claims of rightmost primary stress in Yup'ik and complete non-culminativity in Alutiiq. Chapter 4 addresses the research questions in (8a-c). Finally, Chapter 5 concludes the dissertation.

In terms of contributions, this dissertation firstly gathers acoustical evidence in order to investigate claims made in the Yup'ik and Alutiiq prosodic literature regarding the distribution and expression of stress. The acoustic evidence shows that duration, intensity, and F0 are all utilized in both Yup'ik and Alutiiq to distinguish instances of stress and non-stress. Furthermore, both languages feature a tripartite distinction of vowel types (long, stressed short, and unstressed short) that is maximally preserved even under ostensibly length-neutralizing conditions. We offer an analysis of syllable weight that considers the relationship between moraic weight and phonetic duration as potential evidence of mora-sharing, polymoraic (e.g. more than bimoraic) heavy syllables, and incomplete length neutralization (see Chapter 2).

Second, the Alutiiq stress study (Chapter 3) provides evidence for the re-examination of certain claims about Alutiiq metrical prosody: namely, that the tone contrasts described in the literature are not acoustically distinguished by F0 and that the distinction between a minimal and maximal foot head does not utilize duration. However, the study does affirm extant descriptions regarding the distribution of these phenomena. We interpret these results as evidence that additional lengthening, here re-named additional prominence, and tone, here reconsidered as accent, are expressions of metrical structure that co-occur with and are parallel to stress.

Third, the culminativity studies in Chapter 4 specifically target the critical claim that neither Yup'ik nor Alutiiq stress is culminative, and thereby, that the systems violate a foundational principle of stress languages. Specifically, these studies examine claims that rightmost stresses in Yup'ik (and, for the sake of comparison, Alutiiq) are primary (see Heinrich et al., 1979; Miyaoka, 1971, 1985). However, they find no evidence that supports these claims. We conclude that neither Yup'ik nor Alutiiq express culminativity at the word level via stress. However, we examine two possibilities for ways in which culminativity might still apply to Yup'ik and Alutiiq prosody. It may be the case that the domain for culminativity is smaller than the word level, as has been suggested for other polysynthetic languages (Bogomolets, 2020; Hyman, 2006). Alternatively, the complex prosody of these languages may allow for the language to be culminative with respect to another aspect of prosody than stress. Referring to the results of Chapter 3, in this view, metrically bound phonology like Alutiiq accent, additional prominence, and upstep may be able to satisfy the basic criterion for word-level culminativity. In such a case, culminativity is seen as a feature of metrical systems as a whole, rather than limited to being a feature of stress alone.

Lastly, this dissertation also makes contributions to language documentation and archive-based linguistic research. Like many areas of linguistic research at this point in history, phonetic and phonological research is more readily accessible for so-called languages of convenience (e.g. English, with its large speaker population and prolific documentation). Recent work, such as the special issue edited by Tucker & Wright (2020), has sought to rectify this bias by specifically highlighting the phonetics of understudied languages. Significant barriers to such research may include critically low speaker populations, community inaccessibility due to global circumstances,[6] or different community priorities (e.g. focusing on documentation, education, or materials development over laboratory research). Fortunately, with the rise in (digital) language archiving in the past several decades and the development of language documentation as a field of linguistics (see Himmelmann, 1998; McDonnell et al., 2018), analysis-quality recordings of underdocumented languages are more accessible than ever before (see Whalen & McDonough,

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[6] For instance, the bulk of research for this dissertation was done during the COVID-19 pandemic.

2019 and Babinski et al., 2022, for discussions on phonetic research in the context of language archiving). The studies presented in this manuscript were all performed on archival data: any insights and observations made, and any theoretical discussions prompted, were only possible because the Alaska Native Language Archive made Yup’ik and Alutiiq recordings accessible (*Alaska Native Language Archive*, n.d.). In this way, this research underscores the importance of long-term storage and maintenance of underdocumented language materials in archives and demonstrates how such materials can be used for phonetic and phonological research.

In sum, this dissertation offers an in-depth acoustical examination of prior descriptions of Yup’ik and Alutiiq metrical prosody and situates the findings of said acoustic studies in the framework of metrical stress theory, while at the same time highlighting the importance of studying Indigenous languages.

2. Acoustics of Stress and Weight in Central Alaskan Yup’ik

2.1. Introduction

The Yupik languages are spoken across northeastern Siberia and western to southern Alaska. There are several varieties of Yupik; this project focuses on Central Alaskan Yup’ik, specifically the General Central dialect (*Yugtun*; henceforth *Yup’ik*). This article seeks to explore the acoustic correlates of stress and weight in Yup’ik by acoustically analyzing a series of recordings housed in the Alaska Native Language Archive (Alaskan Native Language Archive, n.d.). The goals of this paper are to investigate claims regarding the distribution of gemination, which is relevant to questions of stress as a process that affects syllable weight, and to examine the ways in which phonemic vowel length and stress are expressed.

Section 2.2 introduces Yup’ik stress patterns as described in the literature, as well as the metrical model used to assign stress in the recordings analyzed here. Section 2.3 summarizes the existing literature on correlates of stress in Yup’ik, which includes only one small-scale acoustic study. Section 2.4 introduces the materials and methods used in the present study before sections 2.5 and 2.6 present results regarding gemination and acoustic correlates of stress and vowel length, respectively. Section 2.7 compares the findings to previous descriptions and discusses their implications before section 2.8 concludes.

2.2. Yup’ik Stress Patterns

This study utilizes extant metrical accounts of Yup’ik stress to categorically identify the syllables that receive stress in the acoustic dataset. The goal of this section is to provide an overview that informs and justifies the phonetic analysis of stress given in section 2.6. To that end, this section will first present the basic facts of Yup’ik stress and the way they have been modelled in the literature, focusing on the metrical framework proposed in Hayes (1995) . When predictions made by this model were applied to real-world data (see section 2.4), some adjustments were made to the Hayes model; these are also discussed in this section (see supplementary materials in Alden & Arnhold, 2022, or Appendix A, for more details).

The literature on the Yup’ik stress system can be divided into two main groups: foot-based metrical frameworks and apodal accounts. The metrical framework assumes the existence of feet as the primary vehicle for stress assignment and uses rules to constrain foot shape, while the apodal approach assigns stress based on a syllable's position within a word using classic phonological rules without making reference to feet. Authors that utilize a metrical framework include Halle (1990); Leer (1985); Miyaoka (1971); and Woodbury (1987), with the most comprehensive and theoretically-founded account presented by Hayes (1995). Authors that adopt the apodal approach to Yup'ik stress include Jacobson (1984, 1990) and Lipscomb (1992). Another account worth mentioning is van de Vijver (1998), which takes principles outlined by Jacobson and Woodbury and adapts them into an Optimality Theory framework (see also Bakovic, 1996).

These scholars agree that in Yup'ik, syllables with long vowels or diphthongs are always stressed, while open syllables with short vowels alternate stress from left to right (see Table 4). Intonational phrase-final syllables are destressed; however, unless otherwise stated, in this paper examples are assumed to not be IP-final for the purposes of demonstrating stress patterns.

Table 4: Examples of stress alternation in Yup'ik words made up of CV syllables.

Example	Transcription	Source: Jacobson & Jacobson, 1995
nuna 'land, village'	[nu.ˈna]	p. 4
patu 'cover'	[pa.ˈtu]	p. 4
quyana 'thank you'	[qu.ˈja.na]	p. 9
acaka 'my paternal aunt'	[a.ˈtʃa.ka]	p. 9
nalluyagucaqunaku 'don't forget it'	[na.ˈɬu.ja.ˈgu.ʧa.ˈqu.na.ˈku]	p. 10
qayaliqataraqama 'whenever I'm going to make a kayak'	[qa.ˈja.li.ˈqa.ta.ˈχa.qa.ˈma]	p. 10
ekumaqatalliniluni 'evidently being about to be in a conveyance'	[ə.ˈku.ma.ˈqa.ta.ˈɬi.ni.ˈlu.ni]	p. 10

Several factors complicate what may at first glance seem like a simple iambically alternating stress system. The first of them is the issue of syllable weight. The Yup'ik syllable is (C)V(V)(C), and intrasyllabic consonant clusters are disallowed (Jacobson, 1984:9; Leer, 1985a:164; Lipscomb:65, 1992; Woodbury, 1987:694). While syllables containing long vowels or diphthongs are always heavy and stressed, and open syllables with short vowels are always light, whether or not the codas of closed syllables contribute to weight is contested. Closed syllables are always stressed word-initially, and while they can receive stress in other positions, they do not always (cf. examples in Table 5).

Table 5: Examples of stress alternation in Yup'ik words containing (C)VC syllables.

Example	Transcription	Source
ayagtuq 'he leaves'	[a.ˈjax.tuq]	p. 18 (Jacobson & Jacobson, 1995)
up'nerkaq[7] 'spring'	[ˈup.nəχ.ˈkaq]	p. 226 (Jacobson & Jacobson, 1995)
akngirtaatnga 'they hurt me (indic.)'	[ˈɑk.ˈŋ̥iχ.ˈtaːt.ŋ̥a]	p. 254 (Hayes, 1995)
akngirtatnga 'they hurt me (interr.)'	[ˈɑk.ŋ̥iχ.ˈtat.ŋ̥a]	p. 254 (Hayes, 1995)

When determining which syllables receive stress in the acoustic dataset, it was important to be able to systematically identify which of these closed syllables receive stress. Most accounts across all frameworks, including Halle (1990), Jacobson (1984), Leer (1985b, 1985c, 1994), van de Vijver (1998), and Woodbury (1987), require complex solutions to resolve closed syllables' intermediary status—specifying narrow environments as exceptions to general stress tendencies—in order to solve the CVC problem. Here, we follow Hayes (1995) in assuming that codas always contribute to syllable weight (also cf. the less categorical statement by Miyaoka, 2012:222), except in positions of double clash, i.e. between two stressed syllables or between a stressed syllable and the right edge of the word. In double clash positions, the coda's mora is removed and the closed syllable destressed. For example, compare *ayagtuq* and *up'nerkaq* in Table 2: the middle CVC syllable is stressed in the former, but not in the latter, where it appears between two stressed syllables; the mora associated with /χ/ is lost in double-clash. While Hayes (1995) does not explicitly discuss CVVC syllables, he states that codas are always moraic except in double clash positions. We therefore assume that coda weight is consistent across all syllables, including closed,

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[7] The apostrophe serves many functions in Alutiiq orthography. Here, it indicates that the rule that devoices nasals following voiceless plosives does not apply. An example where this rule does apply is *akngirtaatnga* [ˈɑk.ˈŋ̥iχ.ˈtaːt.ŋ̥a].

heavy CVVC syllables. Such syllables also lose a mora when in double-clash; however, as their nuclei are long, they retain their stress (see a more detailed discussion in section 2.7).

A second complicating factor is that Yup’ik stress assignment is not only influenced by syllable weight, but frequently influences syllable structure in turn, at least according to Hayes’ description. Several phenomena are notable here. The first is that the onset of a heavy syllable may geminate to close a preceding open syllable, as illustrated in (9), which is called “automatic gemination” or “pre-long strengthening” (Bakovic, 1996:5; Hayes, 1995:243; Jacobson, 1984; Lipscomb, 1992:70; Miyaoka, 1971:225).[8]

(9) *maqikaatggun* ‘with their (other’s) future steambath material’ /ma.qi.**k**aː.t.xun/ ->
[ma.ˈqi**k**.ˈ**k**aː.t.xun]
(Hayes 1995:243)

In (9), the second and third syllables /qi.kaːt/ constitute a gemination environment, in which the onset of the latter syllable spreads backwards to close the former. The result is [ma.ˈqi**k**.ˈ**k**aː.t.xun]. Such gemination is prosodically impactful, insofar as it creates new CVC syllables, whose clash position must then be considered in the next cycle of stress derivation. In (9), the newly formed CVC syllable *qik* is not in a double-clash position, and so retain its stress.

Hayes (1995) introduces a constraint on the distribution of automatic gemination that is not consistent with the rest of the Yup’ik literature. While accounts such as Bakovic (1996), Jacobson (1984), Lipscomb (1992), and Miyaoka (1971), define the environment for gemination as any (C)V.CVV sequence, Hayes redefines gemination as a metrical process that only occurs within feet, in the environment ((C)V.CVV). The examples in (2) demonstrate gemination occurring within feet, as described by Hayes (2a), as well as across feet, as defined by Miyaoka and other authors (2b).

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[8] Automatic gemination is not to be confused with the second type of consonant lengthening, lexical (or “marked”) gemination, which refers to the presence of geminates pre-syllabification. Marked gemination is reflected orthographically and is phonemically distinctive: for example, compare taq’uq /taqːuq/ ‘he quit’ to taquq /taquq/ ‘braid’ (Reed, 1977). The sequence C’V, as in Yup’ik, indicates marked gemination in the orthography. Note that the apostrophe has many functions, and for it to express lexical gemination, the spelling must be in the sequence <C’V>, where C’ is the onset of the syllable.

(10) Gemination within vs. across feet (gemination marked based on Alden & Arnhold, 2022)

a. *ipuun* ‘ladle’ (i**p.p**uːn) (Jacobson & Jacobson, 1995:493)

b. *tegumiaq* ‘a thing one is taking along in his hands’ (te.gu**m**).(**m**iaq) (Jacobson & Jacobson, 1995:503)

As there were many instances in the acoustic dataset where gemination crossed foot boundaries, part of this study was an examination of the distribution of gemination (see section 2.5). The results will show that gemination does occur in any (C)V.CVV environment and is not restricted to occurring within feet. This justifies the broader definition of the gemination environment used in the rest of the study.

The second weight-affecting phenomenon is iambic lengthening, also called “rhythmic lengthening”, meaning that stressed short vowels in open syllables are lengthened (Bakovic, 1996; Hayes, 1995; Heinrich, 1979; Lipscomb, 1992; Miyaoka, 1970, 1971, 1985, 2012; Woodbury, 1987, 1995; for an overview of iambic lengthening in other languages, see Hyde, 2011; for specific languages, see Chung, 1983; Topping, 1973, on Chamorro; Gordon & Munro, 2007, on Chickasaw; Nicklas, 1974, 1975, on Choctaw; Derbyshire, 1985, on Hixkaryana; Árnason, 1985, on Icelandic; Michelson, 1988, on Kanien’kéha (Mohawk); (Mithun & Basri, 1986, on Selayarese; among others).[9] In this paper, vowels that are lengthened in this way are marked with a half-long diacritic V·, so as to distinguish them from vowels that are underlyingly long.

Iambic lengthening cannot apply to the schwa vowel /ə/, which, unlike the other Yup’ik vowel phonemes /a/, /i/, and /u/, never appears as long and cannot be lengthened by any phonological or prosodic process. If the nucleus of a stressed syllable is a schwa, additional steps must be taken to ensure that that stress is expressed. In the General Central dialect, the solution is schwa deletion (on different outcomes in other Yup’ik dialects, see Hayes, 1995; Jacobson, 1985; Miyaoka, 1985). To illustrate how schwa deletion works, take *qanruteqaka* /qan.χu.**tə**.qa.ka/ ‘I speak about it’ (Hayes 1995:255): iambic footing would result in *[(ˈqan).(χu.ˈ**tə·)**.(qa.ˈka·)].

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[9] There is also a relationship between iambic lengthening and higher-order prosody: while the Yup’ik destressing of IP-final syllables is a priori unexpected, given general cross-linguistic trends towards final lengthening, there is a tendency for final syllable suppression in languages that employ iambic lengthening (Hayes, 1995; see Buckley, 2019 for a discussion of cross-linguistic word-final vowel length and extrametricality). We thank an anonymous reviewer for pointing out this connection.

Instead the schwa is deleted, giving [(ˈqan).(ˈ**χut)**.(qa.ˈka·)]. Note that deletion of a stressed vowel will lead to the stress migrating to a neighboring syllable; since Yup'ik feet are iambic, stress will shift to the left as a result of the hanging onset attaching to the preceding syllable as its new coda. The closure of a formerly open syllable, as with gemination, triggers re-footing. While Hayes (1995) does not explicitly describe the behavior of stressed /ə/ vowels in closed syllables, occasional instances of stressed CəC syllables in our dataset showed that such instances, while rare, do occur, and follow the general ə-deletion tendency, with the orphaned coda becoming syllabic. For instance, /**məχ**.kaχ.tai.tə.ɬi.niuq/, where the initial syllable is closed, and thereby heavy and stressed, and contains a schwa nucleus, surfaces as [ˈ**mχ**.kaχ.ˈtait.ɬin.ˈniuq]. Importantly, optional schwa deletion in CəC syllables is non-metrical and thus does not lead to any differences in predicted stress locations.

Finally, some Yup'ik morphemes bear lexical stress (Jacobson, 1984). Lexical stress differs from metrical stress as it is phonemically distinctive and cannot be predicted. Lexically stressed syllables are identified by the sequence (C)V'(C) in the orthography, as in *qavar**tu'r**tuq* [qa.ˈvaχ**.ˈtuχ**.ˈtuq] 'he keeps on sleeping' (Jacobson, 1995:25). Although not explicitly stated by Hayes, this lexical stress must be assigned before initial footing, meaning that syllables marked as lexically stressed are assigned their own feet before all other syllables, in a sort of pre-initial footing. Lastly, this stress cannot be removed at any point in the derivation, even in clash.

It is worth stating here that, while words can contain multiple stressed syllables, it is uncontroversially claimed by most authors that there is no need to distinguish between primary and secondary stress levels, as Yup'ik stress is non-culminative (Jacobson, 1985; Woodbury, 1987). While rare, this is not unheard of in highly polysynthetic languages (e.g. Blackfoot, Stacy, 2004; Arapaho, Bogomolets, 2011; Mapudungun, Molineaux, 2018; other Yupik languages, Woodbury, 1987). There are claims that the rightmost stress in a Yup'ik word is the most prominent (see Miyaoka, 1970, 1971, 1985, 2012). However, these claims are unsubstantiated by acoustic data and are not maintained across the literature. Since there is no basis in the literature by which the distinction between primary and secondary stresses can be made, this paper will employ only primary stress diacritics in its examples, following Yup'ik transcription traditions.

To sum up, according to Hayes (1995), Yup'ik stress is binary, quantity sensitive, iambic, constructed left-to-right, and iterative, with the foot's head being obligatorily heavy. When applying Hayes' metrical model to our data for the main acoustic study presented here, some adjustments were needed to assign labels of stressed vs. unstressed to all syllables. These include definitively assuming that codas always contribute a mora, including in syllables with long nuclei; explicating the consequences of schwa deletion in closed syllables; expanding the automatic gemination environment from (C)V.CVV sequences within a foot to all (C)V.CVV sequences, to more closely align with the rest of the Yup'ik literature (see section 2.5); and the explicit inclusion of lexical stress and gemination. For more information about the stress derivation model employed in this study, see Alden & Arnhold (2022).

2.3. Literature on Yup'ik Stress Correlates and Hypotheses

In acoustic terms, a syllable's nucleus can be made more prominent by increasing its duration, increasing its amplitude, raising its pitch, or any combination thereof (Gordon & Roettger, 2017). Little of the literature discusses which of these strategies Yup'ik employs. Miyaoka (1971) claims that a strong syllable is phonetically accompanied by a higher pitch (p. 220). He goes on to state that the highest pitch in the word, which is associated with main stress, is on the last stressed vowel of the word. Woodbury (1985) concurs, stating that "syllable stress consists of pitch movement (usually upward), represented by Pierrehumbert (1980) as pitch accent, with an increase in duration and amplitude" (p. 695).

There is one acoustic study of Yup'ik stress, presented in Gabas (1996). Gabas used the Computerized Extraction of Components of Intonation in Language (CECIL) software to analyze the acoustic correlates of stress. The study used a very small sample size (135 words, total number of syllables not specified), all of which were spoken in isolation. Nevertheless, Gabas demonstrates a cue hierarchy in Yup'ik stress wherein F0 is primary, duration is secondary, and intensity is tertiary. Furthermore, he proposes that "short" words (six syllables or less) are prosodically different from "long" words (seven syllables or more). Short words begin high in intensity, which slowly falls, and exhibit the highest pitch on the right-most stressed syllable, as posited by Miyaoka (1971). Long words, on the other hand, begin with high intensity and pitch, both of which decrease across the word, while the right-most stressed syllable is slightly higher in pitch but considerably louder than its neighboring syllables. Whether or not these are intonational effects is unclear. The present research seeks to corroborate Gabas' claims and account for intonational finality effects.

Finally, the acoustic differentiation of phonemic length (short vs. long vowels) from metrical length (stressed vs. unstressed vowels) has yet to be addressed in Central Alaskan Yup'ik. It is unclear what the phonetic result of iambic lengthening is, to what degree lengthened vowels are longer, and whether the resultant length is the same as for phonemically long vowels (but see Koo & Badten, 1974, on Central Siberian Yupik).

Based on extant literature, we predict that stressed syllables are made distinct from unstressed syllables via increased duration and higher F0; furthermore, intensity may behave as a secondary cue. To examine the effects of a higher F0, we investigated F0 maxima as well as F0 falls as a potential indicator of stress. The realization of stress is particularly interesting due to a three-way distinction of syllable types: short, open syllables (CV); short, closed syllables (CVC); and long syllables (CVː or CVV). For short, open syllables to carry stress, they must be either lengthened or closed via gemination of the following syllable onset, resulting in iambic lengthening on CV syllables. What, then, distinguishes a stressed CV syllable from a CVː or CVV syllable? How do intonational phrase-final effects interact with word-level stress? An acoustic study can clarify these questions and set the stage for future work in Yup'ik prosody.

Our hypotheses regarding the acoustic correlates of stress in Yup'ik are as follows:

H_{DUR}: The presence of stress significantly increases the duration of a syllable's nucleus.

H_{INT}: The presence of stress significantly increases the intensity of a syllable's nucleus.

H_{F0MAX}: The presence of stress significantly increases the maximum F0 of a syllable's nucleus.

H_{F0FALL}: The presence of stress significantly increases the post-peak F0 fall of a syllable's nucleus.

$H_{VowelLength}$: There is an acoustic distinction between long, stressed-short, and unstressed-short vowels, such that underlyingly long vowels are distinct from underlyingly short vowels, and the acoustic values of short vowels are increased by the presence of stress.

2.4. Materials and methods

The acoustic study in this project analyzed six recordings of Central Alaskan Yup'ik, spoken by four different speakers. All of the recordings are housed in the Alaskan Native Language

Archive (Alaskan Native Language Center, n.d.). In this section, we will detail the recordings, as well as our transcription practices and analysis methods.

Of the six recordings, four were educational, meant to be listened to as a supplement to a textbook (Reed, 1977), and two were narratives. Two of the speakers were male and two were female. The advantage of using educational recordings (ANLA identifiers: ANLC3111a, ANLC3111b, ANLC3112a, and ANLC3113a) is that the words are clearly articulated and repeated several times. The narratives, meanwhile, provide many more words in connected discourse. The narratives used in this study include Paschal Afcan's *Napam Cuyaa* (Afcan & Hofseth, 1972) and Annie Blue's *Cikmiumalria Tan'gaurluq Yaqulegpiik-llu* from the book *Cungauyaraam Qulirai: Annie Blue's Stories* (Blue, 2007) (ANLA identifiers: CY(SCH)967A1972g and CY970B2007, respectively). These six recordings were chosen specifically because they were publicly available for download from the ANLA website and all have written transcriptions.

The first author manually annotated each recording in Praat (Boersma & Weenink, 2020). Tiers were added for the entire intonational phrase (IP), the word level, the syllable level, and the segment level. The most important criteria for transcription were the onset of frication in consonants surrounding the vowels, presence of and movement in the higher vowel formants (Turk et al., 2012). Figure 2 shows two annotation samples, the words qayacuar 'little kayak' and atu'urkaq 'article of clothing'. These examples demonstrate several notable transcription practices employed in this study. Firstly, the examples given in Figure 1 both contain vowels in open and closed syllables (note that syllable boundaries were marked on a separate tier that, for the sake of simplicity, has been excluded from these figures). It also demonstrates how boundaries were placed considering fluctuations in higher formants in neighboring segments when a vowel was beside a voiced continuant: note the rise in F2 between the first /a/ and /j/ in Figure 1a. Figure 1b, meanwhile, further shows how boundaries were placed around fricated segments and plosive closures. Both panels also show that that the onset of frication and the offset of higher formants outranked F1 and voicing as segmentation criteria, as illustrated by the boundaries between /χ/ and the preceding vowels. Given that this study examines intensity, F0, and duration, we used these criteria systematically so all three measurements could be obtained from the same intervals.

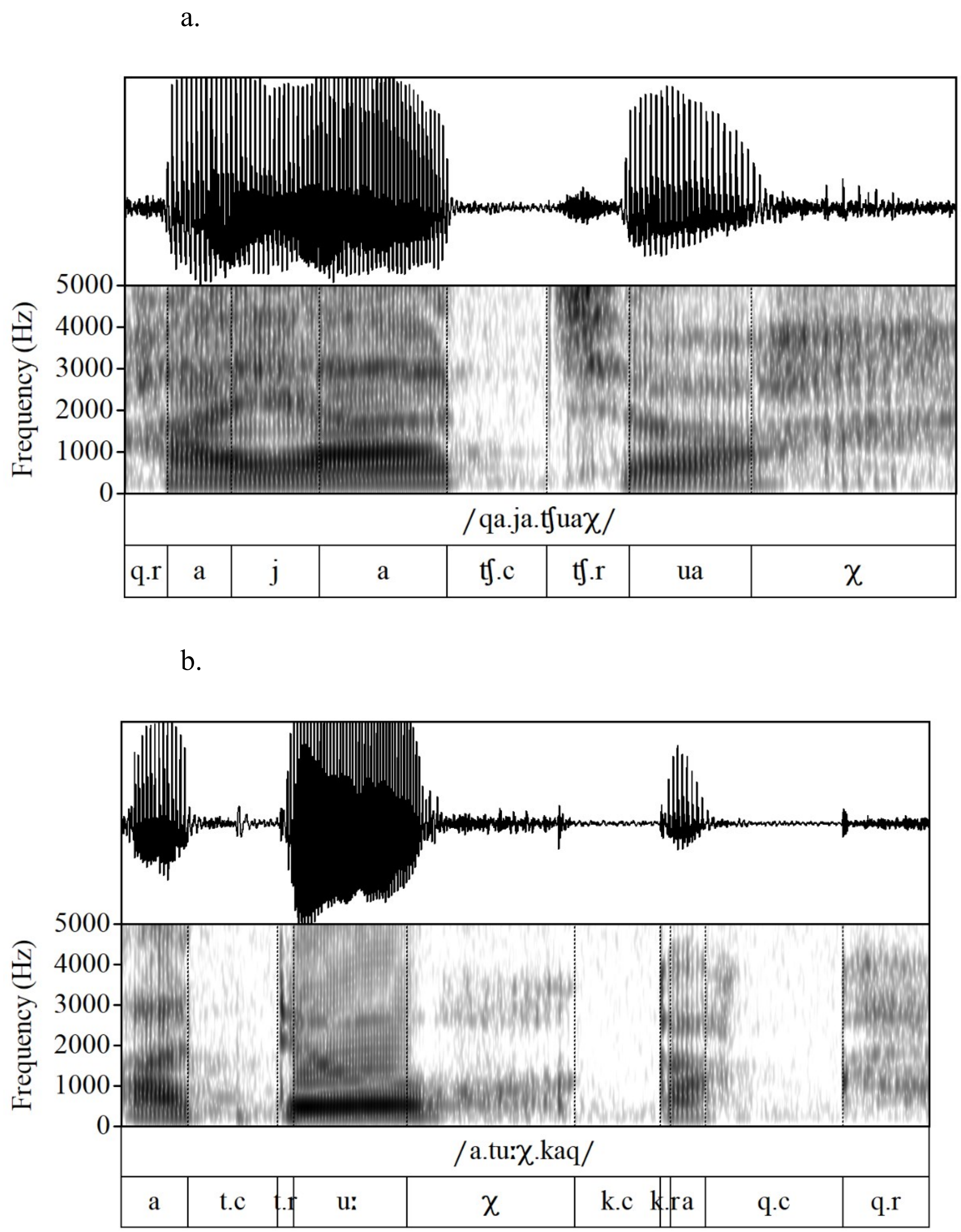

Figure 2: Annotated waveform and spectrogram for the words qayacuar 'little kayak' and atu'urkaq 'article of clothing'. Note that 'C.c' marks the closure phase of a plosive, and 'C.r' marks the release phase.

IP boundaries were determined by pauses between words, combined with punctuation cues (commas and periods) in the written narratives. This means that a word in isolation constituted its own IP. Stress correlates were measured only on vowels for consistency and ease of measurement (see section 7 for details).

At this point, the preliminary study of gemination was performed (see section 2.5) to confirm the distribution of geminates in the dataset. The Yup'ik literature presents divergent descriptions of gemination. According to models that rely on syllable shape and environment to predict gemination (Halle, 1990; Jacobson, 1984; Miyaoka, 1971; Woodbury, 1987), the onset consonant preceding a long vowel geminates leftwards when preceded by an open, light syllable. In Hayes' model, this gemination is restricted to occurring only within a foot. As gemination results in the closure of open syllables, and syllable closure can in turn affect the stress environments of surrounding syllables, it was important to identify where gemination occurs prior to performing the full metrical analyses of the tokens for the acoustic study.

The dataset contained a total of 458 IPs, 440 words and 2,282 vowels. Analysis was done via linear mixed-effect models using the package lme4 in R (Baayen et al., 2008; Bates et al., 2015b, 2015a; R Core Team, 2014). The best models reported below for each dependent variable were chosen to be only as complex as justified by an improved fit to the data (Matuschek et al., 2017). Improved model fit was determined by ANOVA comparison between models with or without each added variable. If the ANOVA did not reveal significant differences between two models, the model without the added variable was preferred. Where ANOVA comparison indicated a significant difference, the model with a higher log likelihood and a lower Akaike Information Criterion (AIC) was chosen. Model selection began with a model containing only the most relevant predictor as a fixed effect, and as random intercepts speaker and genre (educational or narrative). Models of potential stress correlates as reported in section 2.6 additionally included vowel quality (/a, i, u/ or /ə/; diphthongs were coded for the quality of their first segment, e.g. /au/ was simplified to /a/, but retained its long specification) as a random intercept. Starting with this model, the fixed variables were forward fitted, so long as each addition improved model fit; each results section for the gemination and stress studies will describe the tested fixed effects variables for each model. The random-effects structure was then forward fitted by stepwise adding by-subjects random slopes for each of the fixed effects variables. However, none of the models with random slopes converged, so all models below contain only random intercepts. Finally, we tested whether all random intercepts significantly contributed to model fit and simplified models where appropriate. The dependent and independent variables for each resulting best model are specified in the results (see sections 2.5 and 2.6).

After model selection, the residuals were plotted and datapoints with residuals more than 2.5 standard deviations from zero were trimmed. The models were then refit to the trimmed dataset. Information about the number of trimmed data points for each model can be found in the table captions for each model below. Additionally, p-values for fixed effects were obtained with the package lmerTest (Kuznetsova et al., 2017). For models containing significant interactions (see section 2.5 and 2.6.1), pairwise comparisons were performed with the lsmeans function from the package emmeans (Lenth et al., 2022), to further examine the interactions, using the Tukey method for p-value adjustments and the (default) Kenward-Roger method for calculating degrees of freedom.

2.5. First Study: Gemination and Onset Length

In order to examine the distribution of gemination, prior to stress derivation all onsets in the dataset were isolated, resulting in a total of 2,602 consonants[10]; see Table 6 for distribution. Each onset consonant was then assigned one of three categorical labels: one group in which our predictions matched Hayes', in which geminates occurred within a foot (N = 179, labelled 'agreed'); one group in which we predicted gemination where Hayes would not, across foot boundaries (N = 71, 'predicted'); and one group of uncontroversial non-geminates (N = 2352, 'none'). Secondly, each onset was assigned a categorical label based on manner of articulation in order to examine the degree to which duration is affected by consonant identity. Onsets were either plosive closures (N = 492), fricatives (N = 1379), nasals (N=459), or approximants (N = 272). Figure 3 shows the distribution of onset duration for the different gemination and manner categories.

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[10] The disparity between the number of onsets and vowels in the dataset is due to the fact that Yup'ik vowels, especially schwas, are often deleted, and that syllables with onsets are more common than syllables without them, which are illegal word-medially. Syllabic consonants, which are also frequent as a result, were excluded in the data for this dissertation.

Table 6: Distribution of onsets by manner and gemination.

	Manner of Articulation			
Gemination	Approximant	Fricative	Nasal	Plosive Closure
None	247	1252	410	443
Predicted	5	34	25	7
Agreed	20	93	24	42

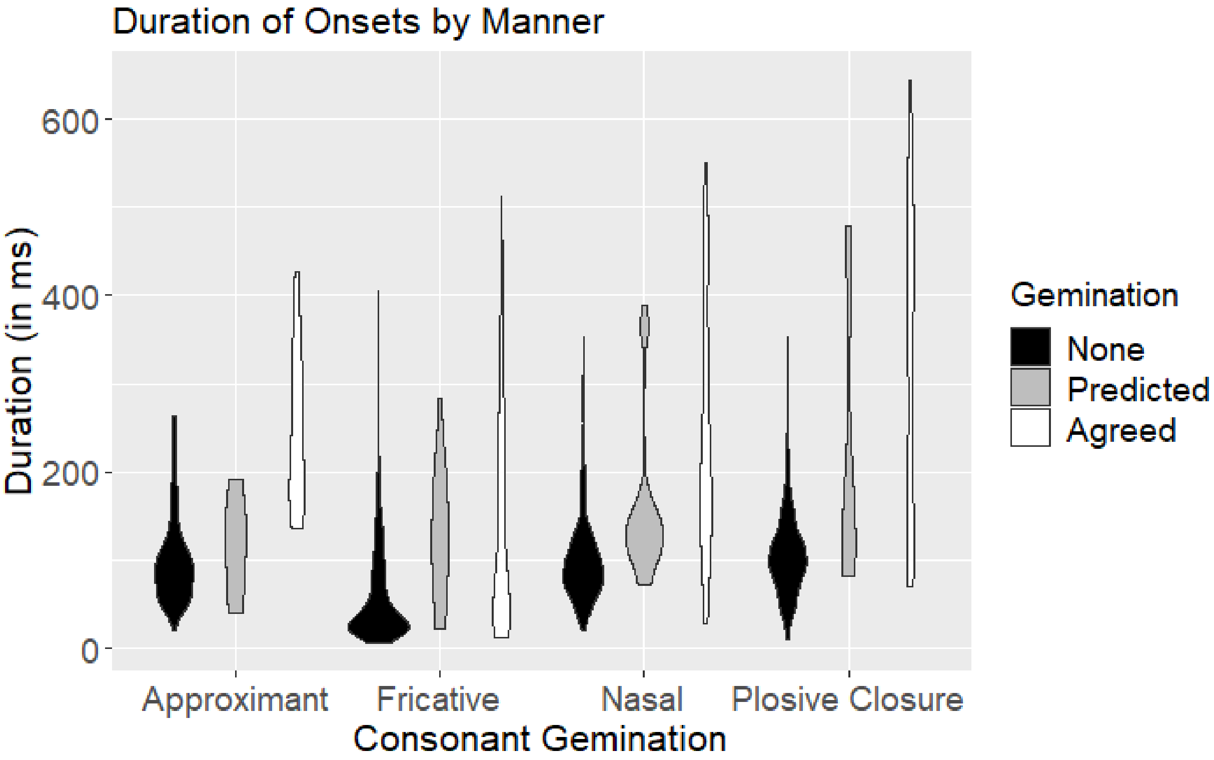

Figure 3: Durations of onsets by manner and predicted gemination.

These onsets were then compared via a mixed-effects linear regression model in order to examine the degree to which duration is affected by geminate status, and the degree to which manner of articulation plays a role in this effect. The base model included gemination (agreed, predicted, none), manner (fricative, approximant, nasal, plosive closure), and syllable stress as fixed effects; model comparison showed that all predictors contributed significantly to model fit. While both speaker and genre as random effects were tested, only the inclusion of the speaker as a random effect improved model fit. The model was then releveled for both gemination and manner of articulation, such that the intercept in Table 7 is an unstressed fricative geminate within a foot (in the ‘agreed’ category of geminates). Finally, the model was further improved by including an interaction between gemination and manner.

Table 7: Fixed effects summary of best model of onset duration. Trimming removed 82 data points (3.15%).

Gemination Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Agreed Geminated Fricative)	102.4313	14.2775	4.0535	7.1743	0.0019
Gemination (None)	-37.7734	5.5226	2504.017	-6.8398	9.93E-12
Gemination (Predicted)	23.1689	9.6902	2503.993	2.391	0.0169
Manner (Approximant)	146.4164	11.5735	2504.222	12.651	<2E-16
Manner (Nasal)	97.8518	12.047	2504.004	8.1225	7.09E-16
Manner (Plosive Closure)	237.7714	11.5671	2504.363	20.5559	<2E-16
Gemination (None) : Manner (Approximant)	-104.852	12.0068	2504.197	-8.7327	<2E-16
Gemination (Predicted) : Manner (Approximant)	-141.028	24.8306	2504.033	-5.6796	1.51E-08
Gemination (None) : Manner (Nasal)	-56.6288	12.3329	2503.997	-4.5917	4.61E-06
Gemination (Predicted) : Manner (Nasal)	-84.7549	17.4622	2503.981	-4.8536	1.29E-06
Gemination (None) : Manner (Plosive Closure)	-190.803	11.8459	2504.404	-16.1071	<2E-16
Gemination (Predicted) : Manner (Plosive Closure)	-229.733	24.8575	2504.062	-9.242	<2E-16
Syllable Stressed	4.9129	1.8832	2503.953	2.6087	0.0091

The significant interaction between manner and gemination, as given in Table 7, shows that differences between gemination categories were not equally pronounced within the individual manners of articulation. This is further reflected in Table 8, which summarizes the gemination results by manner of articulation. Interestingly, geminated onsets in the ‘agreed’ category have much broader ranges than the other two categories, and there is a notable overlap across categories of gemination for all manners.

Table 8: Pairwise comparison results for gemination. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Approximant					
Contrast	Estimate	SE	df	t ratio	p value
None vs. Predicted	-26.0	21.10	2504	-1.230	0.4356
None vs. Agreed	-143.2	10.90	2504	-13.138	<.0001
Predicted vs. Agreed	-117.2	23.31	2504	-5.030	<.0001
Fricative					
Contrast	Estimate	SE	df	t ratio	p value
None vs. Predicted	-61.3	8.36	2504	-7.334	<.0001
None vs. Agreed	-70.8	5.79	2504	-12.239	<.0001
Predicted vs. Agreed	-9.5	9.96	2504	-0.953	0.6066
Nasal					
Contrast	Estimate	SE	df	t ratio	p value
None vs. Predicted	-32.7	10.27	2504	-3.187	0.0042
None vs. Agreed	-94.1	11.26	2504	-8.360	<.0001
Predicted vs. Agreed	-61.4	14.81	2504	-4.149	0.0001
Plosive Closure					
Contrast	Estimate	SE	df	t ratio	p value
None vs. Predicted	-22.9	20.98	2504	-1.089	0.5210
None vs. Agreed	-104.8	10.70	2504	-9.792	<.0001
Predicted vs. Agreed	-81.9	23.30	2504	-3.517	0.0013

Table 8 presents the results of the pairwise comparisons, which tested the significance of all gemination contrasts within the individual manners of articulation. These results are most reliable for fricatives, as they were the most frequent manner of articulation in the dataset (c.f. Table 6). Within the category of fricative, non-geminated onsets were significantly shorter than predicted geminates, as well as being shorter than agreed geminates. Crucially, there was no significant difference between predicted and agreed geminates. Together, these results indicate that gemination occurs both within and across foot boundaries, with no significant difference between the two. Within nasals, there were significant differences between all three gemination categories. Non-geminates were significantly shorter than both predicted and agreed gemination, and predicted geminates were significantly shorter than agreed ones. Finally, within approximants and plosive closures, predicted geminates differed significantly from agreed geminates, but their difference from non-geminates did not reach significance. This would imply that for approximants and plosive closures, geminates do not cross foot boundaries; however, those results are unreliable due to the critically low number of predicted geminates within these categories, with only 5 and 7 predicted geminates, respectively. For this reason, we take the fricative (and nasal) results as the only reliable outcomes of the pairwise comparisons.

The results of this gemination study show that Hayes was not wrong to attest that geminated onsets are longer within feet; however, consonants in any (C)V.CVV sequence, indicated by the 'predicted' portion of Figure 3, are longer than other onsets, justifying their analysis as geminates regardless of their relationship to foot boundaries and stress. Because of Yup'ik's interactions between vowel length, syllable closure, and stress (recall section 2.2), broadening the environment for automatic gemination has significant effects on stress derivation. More opportunities for the creation of new closed syllables create more clash environments in which closed syllables are destressed. Together, the observations that automatic gemination is not limited by foot boundaries and that it affects syllable shapes lead to the conclusion that automatic gemination is a phonological process with metrical consequences. This diverges from Hayes' account, which asserts that gemination is already beholden to phonological structures, namely the foot, before it applies. However, these findings are in line with the rest of the literature on automatic gemination in Yup'ik.

One question, then, concerns the motivating factors of gemination. There are three options. First, it could be an entirely phonetic process, with no mind paid to the phonology (similarly to sub-phonemic duration adjustments which shorten the overall duration of one of two adjacent CVVC syllables in Kalaallisut; see Jacobsen, 2000). Second, it could be triggered by specific phonological environments without reference to foot structure (similar to most scholars' analyses of the Law of Double Consonants, or Schneider's Law, in Nunavik Inuktitut and Labrador Inuttut, cf. e.g. Dresher & Johns, 1995; Rose et al., 2012). Third, gemination could indeed be contingent on the presence of a foot, as assumed by Hayes, in which case the lengthening across foot boundaries would need to be explained by appealing to another mechanism. Of these, the third option can probably be discarded as unnecessarily complex in the absence of firm acoustic evidence for a difference between gemination within and across foot boundaries. Therefore, the motivating factor of gemination seems to be the presence of a V.CVV environment, as is assumed in the literature on Yup'ik.[11] Regarding the first two options, the evidence that gemination is phonological (and involves the addition of a mora) can be seen insofar as syllables that are closed via gemination and are *not* in double-clash environments behave as heavy for the purpose of stress assignment, as described by Hayes. The mora is always added to syllables preceding geminated onsets, but it is not subsequently removed unless in double-clash. This implies a rule order wherein gemination must occur before double-clash resolution.

To conclude, while we leave the precise analysis of Yup'ik gemination across foot boundary as a subject for future research, based on the preliminary findings presented here, we treated any consonant in a V.CVV environment as geminated for the purpose of stress assignment as evaluated in section 2.7. Note, however, that due to the small number of geminates straddling foot boundaries in the present dataset, the impact of this decision should be relatively minor.

2.6. Acoustic Correlates of Stress

The goal of the study in this section is to examine the acoustic correlates of stress in spoken Yup'ik. All 440 words in the dataset were taken through the stress derivation process as described in the User's Guide to Central Alaskan Yup'ik Stress Derivation (Alden & Arnhold, 2022; see Appendix A), which is based on Hayes' (1995) description of the Yup'ik stress system (cf. section

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[11] Gemination is but one form of onset fortition attested in the Yupik language family. Alutiiq has been claimed to feature onset fortition in order to demarcate foot boundaries (Leer, 1985a, 1985b, 1994). Leer distinguishes between three levels of consonant length: short, fortified, and geminated. Gemination in Alutiiq is limited to the word-initial environment #V.CVV, but fortition affects all foot-initial consonants. Unlike gemination, Leer does not connect onset fortition with moraic weight, i.e. he does not assume that fortified onset consonants are truly geminated or moraic. The correlates of Alutiiq fortition are not clear, though it may be related to voicing and preclosure (non-moraic onset lengthening), nor is it consistent across speakers. We are planning a follow-up investigation into Alutiiq onset fortition, which would shed light onto other forms of onset fortition in the language family and their relationship to gemination, and the degree to which gemination in this study is similar to onset fortification and gemination processes in Alutiiq (see Section 3.4.4.).

2.3). Each syllable in the output was thereby assigned a label of ‘stressed’ or ‘unstressed’. While it would have been ideal for these stress judgments to be corroborated by native speakers, this was not possible. This is a limitation in this study; however, the use of a guide that was developed, tested, and adapted to be as accurate as possible to the spoken data, based on established descriptions in the literature, does ensure consistency in the stress labels.

Once stressed syllables were identified, a Praat script (Arnhold, 2018) took measurements of duration, F0, and intensity for the sum total 2,282 vowels in the data corpus. Words included in the dataset were between one and nine syllables long; outlier words ten syllables or longer were removed (4 words, 44 vowels total). As a result, there were 436 words and 2,238 vowels in the final dataset, including 854 /a/ vowels, 560 /i/ vowels, 648 /u/ vowels, and 176 schwas. Within the 2,238 vowels, 506 were long (and thereby obligatorily stressed), 785 were short and stressed, and 947 were short and unstressed, cf. Table 6. Altogether around 80% of evaluated vowels appeared in first, second or third syllables. In spite of the use of educational materials, in which words were produced in isolation, only 7.2% of analyzed vowels appeared in IP-final syllables.

For fundamental frequency, there were occasional cases where the measurement script could not return values (excessive creak, noise, poor recording quality, et cetera). With these errors additionally removed, the resultant dataset used for the fundamental frequency models contained 2,166 vowels.

Table 9: Data metrics for the acoustic investigation. The number of tokens in parenthesis are the amount considered in the analysis of F0 measurements.

Data Metric	Number of Tokens	Percentage
Total vowels	2,238 (2,166)	-
Long vowels	506 (504)	22.6%
Short stressed vowels	785 (757)	35.08%
Short unstressed vowels	947 (905)	42.3%
Word-initial syllables	733 (707)	32.8%
Syllables in position 2	666 (649)	29.7%
Syllables in position 3	392 (375)	17.5%
Syllables in position 4	213 (207)	9.5%
Syllables in position 5	128 (124)	5.7%
Syllables in position 6	54 (53)	2.4%
Syllables in position 7	31 (30)	1.4%
Syllables in position 8	17 (17)	0.8%
Syllables in position 9	4 (4)	0.2%
IP-final syllables	162 (160)	7.2%
Non-IP-final syllables	2076 (2006)	92.8%

Analysis was done via linear mixed-effect models, as described in section 2.4. The following dependent variables were modeled individually: vowel duration (in ms), mean intensity (in dB, scaled to a reference level of 70 dB), F0 maximum (in semitones, relative to a reference frequency of 100 Hz), and F0 fall (in st) from maximum F0 to the F0 at 80% of the vowel's total duration. The 80% mark was chosen over the end of the vowel to reduce segment-final creak or effects from neighboring consonants. The mean intensity was measured over the central 50% of the vowel duration; the first and last 25% of the vowel were excluded in the analysis to avoid confounds from transitions to and from segments preceding and following the vowel. This was not necessary for fundamental frequency, as the chosen measure was the pitch maximum, not mean pitch. The models employed for this study were meant to assess the relationship between a vowel's acoustic characteristics and stress. To test the hypotheses shown in section 2.4, the independent variables included whether a syllable was stressed and the underlying length of the vowel.

Model selection always began with a model containing the ternary stress-length distinction (long, stressed-short, unstressed-short) as a fixed effect, releveled with stressed-short as the intercept, and as random intercepts speaker, genre, and vowel quality. The fixed variables were forward fitted, so long as each addition improved model fit. The tested fixed variables included the syllable's position within the IP (final or non-final), the syllable number counted from the left edge of the word (as a factor), the number of syllables within the word (also as a factor), whether the syllable contained an onset, and whether the syllable contained a coda. We also tested the contribution of random intercepts to the fit and found that genre only significantly improved model fit for intensity; genre is not included as an intercept in any of the other models for this reason. Once the best random effects were accounted for in the model, backward-fitting for the stress-length effects was done to ensure that the distinction was critical to the models.

The following subsections present results of the statistical modelling for duration, intensity, maximum F0 and F0 fall, respectively; the intercept is always the vowel of a short, stressed, non-IP-final syllable with both an onset and a coda. In the following sections, each line of a table represents a comparison to the intercept: in Table 7, for example, the first two lines indicate the estimated duration of a short, stressed vowel (125.7905 ms) and the duration of a long vowel (estimated by the model as 86.6617 ms longer than the intercept, or 212.4522 ms).

2.6.1. *Duration*

For the linear mixed-effects models of vowel duration, tested predictors included whether the syllable was stressed and phonemic length (combined into a single factor as described above); IP finality; syllable position relative to the left edge; total number of syllables in the word; presence of an onset; presence of a coda. For duration, all factors improved model fit. Including genre of the audio as a random intercept did not improve model fit, and so this term was excluded in the final model reported in Table 10.

Table 10: Fixed effects summary of best linear mixed-effects model of duration. Trimming removed 61 data points (2.7%).

Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Short Vowel, Stressed)	125.7905	11.4606	11.7826	10.976	1.54E-07
Vowel Length (Long Vowel, Stressed)	86.6617	24.0265	3.0165	3.607	0.03626
Vowel Length (Short Vowel, Unstressed)	-32.969	2.5207	2147.1971	-13.079	<2.00E-16
Syllable Number (2)	3.8006	2.7959	2148.6001	1.359	0.17418
Syllable Number (3)	4.9795	3.4772	2147.5454	1.432	0.15227
Syllable Number (4)	11.6831	4.2485	2147.8389	2.75	0.00601
Syllable Number (5)	7.3923	5.233	2145.985	1.413	0.15791
Syllable Number (6)	2.8677	7.4937	2145.2682	0.383	0.702
Syllable Number (7)	5.8321	9.704	2144.6718	0.601	0.5479
Syllable Number (8)	-7.8135	13.1426	2144.4838	-0.595	0.55223
Syllable Number (9)	-14.9254	25.3569	2143.8695	-0.589	0.55618
Word length (2 syllables)	-22.9186	7.6455	2147.3254	-2.998	0.00275
Word length (3 syllables)	-32.7853	7.815	2147.5667	-4.195	2.84E-05
Word length (4 syllables)	-46.7042	8.0584	2146.7237	-5.796	7.81E-09
Word length (5 syllables)	-51.0858	8.1381	2147.0861	-6.277	4.16E-10
Word length (6 syllables)	-47.0694	8.6077	2146.1206	-5.468	5.07E-08
Word length (7 syllables)	-54.2454	9.2366	2146.8828	-5.873	4.95E-09
Word length (8 syllables)	-37.9638	9.5978	2147.1316	-3.955	7.89E-05
Word length (9 syllables)	-61.6575	12.2941	2147.2907	-5.015	5.73E-07
Onset (No onset)	0.2667	3.0478	2146.4982	0.088	0.93027
Coda (No coda)	44.1644	2.3908	2139.2113	18.472	<2.00E-16
IP Position (Final)	49.003	4.4385	2148.564	11.041	<2.00E-16

Table 10 shows that long vowels were significantly longer than stressed short vowels, while unstressed short vowels were significantly shorter than stressed short vowels; however, the boxplots in Figure 4 below demonstrate that the ranges of all three categories overlap considerably. Relevelling also confirmed that unstressed short vowels had shorter durations than stressed long vowels (estimate = -86.6618; std. error = 24.026; df = 3.0166; t = -3.607; Pr(>|t|) = 0.03625). While the result that long vowels are longer than short vowels is not surprising, it does demonstrate that the result of iambic lengthening is not the same as phonemic length. Another notable distinction is between stressed-short and unstressed-short vowels. The fact that the only difference between the two is stress, and that that difference is statistically significant, demonstrates that a change in duration is in fact correlated with stress in Yup'ik.

The rest of the results in Table 10 suggest that vowels got longer the further they got from the left edge of the word, but this effect was only significant for the fourth syllable when compared to the first syllable. Word length also affected vowel duration, with all other words lengths having significantly shorter vowel durations than monosyllabic words. The estimates indicate that the shortening compared monosyllabic words increases with each extra syllable, although 6-syllable and 8-syllable words form an exception to this generalization, likely due to a paucity of data for exceptionally long words (cf. Table 9). Regarding syllable structure, the intercept was a vowel with an onset and a coda: while the absence of an onset did not significantly affect length, the vowel's duration was significantly longer when a coda was absent. Finally, IP-final vowels were significantly longer than non-final vowels, in line with cross-linguistic tendencies towards final lengthening (see overview in Fletcher, 2010).

Following up on these results, in order to specifically assess iambic lengthening, a linear mixed-effect model examined the extent to which syllable closure has a measurable effect on the duration of vowels in different phonemic length and stress categories. If iambic lengthening applies only to Yup'ik stressed short vowels, as described in the literature, then we expect that syllable closure will have a noticeable effect on stressed short vowels that is distinct from syllable closure's effect on long or unstressed short vowels.

The model tested the duration of vowels by phonemic length and whether or not a coda was present in the syllable, with speaker and vowel phoneme as random effects. The fixed effects additionally included an interacti43on between the stress-length distinction and presence/absence of a coda, which significantly improved model fit. The intercept of this model was a stressed short vowel in a closed syllable. Table 11 provides the distribution of the data, and the model summary given in

Table 12.

Table 11: Distribution of syllable closure and length for pairwise comparisons.

	Syllable Closure	
Stress-Length Distinction	Closed	Open
Stressed Long	169	337
Stressed Short	497	288
Unstressed Short	243	704

Table 12: Fixed effects summary of linear mixed-effects model of syllable closure and duration. Trimming removed 61 data points (2.7%).

Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Short Vowel, Coda Present)	90.843	13.848	5.793	6.560	0.000693
Stress-Length (Stressed Long)	83.514	4.101	2165.222	20.363	<2.00E-16
Stressed-Length (Unstressed Short)	-10.541	3.582	2164.978	-2.942	0.003291
Coda (No Coda)	64.396	3.416	2165.808	18.851	<2.00E-16
Stress-Length (Stressed Long): Coda (No Coda)	-24.811	5.564	2165.071	-4.459	8.65E-06
Stress-Length (Unstressed Short): Coda (No Coda)	-38.311	4.821	2165.076	-7.946	3.07E-15

As the interaction between the stress-length distinction and closure was significant, pairwise comparisons were run in order to examine the effect of closure across the stress-length categories, see Table 13. For the purposes of examining iambic lengthening, the crucial result in Table 13 is that stressed short vowels in open syllables are longer than those in closed syllables, as expected. However, this holds true for all three stress-length categories. As reflected in Figure 4, the closure of a syllable significantly affected the duration of a vowel, regardless of that vowel's underlying length or stress: vowels in closed syllables consistently had shorter durations than those in open syllables.

Table 13: Pairwise comparisons for syllable closure by phonemic length and stress. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Stressed Long Vowel

Contrast	Estimate	SE	df	t ratio	p value
Closed vs. Open	-39.6	4.40	2165	-8.994	<.0001

Stressed Short Vowel

Contrast	Estimate	SE	df	t ratio	p value
Closed vs. Open	-64.4	3.42	2166	-18.844	<.0001

Unstressed Short Vowel

Contrast	Estimate	SE	df	t ratio	p value
Closed vs. Open	-26.1	3.45	2166	-7.554	<.0001

Figure 4: Boxplot of the vowel durations for each of three different stress-length combinations by syllable closure.

A second set of pairwise comparisons, given in Table 14, shows the differences in duration between stress-length categories within closed and open syllables, respectively. Note that the difference in duration between stressed and unstressed short vowels is significant also in closed syllables, where iambic lengthening does not apply. This shows that the distinction between the two categories is due to more than iambic lengthening alone. Specifically, it shows that stress significantly distinguishes short vowels even when iambic lengthening is not involved. However, the effect of iambic lengthening is observable insofar as the estimate for the difference between the two categories in open syllables (48.9 ms) is much larger than the difference in closed syllables (10.5 ms). Here, the former seems to be a combination of the effects of both iambic lengthening and stress: the larger duration effect may be the result of two lengthening processes affecting the vowel. The latter, meanwhile, is presumably the lengthening effect of stress alone—or, alternatively, it may be the case that in closed syllables, some of the stress effect appears on the coda. The critical result is that the ternary stress-length distinction is preserved even when iambic lengthening does not apply, i.e. regardless of syllable closure.

Table 14: Pairwise comparisons for phonemic length and stress by syllable closure. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Closed Syllable

Contrast	Estimate	SE	df	t ratio	p value
Stressed Long vs. Stressed Short	83.5	4.10	2165	20.359	<.0001
Stressed Long vs. Unstressed Short	94.1	4.63	2166	20.308	<.0001
Stressed Short vs. Unstressed Short	10.5	3.58	2165	2.942	0.0092

Open Syllable

Contrast	Estimate	SE	df	t ratio	p value
Stressed Long vs. Stressed Short	58.7	3.73	2164	15.718	<.0001
Stressed Long vs. Unstressed Short	107.6	3.14	2166	34.213	<.0001
Stressed Short vs. Unstressed Short	48.9	3.23	2166	15.118	<.0001

Altogether, the results in this section indicate that vowel duration serves multiple functions: the expression of syllable structure, such that the presence of a coda shortens the vowel, and the expression of a syllable's stress, such that stressed syllable vowels are longer than unstressed ones.

In this way, duration is an important acoustic correlate for communicating syllable shape information as well as stress in Yup'ik. Moreover, vowel duration reliably cues phonemic vowel length at the same time.

2.6.2. *Intensity*

Modelling of intensity tested the same fixed and random effects as for duration. The only predictor that did not improve model fit, and was therefore excluded from the final linear mixed-effects model (Table 15), was the sum total number of syllables in the word. Note also that the intensity model is the only one to incorporate genre as a random effect. While this effect was tested in every model, it only contributed to model fit for intensity. This is likely due to differences in microphone sensitivity and audio quality among the recordings, where the educational materials were very loud and clear, while the narrative materials were often much quieter, which also affected the scaled intensity values evaluated here.

Table 15: Fixed effects summary of best linear mixed-effects model of intensity. Trimming removed 40 data points (2.11%).

Intensity Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Short Vowel, Stressed)	78.8326	4.0547	1.0497	19.442	0.028523
Vowel Length (Long Vowel, Stressed)	1.2004	0.221	2170.4585	5.431	6.21E-08
Vowel Length (Short Vowel, Unstressed)	-1.3019	0.1949	2171.8781	-6.68	3.03E-11
Syllable Number (2)	-0.3716	0.2114	2172.9126	-1.758	0.078886
Syllable Number (3)	-1.2176	0.2493	2172.46	-4.885	1.11E-06
Syllable Number (4)	-2.3477	0.3015	2172.9078	-7.786	1.06E-14
Syllable Number (5)	-3.3722	0.3693	2172.1623	-9.132	<2.00E-16
Syllable Number (6)	-3.6842	0.5327	2171.5264	-6.916	6.07E-12
Syllable Number (7)	-4.2178	0.6789	2170.6194	-6.213	6.23E-10
Syllable Number (8)	-5.2103	0.9147	2170.6231	-5.696	1.39E-08

Syllable Number (9)	-2.0675	1.8365	2169.9757	-1.126	0.260387
Onset (No onset)	-0.9202	0.2348	2168.074	-3.919	9.15E-05
Coda (No coda)	0.6399	0.1819	2170.7299	3.519	0.000443
IP Position (Final)	-3.9498	0.3345	2172.5633	-11.809	<2.00E-16

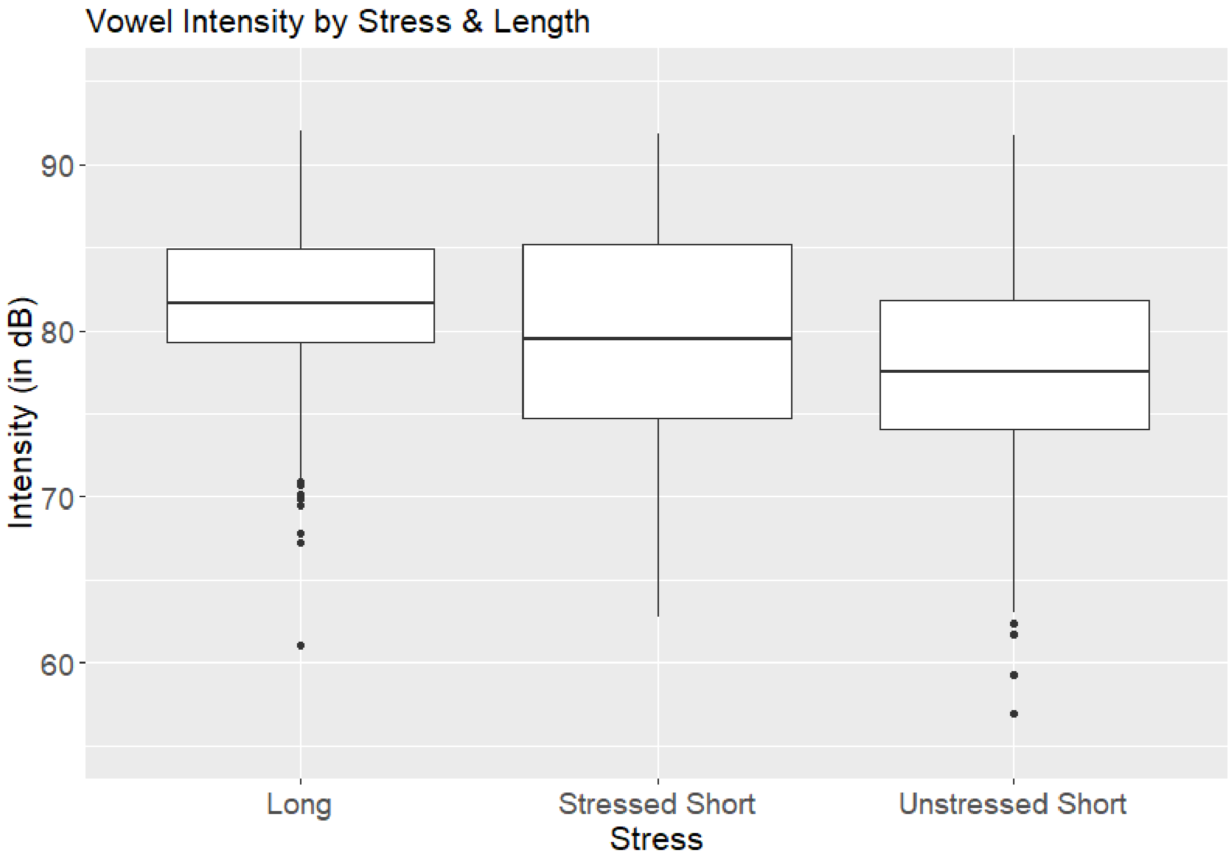

Figure 5: Boxplot of the vowel intensity for each of three different stress-length combinations.

The final model for intensity in Table 15 showed that long vowels were significantly louder than stressed short vowels, while unstressed short vowels were significantly less loud than stressed short vowels, as also illustrated in Figure 5. Relevelling also confirmed that unstressed short vowels had significantly lower intensities than stressed long vowels (estimate = -1.2004; std. error = 0.2210; df = 2170.46; t = -5.431; Pr(>|t|) = 2.61e-08). Like duration, then, intensity is associated with the production of both long vowels and stressed vowels.

In the rest of Table 15, decreasing intensity estimates for syllable number mean that vowels are quieter the later they come in the word, relative to an initial syllable. This difference was significant except for syllables in second position, which only differed marginally from initial ones, and for the ninth syllable from the left edge. Syllables in second position come early in the word and are likely affected by the intensity of the initial syllable. That the effect was not significant for ninth syllables is likely due to the low number of nine syllable words in the data. While vowels without onsets had significantly lower intensity than those with onsets, vowels in an open syllable were louder than in a closed one. The last vowels in IP-final words were significantly quieter than non-IP-final vowels.

2.6.3. *Maximum F0*

The tested factors that did not improve model fit for maximum F0 include the presence of an onset and total number of syllables; as with the duration model, recording genre as a random effect did not improve model fit, and so it was excluded in the final maximum F0 model.

Table 16: Fixed effects summary of best linear mixed-effects model of maximum F0. Trimming removed 68 data points (3.14%).

Maximum F0 Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Short Vowel, Stressed)	8.35351	1.21844	3.42104	6.856	0.004115
Vowel Length (Long Vowel, Stressed)	-0.65611	0.51476	3.02931	-1.275	0.291437
Vowel Length (Short Vowel, Unstressed)	-1.51746	0.157	2077.69558	-9.665	<2.00E-16
Syllable Number (2)	-0.04885	0.16507	2075.45388	-0.296	0.767298
Syllable Number (3)	0.05506	0.19338	2078.1831	0.285	0.775893
Syllable Number (4)	-0.58626	0.23973	2078.35679	-2.446	0.014547
Syllable Number (5)	-1.10458	0.29392	2077.37198	-3.758	0.000176
Syllable Number (6)	-0.44352	0.42786	2076.82697	-1.037	0.300039
Syllable Number (7)	-0.94626	0.55937	2075.36566	-1.692	0.090863
Syllable Number (8)	-0.91483	0.72007	2076.48214	-1.27	0.204054
Syllable Number (9)	0.10948	1.45021	2075.13676	0.075	0.939832

Coda (No coda)	0.76608	0.14612	2076.42625	5.243	1.74E-07
IP Position (Final)	-2.22453	0.26372	2078.9518	-8.435	<2.00E-16

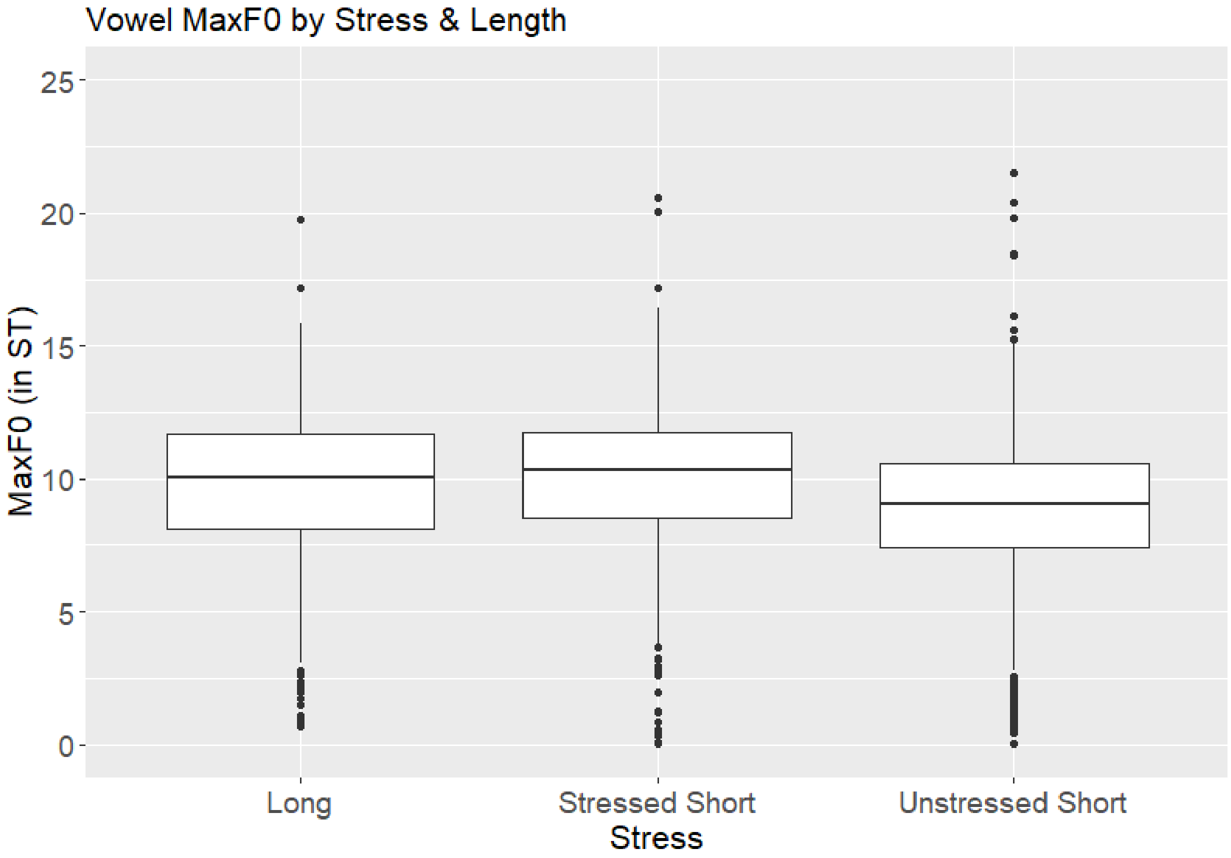

Figure 6: Boxplot of the vowel maximum F0 for each of three different stress-length combinations.

Table 16 presents the fixed effects of the best linear mixed-effect model for maximum F0. Recall that the F0 models were based on a smaller dataset than the other analyses due to the removal of any F0 measurement errors. The results given in the first three rows of Table 16 show that while stressed short vowels were significantly higher in F0 than unstressed short vowels, they were not significantly different from long vowels. Relevelling revealed that the max F0s of unstressed short vowels were not significantly different than those of stressed long vowels (estimate = 0.86135; std. error = 0.51264; df = 2.97738; t = 1.680; Pr(>|t|) = 0.192). This result indicates that max F0 is not associated with length, but is associated with stress on short vowels, although, as Figure 5 shows, the max F0 ranges for stressed and unstressed short vowels overlap.

The most striking feature of the rest of Table 16 is the general tendency for F0 to fall across the word: the later in the word a syllable comes, the lower its pitch. Compared to the initial syllable, the difference was significant for the fourth, fifth, and seventh syllable (again, the effect was probably not significant for later syllables due to their small number). Lastly, Table 16 shows that vowels in open syllables were higher in max F0 than those in closed syllables, while IP-final vowels were lower in max F0 than non-IP-final ones.

2.6.4. *F0 Fall*

In the modelling of F0 fall, including syllable number and the presence of an onset as a predictor did not improve model fit and these factors were therefore excluded from the final model, presented here in Table 14. As with duration and maximum F0, genre as a random intercept did not improve model fit.

Table 17: Fixed effects summary of best linear mixed-effects model of F0 fall. Trimming removed 58 data points (2.95%).

F0 Fall Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Short Vowel, Stressed)	10.4893	2.2808	207.4453	4.599	7.38E-06
Vowel Length (Long Vowel, Stressed)	4.5056	0.8888	1947.7928	5.069	4.38E-07
Vowel Length (Short Vowel, Unstressed)	-1.538	0.7492	1946.0471	-2.053	0.040221
Word length (2 syllables)	-4.0142	2.1928	1947.7834	-1.831	0.067315
Word length (3 syllables)	-5.7668	2.2194	1947.5491	-2.598	0.009437
Word length (4 syllables)	-5.4179	2.2801	1946.6136	-2.376	0.017589
Word length (5 syllables)	-5.9493	2.2885	1945.8254	-2.6	0.009404
Word length (6 syllables)	-6.9504	2.4289	1946.4903	-2.862	0.00426
Word length (7 syllables)	-8.3744	2.6039	1947.1291	-3.216	0.001321
Word length (8 syllables)	-5.6231	2.7087	1942.0919	-2.076	0.038034
Word length (9 syllables)	-7.4338	3.3558	1947.7951	-2.215	0.026862

Coda (No coda)	2.3855	0.7036	1919.4521	3.39	0.000713
IP Position (Final)	12.1406	1.3416	1947.6247	9.05	2.00E-16

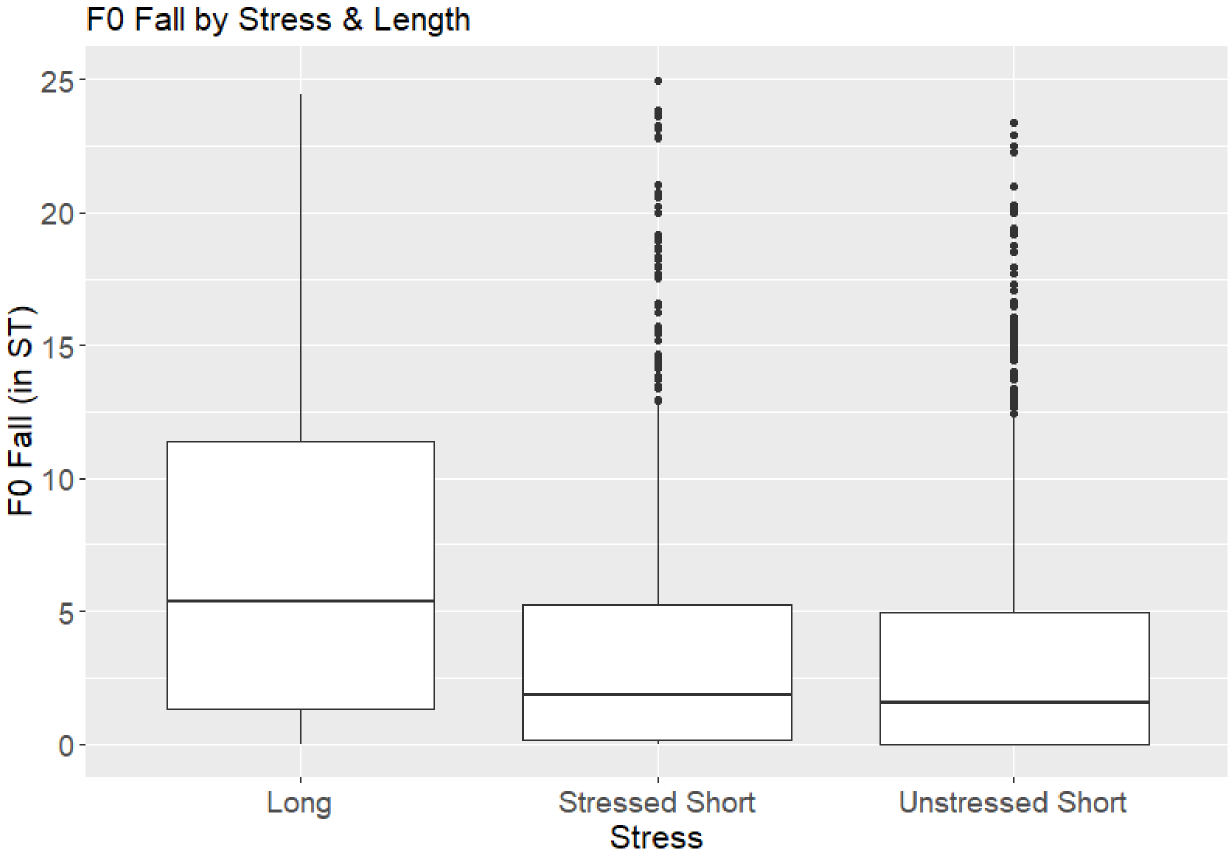

Figure 7: Boxplot of the F0 fall for each of three different stress-length combinations.

Figure 7 illustrates that stressed long vowels had the greatest F0 fall. As shown in Table 17, linear mixed-effects modelling indicated that their falls were significantly larger than those of stressed short vowels. Relevelling also confirmed that unstressed short vowels had smaller falls than stressed long vowels (estimate = -4.5056; std. error = 0.89; df = 1947.7928; t = -5.069; Pr(>|t|) = 4.38e-07). The difference between stressed and unstressed short vowels, however, was only marginally significant. F0 fall was further significantly impacted by the total number of syllables in the word, such that the longer the word, the less the F0 falls. An open syllable had a larger F0 fall than a closed syllable. Finally, an IP-final syllable had a significantly larger F0 fall than a non-IP-final syllable.

Since these results suggest that F0 falls are affected by phonemic vowel length, but not by stress, it stands to reason that the size of the fall is mainly affected by the "space" available for it, i.e. by vowel duration. In order to examine the degree to which F0 fall and duration are correlated, a Pearson correlation test was run between the two variables. The result was significant (t = 17.816, df = 2017, p-value < 2.2E-16), indicating that there is indeed a positive correlation between a vowel's duration and its F0 fall (r = 0.44). This result is reflected in Figure 8. In this graph, values with low F0 fall are clearly associated with lower vowel durations. Together with the model in Table 17, these results imply that F0 fall is more of a characteristic of long vowels than it is a cue for stress, though its marginal relationship with stress may be associated with the role of duration as a stress correlate (see section 2.6.1).

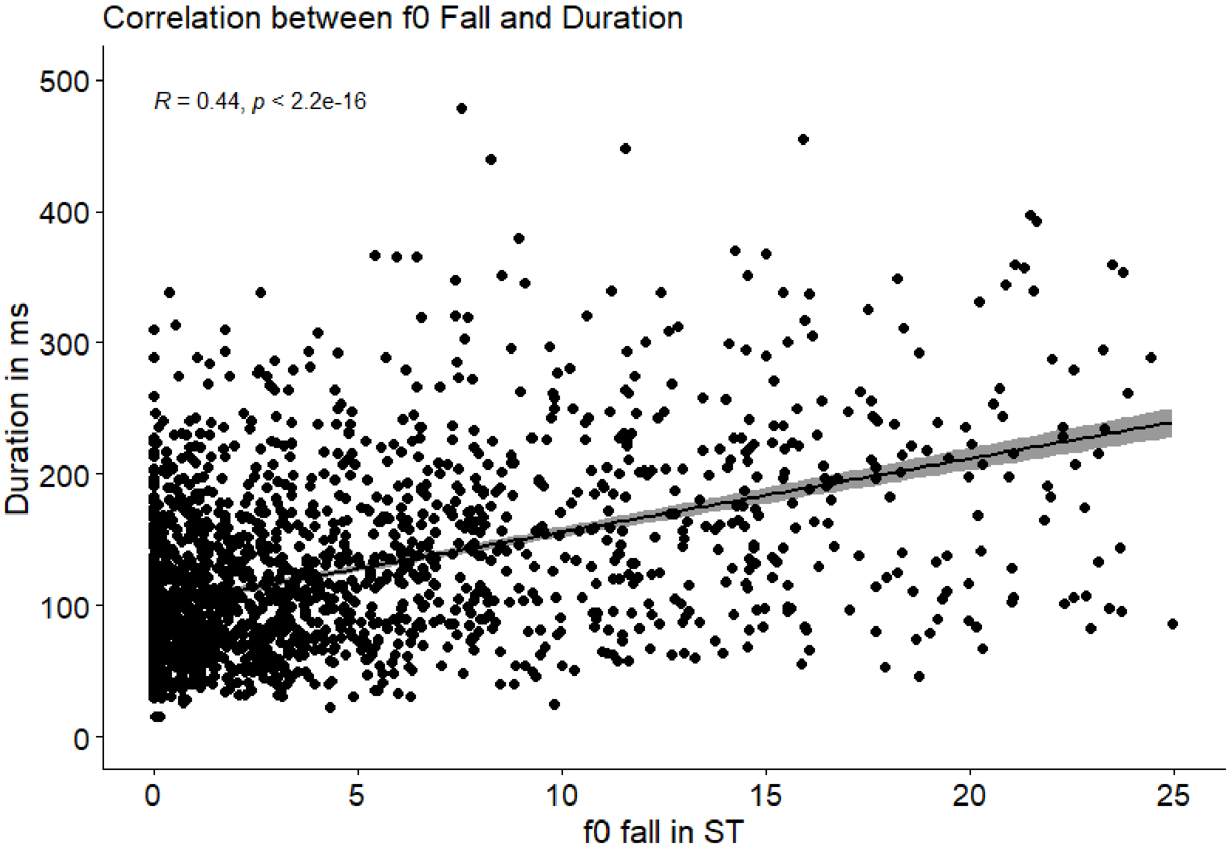

Figure 8: Scatter plot of F0 fall and duration, demonstrating the correlation.

2.7. Discussion

Table 18 briefly summarizes the results of the statistical models.

Table 18: Summary of the effects of stress and length on each examined acoustic correlate.

	Duration	Intensity	Max F0	F0 Fall
Stress	Significant	Significant	Significant	Marginal
Phonemic Length	Significant	Significant	Not Significant	Significant

In order to examine characteristics of stress alone, we can consider the differences between stressed and unstressed short vowels. Duration, intensity, and maximum F0 were significantly different between the two. This demonstrates that duration, intensity, and F0 maximum are all correlated with stress. These results affirm the hypotheses HDUR, HINT, and HF0MAX, all of which predicted that values would be higher in stressed vowels than in unstressed vowels. F0 fall was shown to be only marginally affected by stress, leading to a rejection of HF0FALL. In general, however, there was a correlation between F0 fall and duration, such that longer vowels had more time for their F0 to fall. In this way, the marginal relationship of F0 to stress may be more associated with the durational effect of stress than F0 fall behaving as a stress correlate itself.

These findings corroborate and notably expand upon observations by Miyaoka (1971) and Woodbury (1987), both of whom describe pitch movement on strong (stressed/heavy) syllables, without distinguishing between stress and length effects. The results of the present study also affirm Gabas' observations about duration, intensity, and F0 affecting stress production. However, there is no evidence that any of the acoustic correlates of stress—duration, intensity, and max F0—are ordered relative to one another, as suggested by Gabas. A perception study that isolates these correlates would serve to test Gabas' claims regarding the cue hierarchy. While our dataset suffers from a dearth of exceptionally long words, comprising 2.4% of the data, results indicate that syllables that come later in the word (syllable number as counted from the left edge) tend to be shorter and quieter. Furthermore, word length was only significant for duration and F0 fall, both of which decrease as word length increases—that is to say, syllables in longer words tend to have nuclei that are shorter and feature less F0 fall. Our results in this regard do not corroborate Gabas' claim about two categories of word length affecting prosodic performance, i.e. stress being marked differently in long vs. short words. Instead, the present study found consistent correlates of stress across the whole data set. Finally, this study limits its scope to exploring the relationship between unstressed short, stressed short, and long vowels. A follow-up study to compare stressed vowels to one another and relative to the right edge will clarify Gabas' claims regarding penultimate prominence.

In addition to stress, the present study also investigated the acoustic correlates of phonemic vowel length. Our results showed a three-way distinction in the acoustic characteristics of the stress-length categories wherein stressed long vowels were longer and louder than stressed short vowels, which were in turn longer and louder than unstressed short vowels. Each of the three categories is therefore made audibly distinct by the speaker, and critically, these distinctions were preserved even in cases of confounding phonology, e.g. iambic lengthening and effects of syllable closure. The result is a durational scale of vowel durations, illustrated in Table 19:

Table 19: Observed scale of vowel duration by syllable closure, underlying vowel length, and stress.

Short, Closed, Unstressed	<	Short, Open, Unstressed	<	Short, Closed, Stressed	<	Short, Open, Stressed (Iambically Lengthened)	<	Long, Closed	<	Long, Open
(C)**V**C		(C)**V**		ˈ(C)**V**C		ˈ(C)**V**ˑ		ˈ(C)**V**ːC		ˈ(C)**V**ː

Similar to the findings in Koo & Badten (1974) regarding a ternary stress-length distinction in the durations of Central Siberian Yupik vowels, the acoustic portion of this study revealed a distinction in the expression of phonemic and metrical length, such that they are audibly distinct from one another. While Koo & Baadten (1974) only investigated duration, the present results revealed differences between long and short vowels also regarding other acoustic correlates, in line with what has been observed for a range of other languages such as Estonian (Lippus, 2011; Lippus et al., 2013), Finnish (Järvikivi et al., 2010; Vainio et al., 2010), Japanese (Isei-Jaakkola, 2004; Kubozono et al., 2011; Yoshida et al., 2015), and Sakha (Vasilyeva et al.; 2016; also see Yu, 2010, on general effects of F0 on perceived duration). Acoustic measures that were significantly different between stressed short and stressed long vowels highlight the acoustic effects of phonemic length: duration, intensity, and F0 fall, but not maximum F0, were associated with length. This result affirms the hypothesis $H_{VowelLength}$, which predicted that this phonological distinction would be observable in the acoustics. Indeed, phonemic vowel distinctions in length are preserved when stressed. Stress surfaces mostly the same way on long and short vowels and is marked by a higher duration and intensity, as well as higher F0 on stressed short vowels only. However, the function of F0 falls appears to be to differentiate (stressed) short vowels from long vowels, as long vowels have a greater F0 fall than both stressed and unstressed short vowels. In short, the phonemic length contrast and metrical lengthening phenomenon of Yup'ik are acoustically distinct.

Finally, the results also showed acoustic correlates of prosodic units both above the foot (the word and the IP) and below the foot (the syllable). The results for duration (section 2.6.1) showed generally shorter vowel durations in longer words than in shorter ones and shortening of vowels in syllables with onsets or codas compared to those without, i.e. tendencies towards isochrony at both the word and the syllable level. Furthermore, the duration results also showed that IP-final syllables are significantly longer than non-IP final syllables. In terms of intensity (section 2.6.2), syllables towards the end of a word are quieter than those towards the beginning. Lastly, F0 maxima for later syllables tend to be lower than those for early syllables (section 2.6.3), and longer words tend to exhibit overall more F0 fall than shorter words (section 2.6.4). Although this study did not explicitly seek to corroborate claims regarding prosodic units above the foot, all of these observations are in line with trends towards isochrony and finality effects that are common cross-linguistically (see overview in Fletcher, 2010; also see Arnhold, accepted, for an overview of phonetic and phonological marking of prosodic domains and adjustments to syllable structure in Inuit and Yupik languages).

One particularly interesting theoretical question that arises out of the acoustic results addresses the relationship between the mora and its measurable value as a unit of phonemic length (also see Broselow et al., 1997; Cohn, 2003; Duanmu, 1994; Gordon, 2002, 2004, 2007; Ham, 2013; Khattab & Al-Tamimi, 2014). Our study suggests that Yup'ik may not simply have binary system of syllable weight, but instead is reminiscent of what Gordon (2002) calls scalar syllable weight systems. The acoustic results show a large number of distinctions in vowel durations, as summarized in Table 19, which cannot straightforwardly be explained in terms of moraic constituency as laid out by Hayes (1995). Recall that, according to Hayes, Yup'ik unstressed open syllables with short vowels are monomoraic, while closed syllables (except in double clash environments), stressed open syllables with short vowels, and syllables containing long vowels are bimoraic. A particular challenge to this account is the fact that stressed short vowels had shorter durations than long vowels, both of which are assumed to be bimoraic in Hayes' (1995) conception of Yup'ik syllable weight. That the two are distinctively produced points to the extent to which Yup'ik prioritizes maintaining the ternary stress-length distinction. However, if the addition of a mora is the vehicle of iambic lengthening, then it is surprising that short vowels that are lengthened in this way are not as long as vowels with underlying length.

In a scalar system, as found, for example, in Klamath (Barker, 1964), Kashmiri (Kenstowicz, 1994), Chickasaw (Munro & Willmond, 1994), and Yapese (Jensen et al., 2019), syllables have intermediary weight categories, more than a simple light-heavy dichotomy. Scalar weight systems are still fundamentally binary: Gordon interprets the scale of weight between, for instance, CVV, CVC, and CV syllables as a series of binaries, such that {CVV > CVC, CV} and {CVV, CVC > CV}. This scalar framing mirrors Yup'ik vowel distinctions, in which long syllables are longer than both stressed short and unstressed short syllables, and all stressed syllables are longer than unstressed short syllables.

There are several analyses that may explain the scalar nature of Yup'ik vowel durations. First, moras may contribute different amounts of length in different positions. Second, the observed length distinctions may be exclusively stress effects compounding on underlying length distinctions. In this view, iambic lengthening does not apply as described in the literature. Third, if stress always adds a mora to affected syllables, in closed syllables, that mora may be shared between the nucleus and the coda, resulting in stressed vowels in closed syllables appearing shorter, but having equal weight, to vowels in open syllables. Fourth, there may be a disparate number of moras between stressed short and long vowels, such as in Nilotic languages, while further length differences are non-moraic. Finally, iambically lengthened (short stressed) vowels and long vowels may have the same number of moras, namely 2, per Hayes (1995). Here, the observed vowel length disparities must be either non-moraic or the result of incomplete neutralization.

The first possible analysis would assert that the mora that is added to a short vowel when it is stressed contributes less duration than either mora of a long vowel. This implies a quality distinction among moras: though all moras contribute to weight, such that the presence of two moras constitutes a heavy syllable, some contribute more acoustically than others, resulting in some heavy syllables surfacing as longer than others. In this case, moras assigned to underlyingly long vowels would contribute more to duration than moras assigned by the metrical component. While theoretically interesting, there is little evidence for this line of argumentation, which would need to be backed up by strong cross-linguistic data due to the far-reaching implications of assuming non-uniformity among moras. Moreover, even if such an analysis were chosen to account for the difference between stressed short and long vowels, it would either need to acknowledge that there are additional durational differences that cannot be accounted for by moras (cf. Table 19) or would need to be expanded into a system where moras were able to have not only two different values or degrees of contributing to duration, but several.

The second possible analysis reconsiders the assumption that the observed lengthening of stressed short vowels is iambic lengthening as it is described in the literature. In this view, rather than iambic lengthening resulting from an added mora, the trigger for the observed lengthening may be the presence of stress—that is, it may not be the case that stress requires that a light syllable be made heavy via iambic lengthening, but rather that the durational effects of stress itself, compounded onto the underlying length of a short or long vowel, result in the observed lengthening.

There is some evidence against this option, however. If the observed lengthening on stressed short vowels in open syllables was just a stress effect, without any durational contributions from iambic lengthening, then, presumably, this single effect would apply evenly to stressed short vowels regardless of syllable closure. We would not expect the significant difference between stressed short vowels in open and closed syllables that was observed in the acoustic measurements of duration (cf. Table 13). While one could explain this difference as an effect of syllable isochrony (vowels are shorter in syllables with codas than in those without, as seen for all vowel categories), it is noteworthy that the difference between vowels in open and closed syllables was much larger for stressed short vowels (estimated by pairwise comparisons as 64 ms) than for both unstressed short vowels and stressed long vowels (40 ms and 26 ms, respectively, cf. Table 13). This strongly suggests that iambic lengthening is in fact distinct from regular stress lengthening, and that only stressed short vowels in open syllables are affected by both. Since iambic lengthening seems to have a distinct effect on vowel duration, the addition of a mora can be assumed to explain why iambic lengthening occurs in the first place: to ensure that all foot heads are heavy.

Thirdly, it may be the case that the codas of stressed closed syllables with short nuclei share the burden of stress lengthening with the vowel. This would allow stress to lengthen stressed open and closed syllables equally, but in closed syllables, some of that lengthening would be realized on the coda, and their nuclei would appear shorter. This would be similar to Levantine Arabic, where, outside of the word-final position, codas dominate moras when the preceding vowel is long. In word-final position, however, the mora is shared between the nucleus and the coda (Broselow et al., 1997). Broselow et al. show that, in Levantine Arabic, because a non-final coda shares its mora with the preceding (long) nucleus, only long vowels are shortened in closed syllables. Short vowels have the same duration in both open and closed syllables, as they do not share moras with codas. This, however, is not the case in Yup'ik, where both long and short vowels in open syllables are longer than those in closed syllables, as indicated by the results of the present study (cf. section 2.6.1). Though the gap between open and closed syllables is much larger for short stressed vowels than it is for long vowels, if the discrepancy was due to mora sharing alone, there would be no difference between long open and long closed syllables. Thus, while mora sharing could contribute to the observed special behavior of stressed short vowels, it cannot explain it completely.

The fourth analysis posits that the difference is seen between vowels with ostensibly the same number of moras because they do not, in fact, have the same number of moras. That is, stressed short/iambically lengthened vowels have more moras than unstressed short vowels, but fewer than long vowels. In this view, durational differences are explained as a combination of moraic and non-moraic factors. Table 20 visualizes such an analysis, following the assumptions that a) iambic lengthening is caused by the addition of a mora to short vowels targeted for stress in open syllables (following Hayes, 1995), b) codas contribute to weight outside of clash environments (again following Hayes, 1995, and supported by the fact that these closed syllables receive stress, but extending Hayes' assumption that moras contribute weight also to syllables with long vowels), and c) the consistent durational distinctions between the three stress-length categories as observed in the acoustic measurements can be attributed to different mora counts. The resulting system would posit that Yup'ik syllables can have between one and four moras. This is notably more complex than Hayes's account, but is not unheard of in the language family (Arnhold, accepted; Holtved, 1964; Jacobsen, 2000; Kleinschmidt, 1851, pp. 7-8; Nagano-Madsen, 1990). There is also typological precedence for a phonetic long-overlong vowel distinction in languages that permit trimoraic vowels. In Nilotic languages, such as Dinka and

Nuer, for instance, the ternary vowel length distinction between short, long, and overlong vowels is phonemically contrastive, and expressed via three degrees of duration (see Monich, 2017; Remijsen & Gilley, 2008).

Table 20: Possible distribution of moras accounting for observed durational effects of phonemic length, iambic lengthening, and the contribution of codas to syllable weight, but not for effects of syllable closure on vowel duration.

Syllable	Mora Count
Short, Open, Unstressed	1 mora (from the nucleus)
Short, Closed, Unstressed	1 mora (1 from the nucleus, 1 from the coda; however, the second mora is removed due to double clash, resulting in an unstressed syllable)
Short, Open, Stressed	2 moras (1 from the nucleus underlyingly, 1 from iambic lengthening)
Short, Closed, Stressed	2 moras (1 from the nucleus, 1 from the coda)
Long, Open, Stressed	3 moras (3 from the nucleus, in order to differentiate it from stressed short vowels)
Long, Closed, Stressed	4 moras (3 from the nucleus, 1 from the coda)

While this analysis does account for the difference between long and short stressed vowels, it leads to another discrepancy: if Table 20 is a true account of moraic constituency in Yup'ik and moras are directly reflected in vowel duration, then we expect unstressed vowels and short stressed vowels in closed syllables to have roughly the same duration, as they have the same number of moras, namely one (since the second mora of stressed CVC syllables comes from the coda). However, as seen in Table 13 and Table 14, this is not the case. In other words, this hypothesis cannot account the observed vowel duration differences beyond iambic lengthening and phonemic length, nor does it account for the observed effects of codas on vowel durations (i.e. isochronic lengthening/shortening). Thus, even expanding the inventory of possible mora counts to syllables with up to four moras does not allow for an exhaustive mapping between moras and duration effects, i.e. there are durational effects that cannot be accounted for with a strictly moraic analysis.

The fifth and final analysis of the durational discrepancy between stressed short and long vowels strictly follows the description of moraic distribution in Hayes (1995): syllables in Yup'ik are maximally bimoraic, with all heads necessarily containing two moras. This account justifies iambic lengthening as moraic, giving light, monomoraic syllables an extra mora in order to function as a foot head. It is futher supported by classical accounts of moraic theory: in Hyman (1989) and Hayes (1995), for instance, moras are a result of projections from underlying length contrasts, rather than distributed on the basis of phonetic length. Under this assumption, while factors such as syllable closure may create differences in vowel durations, such differences are not necessarily reflected moraically. In this way, the observed lengthening distinctions are not reflected in mora count at all: as the weight distinction in Yup'ik identifies monomoraic (light) and bimoraic (heavy) syllables, the maximal number of moras a syllable may have is two. In terms of syllable closure, this allows for (C)VC syllables outside of double-clash positions to be heavy. For (C)VVC syllables, it may be the case the second mora is shared between the nucleus and coda—regardless, the syllable will always be treated as heavy, just as any syllable with a long nucleus would be. However, such an analysis also implies that all bimoraic syllables are made equal, for instance, that iambically-lengthened short vowels are equal in length to long vowels, which is not supported by the evidence in this paper.

There are two ways to maintain this analysis. Firstly, we could assume that moras are more or less completely divorced from acoustic duration. The only correspondence between the two would be that monomoraic short unstressed vowels have shorter durations than short stressed and long vowels, both of which are bimoraic, at least in open syllables. All other observed durational differences summarized in Table 19 would not be reflected in the moraic distribution. Moras would thus be central to the assignment of stress, but untethered from the rest of the phonological system and its phonetic expression. Such a strong dissociation between duration and moras is probably not theoretically desirable. Furthermore, the acoustic results clearly distinguish three vowel categories, and demonstrate that Yup'ik prioritizes preserving length distinctions wherever possible. This suggests that these vowel categories play a central role in the phonology of the language, as in other Inuit and Yupik languages (cf. overview in Arnhold, accepted), and that vowel length distinctions should be captured in moras.

The second alternative would be that, while long vowels and stressed short vowels are both bimoraic—long vowels by nature of their underlying length, and stressed short vowels by way of iambic lengthening—the discrepancy between the two is the result of incomplete neutralization. This echoes monomoraic lengthening in Japanese (Braver, 2019). Japanese has a bimoraic minimality requirement: each prosodic word must contain one foot, and each foot must contain two moras (McCarthy & Prince, 1986, 1993). In order to fulfill this requirement, monomoraic nouns with short vowels are lengthened. This is parallel to Yup'ik's iambic lengthening fulfilling the requirement that foot heads be heavy. While in Japanese, the mora counts of lengthened monomoraic vowels and bimoraic vowels are ostensibly identical, Braver & Kawahara (2016) found that the vowel durations of lengthened nouns were shorter than for underlyingly long nouns. Lengthened vowels were produced with an intermediate duration, between unlengthened short vowels and long vowels. This very strongly resembles the observed stress-length distinction in Yup'ik.

Braver (2019) interprets the results of Braver & Kawahara (2016) to mean that monomoraic lengthening is attempting to neutralize the length distinction between monomoraic and bimoraic vowels. However, this neutralization is incomplete, resulting in the intermediary duration of lengthened monomoraic vowels. In Braver's Optimality Theoretical account, constraints that govern the surface vowel's faithfulness to its phonemic length (underlyingly short vowels surfacing as short) compete with those that require that monomoraic short vowels be lengthened. The consequence is a trichotomy of length which distinguishes the durations of unlengthened short, lengthened short, and long vowels.

The connections between Japanese monomoraic lengthening and Yup'ik iambic lengthening are quite clear. Both use the addition of a mora to induce lengthening on an otherwise short vowel (which is underlyingly monomoraic), so that it can fill a bimoraicity requirement (binary feet in Japanese, heavy iambic heads in Yup'ik). However, this lengthening competes with the language's desire to maintain its phonemic length distinction. As a result, the moraic lengthening process does not fully neutralize the phonetic differences, even if the targeted vowel is now treated as heavy.

In sum, considering typological parallels, the most plausible analyses for the Yup'ik findings presented here are the possibility of polymoraic syllables, as has been reported elsewhere in the language family (option four above), or that iambic lengthening is an incomplete neutralization process (option five above). In the latter case, in closed syllables, the added mora may be shared between the nucleus and coda (as mentioned under option three above). In open syllables, meanwhile, the vowels' desire to remain short conflicts with their newfound weight, resulting in a phonetic distinction between lengthened short vowels and long vowels.

2.8. Conclusion

In this study, six recordings of spoken Central Alaskan Yup'ik were analyzed in order to examine the acoustic correlates of stress in Yup'ik syllabic nuclei. The Yup'ik stress system can be summarized as a left-to-right iambic system wherein codas contribute to weight and stress is sensitive to weight. The results of this study demonstrate that in Central Alaskan Yup'ik, a vowel's stress affects that vowel's duration, intensity, and F0. The significant effects observed for F0 fall as a stress cue for long vowels are likely more related to length than they are to stress, while a significant effect of stress on the height of the F0 maximum appeared only for short stressed vowels. The results further corroborate the foundational tenet of Yup'ik metrics: that there is a ternary relationship between stress and length, and that stressed long vowels, stressed short vowels, and unstressed short vowels are all different. This project establishes baseline patterns of stress distribution, behavior, and expression that address the outstanding questions surrounding stress in Central Alaskan Yup'ik and open the door for further investigations in the future.

3. Quantitative Evidence of Complex Metrical Prosody in Chugach Alutiiq

3.1. Introduction

Alutiiq is a polysynthetic Alaska Native language spoken in southern Alaska. It spans the Kenai Peninsula to the east, across Kodiak Island, and along the Alaska Peninsula to the west. This project, a study of acoustic expressions of metrical structure, concentrated on the Chugach dialect from the Kenai Peninsula. The language has been the subject of considerable discussion among phonologists since documentation efforts began in earnest in the 1970s. The Alutiiq language (*Sugt'stun*; henceforth *Alutiiq*[12]) in general, and the Chugach dialect in particular, have been described as having complex prosody, with an underlying length distinction among vowels, both binary and ternary feet, metrically-conditioned tone, length neutralization, and morphosyntactic influence on stress distribution (Elenbaas & Kager, 1999; Hayes, 1995a; Hewitt, 1994; Hewitt & Ann, 1991; Kager, 1993, 1995; Leer, 1985b, 1985a, 1985c, 1994; Martínez-Paricio & Kager, 2016; Rice, 1988, 1992). This study seeks to explore the acoustic correlates of the metrical system, namely the effects of stress, length (including the phonemic length contrast, length neutralization, and an additional lengthening process), and tone on vowels in Alutiiq, as well as correlates of metrically-conditioned consonant fortition. While many authors have modelled these phenomena through a variety of theoretical frameworks, this project represents the first acoustic study of the language. The results inform a typological inquiry into the classification of Alutiiq prosody: we will evaluate the language's metrical behaviors to see how closely they match the criteria for stress and tone languages (Hyman, 2006; Jun, 2014). When the Alutiiq stress and tone behaviors are shown to be non-typical, we then compare these metrical behaviors to other similarly-described languages.

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[12] The various terms that the Sugpiaq people use to refer to themselves and their language have largely arisen out of the history of colonization and oppression of the Alaska Native peoples. How an individual relates to their heritage and community is interwoven with this history, and different people may use different terms to refer to their people and their language. The term *Alutiiq* emerged from Russian colonization (Russian *Алеу́тский язы́к* /aˈlʲutskɪj (j)əˈzɨk/ 'Aleut language'), where the various groups in the region were sorted into either Yupik or Aleut categories. Note that even though this categorization applied the term Aleut to the Sugpiaq people and their language, Alutiiq is part of the Yupik subbranch of the Inuit-Yupik-Unangan language family and thereby much more closely related to other Yupik languages than to Unangam Tunuu, which was also called Aleut. The name Alutiiq is an "Alutiicized" version of the name Aleut, which has now become the widely known English term for the language. As language suppression was a large part of colonial history, many community members do not have access to the language today, and the autonym *Sugt'stun* (alternatively, *Sugcestun*) is not widely known. In referring to the language as Alutiiq, our intention is to use the term that is most accessible to both researchers and community members.

This chapter is structured as follows: Section 3.2 presents the materials and methods used in the study, including the measured variables and tested effects. Section 3.3 presents the results for the acoustic correlates of stress, while Section 3.4 provides the results for the other relevant prosodic phenomena: length neutralization and the relationship between duration and syllable closure, and the correlates of additional lengthening, tone, and onset fortition. Section 3.5 discusses these findings and their implications for Alutiiq metrical modelling before Section 3.6 concludes.

The rest of this section provides a general account for the prosody of Alutiiq as it is described in the literature. Based on descriptions by Leer (1985a, 1985b, 1985c, 1994), the Alutiiq stress system has been modelled in metrical stress theory (Hayes, 1995; Hewitt, 1994; Hewitt & Ann, 1991; Rice, 1988) and Optimality Theory (Elenbaas & Kager, 1999; Houghton, 2006b; Kager, 1993; Martínez-Paricio & Kager, 2016). Most authors have a special interest in Alutiiq's binary-ternary metrical system, focusing on modelling the alternation of minimal binary and maximal ternary feet in theoretical terms. Others, such as Fine (2019), concentrate on aspects of prosodic stylization, such as speech rate, phrase intonation, and voice quality.

3.1.1. Syllable Structure & the Distribution of Stress

The Alutiiq syllable is given in Leer (1985b:82-83) as XV(V)(C), where X = 0-3 consonants. Light syllables ((C)V)[13] contain a single vowel, while heavy syllables ((C)VV and presumably (C)VVC)[14] contain two full vowels (i.e. vowels other than /ə/). Vowel length is contrastive in Alutiiq, such that there is a contrast between the underlyingly long /aː/, /iː/ and /uː/ and short /a/, /i/, and /u/ vowels. Diphthongs are considered long, meaning that a phonemic long vowel can consist of any combination of two full vowels, either homogenous, as in /aː/, or heterogenous, as in /ai/. Closed syllables, i.e. (C)VC, are treated the same way they are in the Norton Sound and General Central dialects of Yup'ik, with word-initial CVC as heavy and non-initial CVC as light

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[13] While complex onsets are possible in Alutiiq, they are generally either limited to a word-initial position or the result of other phonological processes, e.g. schwa deletion. For the purposes of this article, the issue of complex onsets will be ignored, and consonants in the onset position will simply be referred to as C.

[14] As with the Central Alaskan Yup'ik literature (Halle, 1990; Jacobson, 1985a, 1985b; Leer, 1985d; Miyaoka, 1985, among others), (C)VVC syllables are not explicitly discussed in descriptions of Alutiiq syllable weight. However, there is no evidence to suggest that they are anything other than heavy, and so are treated as heavy here. See further discussion on Central Alaskan Yup'ik syllable weight and the status of CVVC syllables in Alden & Arnhold (n.d., 2022).

(Hayes, 1995; Leer, 1985a, 1985b, 1985d, 1994; Kager, 1993, 1995; Martínez-Paricio & Kager, 2017; Rice, 1988).

In a sequence of light, open syllables, Alutiiq stress basically alternates in an iterative iambic pattern starting from the left edge of the word (Hayes, 1995b; Leer, 1985b, 1985a). Heads of iambs are lengthened via iambic lengthening, thereby made distinct from non-head syllables (also see Chung, 1983; Topping, 1973, on Chamorro; Gordon & Munro, 2007, on Chickasaw; Nicklas, 1974, 1975, on Choctaw; Derbyshire, 1985, on Hixkaryana; Árnason, 1985, on Icelandic; Michelson, 1988, on Kanien'kéha (Mohawk); (Mithun & Basri, 1986, on Selayarese; among others on iambic lengthening in other languages). Interestingly, however, stress alternation appears to regularly 'skip' a syllable. Where and when this syllable skipping occurs varies by dialect, being most widespread and straightforward in Chugach Alutiiq and more morphologically restricted in Kodiak Alutiiq (Leer, 1985b:118-128). Hayes (1995:334-335) describes the basic Chugach Alutiiq pattern of syllable skipping as occurring in words with all light, open syllables: the second syllable is stressed, and in words of sufficient length, additional stresses fall on every third syllable thereafter. Syllable skipping[15] is exemplified in Table 21. In this table, skipped syllables are in italics. For the purposes of illustration, skipped syllables are presented as outside of the iambic foot; see section 3.1.3 for a full discussion on the relationship between the skipped syllable and metrical structure. Note that like in other closely related languages, Alutiiq is claimed to not have culminative stress. Examining claims surrounding culminativity in the Yup'ik languages is part of ongoing research; however, for the purposes of this article, following in the Alutiiq literature tradition, we do not distinguish between primary and secondary stress in transcription.

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[15] Leer refers to this process as 'accent advancement'; the terms syllable skipping and accent advancement refer to the same phenomenon and may be used interchangeably. However, it should be noted that syllable skipping refers specifically to the observable surface form phenomenon, while accent advancement is a morphophonological description of the process that results in said surface form.

Table 21: Examples of stress alternation in light, open syllables.

Syllable Number	Alutiiq Word	Source (in Leer, 1985a)
2σ	(pə̥.ˈn̥aq) ‘cliff’	p. 104
3σ	(a.ˈku).*taq* ‘a food (ABSOLUTIVE)’	p. 84
4σ	(a.ˈku).(ta.ˈmək) ‘a food (ABLATIVE SG)’	p.84
5σ	(a.ˈtu).*qu*.(ni.ˈki) ‘if he (REFL) uses them’	p. 113
6σ	(pi.ˈsu).*qu*.(ta.ˈqu).*ni* ‘if he is going to hunt’	p. 113
7σ	(ma.ˈŋaʁ).*su*.(qu.ˈta).(qu.ˈni) ‘if he is going to hunt porpoise’	p. 113

In Table 21, words with between two and four syllables are assigned stress based on expected parameters for an iambic system: stresses fall on every other even-numbered syllable. In words with more than five syllables, however, some syllables are ‘skipped’ in the stress alternation. If we assume that the only permitted feet are binary and iambic, then it appears that these syllables are not counted in the alternation and may be unfooted.

Exactly how this pattern emerges and the relationship of the skipped syllables to metrical structure is not immediately clear. Leer (1985a) proposes that such skipped syllables belong to a degenerate foot category, the ‘unaccented’ foot that cannot bear stress. Later, this claim is rescinded in favor of the proposal that they are entirely unfooted (Leer, 1994; see also Hayes, 1995, Hewitt, 1994, and Kager, 1994). Finally, some authors propose that these skipped syllables are part of a larger prosodic structure above the foot, such as a superfoot (Leer, 1985c) or an Internally Layered Ternary foot (Martínez-Paricio, 2013, Martínez-Paricio & Kager, 2016). This is further discussed in section 3.1.3.

Heavy syllables attract stress, interrupting the otherwise alternating stress pattern, as shown in Table 22. Recall that in Alutiiq, closed syllables with short vowels behave as heavy only in word-initial position. In Table 22, (a) shows how weight attracts stress, with the long vowel in the initial syllable making the syllable heavy. This can happen in sequence, as shown by (b): heavy syllables are always stressed, including when there are only heavy syllables in the word. The effect of weight is not restricted to any given position, as the heavy syllable in (c) is word-final. Syllable closure does not contribute to weight outside of word-initial syllables, and so the second syllable in (d) is considered light whereas the initial (C)VC syllables in (e), (g), (h) and (j) are heavy and attract stress. Examples (f) and (g) show how syllables of varied weights can alternate with one another. Syllable weight works in conjunction with syllable skipping: just as syllables can be skipped after a stressed light syllable, they can also be skipped after a heavy syllable, as shown in (d), (g), (h), (i), (j), and (k).

Table 22: Stress alternation with heavy syllables.

Alutiiq Word		Source (in Leer, 1985a)
a.	(ˈtaː).(ta.ˈqa) ‘my father’	p. 86
b.	(ˈtaː).(ˈtaː) ‘his/her/its father’	p. 86
c.	(mu.ˈluk).(ˈkuːt) ‘milk (PL)’	p. 86
d.	(ˈnaː).*uq* ‘it is burning’	p. 98
e.	(ˈul).(ˈlua) ‘its tongue’	p. 87
f.	(ˈnaː).(ma.ˈtʃi).(ˈqua) ‘I will suffice’	p. 84
g.	(ˈax).(ku.ˈtaʁ).(ˈtua).*ŋa* ‘I’m going to go’	p. 92
h.	(ˈan).*tʃi*.(qu.ˈkut) ‘we’ll go out’	p. 84
i.	(ˈnaː).*qu*.(ma.ˈlu).*ku* ‘apparently reading it’	p. 89
j.	(ˈqaj).(ˈjaː).*kun*	p. 88

	‘by his boat’	
k.	(ˈiq).*sa*.(ˈliːs).*qe*.(ɬu.ˈku) ‘telling (him) to put a hook on it’	p. 115

Lastly, both (e) and (j) feature gemination, in which their first syllables are underlyingly light and their second syllables are heavy.[16] This results in both initial syllables becoming heavy, and therefore receiving stress like all other heavy syllables in the table. Gemination where the onset of a heavy syllable lengthens to close a preceding light, open syllable is limited to two environments in Alutiiq: #(C)V.**C**VV and ˈ(C)V.**C**VV sequences (Leer, 1994:122). This contrasts from Central Alaskan Yup’ik, where gemination occurs in (C)V.**C**VV in any position within the word (Alden & Arnhold, submitted, 2022; Hayes, 1995; Jacobson, 1984; Jacobson & Jacobson, 1995). Also unlike Yup’ik, closed syllables are never considered heavy word-medially in Alutiiq, and so word-medial gemination does not have an effect on foot structure.

Syllable closure and surface vowel length are not always reliable indicators of syllable weight. According to Leer, *compression* affects the surface duration of underlyingly long and short vowels in closed and final syllables, shortening both long vowels and vowels that are lengthened by stress and neutralizing their length contrast with unstressed short vowels (Leer, 1985b:88-89). Compression extends to diphthongs as well, resulting is a phonetic difference between, for example, a full /ai/ vowel and a compressed, ‘short’ /ai/ vowel that is still underlyingly long.

Table 23: A paradigm demonstrating compression, from Leer (1985b:88).

Alutiiq Word	Footing	Phonetic Form	Translation
a. qayakun	(qa.ˈja).*kun*	[qaˈ.jaː.kun]	by boat
b. qayatgun	(qa.ˈ**jat)**.*xun*	[qaˈ.jat.kun]	by boats
c. qayaa	(ˈqaj).**(ja**ː**)**	[ˈqaj.ja]	his boat
d. qayaakun	(ˈqaj).(ˈjaː).*kun*	[ˈqaj.ˈjaː.kun]	by his boat
e. qayaat	(ˈqaj).(ˈ**ja**ː**t)**	[ˈqaj.ˈjat]	their boat
f. qayaatgun	(ˈqaj).(ˈ**ja**ː**t)**.*xun*	[ˈqaj.ˈjat.xun]	by their boat

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[16] Note that in this article, gemination is transcribed as the same consonant on either side of a syllable boundary, $C_1.C_1$, rather than as a long consonant Cː. There are two reasons for this choice: first, in order to explicitly illustrate the new coda in an open syllable preceding a geminate, and second, in order to avoid confusion with onset fortition (see Section 4.4).

In order to illustrate this compression process, a partial paradigm of the word *qayak* /qa.jak/ is given in Table 23. Recall that #CV.CVV sequences result in gemination to close the initial syllable, as in (c-f). Syllables in bold are targets for compression: they include long vowels, either by their underlying length or by stress, and are either in closed syllables or word final. These vowels see their length neutralized, such that they surface the same as an equivalent short vowel, e.g. / ˈqaj.jaː/ > [ˈqaj.ja].

3.1.2. Other Metrical Phenomena

In addition to stress, Alutiiq features three other prosodic phenomena that can cue a word's metrical structure: tone, additional lengthening, and consonant fortition. All of these are associated with either foot constituency, foot boundaries, or intermediary levels of the prosodic hierarchy, and their distribution and function can be accounted for under certain footing models (see Section 3.1.3). In the literature, these processes are not presented as correlates of stress, but rather as prosodic phenomena expressing metrical structure that run parallel to stress.

Firstly, *tone* in the Chugach Alutiiq variety of Alutiiq is not lexically specified: rather, H and L tones alternate, and appear to correspond to metrical structures. As described in the literature, Chugach Alutiiq syllables can bear a high tone H, a low tone L, or be neutral, in which case F0 is dependent on neighboring syllables (Leer 1985c:164; Martínez-Paricio & Kager, 2016).

(11) Tone patterns in words with light syllables

a. ta.ˈqu^{H}.ma^{L}.lu.ˈni^{H}
'apparently getting done' (Leer, 1985a, p. 89)

b. pi.ˈsu^{H}.qu^{L}.ta.ˈqu^{H}.ni^{L}
'if he is going to hunt' (Leer, 1985a, p. 113)

c. a.ˈta^{H}.qa^{L}
'I (SG) put it on' (Leer, 1985a, p. 110)

As illustrated by the examples in (11), stressed syllables always bear a high tone[17], and it appears that syllables immediately following them are always low. This is not a distributional rule for L tones, however: H tones may also occur without intervening Ls, as illustrated in (12) and (13). In sequences of H tones with no intervening L, the second H tone is upstepped, producing a slightly higher H tone (¡H), as in (12). As shown in (13), upstepping will not occur if the preceding H is already upstepped.

(12) a.ˈku^{H}.ta.ˈmək$^{¡H}$
‘Alutiiq ice cream-ABLATIVE’ (Leer, 1985a, p. 84)
(13) ˈan^{H}.ku.ˈtaʁ$^{¡H}$.ˈtua^{H}
‘I’m going to go out’ (Leer, 1985a, p. 92)

The second prominence-adjacent phenomenon is that onsets in certain positions can be strengthened, such that the syllable boundary at the beginning of an iambic foot is phonetically similar to a word boundary (Leer 1985a:83-87). This is referred to as *onset fortition.*

(14) Onset fortification in words with light syllables (Leer, 1985a):
a. **(p**ə̥.ˈnaq)
‘cliff’ (Leer, 1985a, p. 104)
b. **(p**i.ˈsu).*qu*.(**t**a.ˈqu).*ni*
‘if he is going to hunt’ (Leer, 1985a, p. 113)
c. **(m**a.ˈŋaʁ).*su*.(**q**u.ˈta).(**q**u.ˈni)
‘if he is going to hunt porpoise’ (Leer, 1985a, p. 113)

In the examples in (14), onsets targeted by fortition are marked in bold. Leer (1985a) describes the acoustic correlates of this consonant fortition as a complete lack of voicing in voiceless consonants (oral/nasal stops and voiceless fricatives), and preclosure[18]. However, it is

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[17] This is true of Kodiak Alutiiq as well. Unlike in Chugach, however, Kodiak syllables cannot bear an L tone, except IP-finally (Leer, 1985d, 1994).

[18] Preclosure is similar to gemination, but where the gemination of a following consonant closes the syllable, the preclosure associated with a fortis consonant belongs to the syllable headed by the fortis consonant, or otherwise to the syllable boundary itself (Leer, 1985c). This leads to a three-way distinction between fortis, lenis, and geminates.

worth noting that Leer (1985c) retroactively softens his previous claims, emphasizing that the expression of fortition varies by variety, region, and speaker. For the purposes of this study, we are only interested in whether fortition is measurably present at foot boundaries and how the production of fortition interacts with (and differs from) gemination, not in the precise details of its articulation.

Lastly, the third prominence-adjacent phenomenon referred to in the literature is *additional lengthening*. Leer (1985b, c) attests that certain stressed syllables are longer than others, so that the longer stressed syllables are referred to as 'additionally lengthened'. To be exact, Leer claims that open, stressed syllables of disyllabic feet are lengthened by a vowel mora (1985b:136-139). According to Leer (1985c:164), the origin of this additional lengthening is the interaction of foot structure with higher-order prosody, such that a syllable can be the head of both a foot and a higher-order prosodic structure (in Leer's case, the superfoot or pitch group). In this case, that syllable will be produced distinctively from another stressed syllable.

(15) Additional lengthening
(Leer, 1985c:164):
a. a.ˈkuː.taq
'Alutiiq ice cream (ABSOLUTIVE)'
b. a.ˈkuˑ.ta.ˈmek
'Alutiiq ice cream (ABLATIVE)'

In the examples in (15), when comparing the durations of the second syllables of each word, the underlyingly short syllable *ku* in both words is lengthened by nature of its position as iambic head. However, *ku* in (a) surfaces as longer in duration than the equivalent *ku* in (b), although both are stressed and in similar, though not identical, environments. Leer states that the stressed syllable in (a) receives additional lengthening, indicated by the length diacritic [ː], while the equivalent syllable in (b) is not quite as long. In other words, the second syllable in (b) is still lengthened by stress, as indicated by the half-length diacritic [ˑ]. However, this syllable, while longer than any unstressed syllables, is not as long as the additionally lengthened equivalent syllable in (15a). This

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We see on the surface phonetic level three lengths of vowels (short, long, and lengthened) and three inversely corresponding lengths of consonants (short, preclosed, and geminated); see section 4.4 for further discussion.

points to a distinction among stressed syllables wherein some are afforded additional lengthening on top of their regular stress expression, and others are not. Note that this effect is distinct from the impressionaistic descriptions of rightmost primary stress in Yup'ik: the distribution of additional lengthening is determined by ternary syllable spans (see Section 3.1.3.), as opposed to right-edge proximity.

In sum, length in Alutiiq is complex. In addition to the phonemic distinction between short and long vowels, vowels in stressed positions, which already receive length as a correlate of stress, may receive further additional lengthening. Leer creates a set of rules to govern where stressed syllables receive additional lengthening. Alternate accounts assert that only syllables that do not precede fortified consonants can be lengthened (Hayes 1995), and others still attest that this additional lengthening targets ternary foot constructions and is therefore related to syllable skipping, as discussed in the next section (Martínez-Paricio & Kager 2017). However, the exact nature and distribution of this additional lengthening is unclear: to date, no acoustic studies have corroborated Leer's observations.

3.1.3. Metrical Analysis of Alutiiq Phonology

Alutiiq belongs to the small percentage of stress languages that iteratively generate ternary feet. Within this small group, it is further set apart by two characteristics (see Houghton, 2006, for a discussion of ternary footing in Alutiiq, Bangla, Cayuvava, Estonian, and Winnebago). First, where many of these language are only able to construct ternary feet, Chugach Alutiiq is able to generate both binary and ternary feet in sequence with one another. Secondly, it has been proposed that Chugach Alutiiq's ternary feet are internally layered: there is a distinction between the encompassing maximal foot and the internal minimal foot, $((\sigma\ \sigma)_{\text{MIN}}\ \sigma)_{\text{MAX}}$ (see below), as opposed to a flat ternary foot (σ σ σ).

The first to propose a ternary footing span was Leer, in his proposal that binary feet are capable of forming 'superfeet' with skipped syllables (see Leer, 1985c, 1994). It should be noted that Leer's superfoot was conceptualized as a level in the prosodic hierarchy rather than a foot type; it is more accurate to say that in the superfoot model, binary feet and skipped syllables form units on the superfoot level (see Leer 1985c, 1994).[19]

Other relevant works include Hayes, (1995); Hewitt, (1992); Hewitt & Ann, (1991); Hyde, (2001, 2002); Kager, (1993); Martínez-Paricio, (2013); Martínez-Paricio & Kager, (2016); and Rice, (1992). These reinterpretations of the original account as given in Leer (1985a, 1985b) seek to economize the description of the prosodic system along the same lines as Leer (1985c). That is, they assume either at least one intermediary level of prosody between the syllable and the word (Leer, 1985c; Hewitt, 1991, 1992; Hyde, 2001, 2002; Martínez-Paricio, 2013; Martínez-Paricio & Kager, 2016; Rice, 1992) or an additional recursive process that allows for the construction of ternary feet (Kager, 1993; Hayes, 1995). Of these, the framework that accounts for the most stress-related phenomena, including syllable skipping, onset fortition, and tone distribution in Chugach Alutiiq, is that proposed in Martínez-Paricio & Kager (2016).

Martínez-Paricio & Kager (2016) propose an account of Chugach Alutiiq footing that revives the hypotheses laid out in Prince (1980) and Selkirk et al. (1980): namely, that feet may be trisyllabic so long as they are internally layered and binary branching. In Chugach Alutiiq, these ternary feet are internally layered, such that they contain a binary foot within the ternary boundaries, and binary branching, such that the monomoraic adjunct syllable attaches to the right side of the iambic head. This ternary construction is referred to as an *Internally Layered Ternary* foot (henceforth ILT). In constructions made up only of light syllables, the juxtaposition of ternary feet interspersed with disyllabic iambs gives rise to Leer's (1985a, b) observed pattern of syllable 'skipping'. In this schema, the skipped syllables that Leer (1994) left as 'stray' (cf. Table 21) become adjuncts to a binary foot:

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[19] At various times, Leer proposes two different prosodic layers above the foot and below the word: the superfoot (1985c) and the pitch group (1985c, 1994). They are distinct insofar as the superfoot is a structure that contains an unfooted syllable and an iamb, whereas a pitch group is a sequence of two sequential iambs. The superfoot was proposed as an explanation for syllable skipping/accent advancement, while the pitch group is Leer's proposal for upstepping.

(16) ILT foot: $[((\sigma\ \sigma)_{\mathrm{FT}}\sigma)_{\mathrm{FT'}}]\omega$

(a) *akutaq* ((a.ˈku).taq)
‘a food-ABSOLUTIVE’
(b) *pisuqutaquni* ((pi.ˈsu).qu)((ta.ˈqu).ni)
‘if he is going to hunt’
(c) *mangarsuqutaquni* ((ma.ˈŋaʁ).su).(qu.ˈta).(qu.ˈni)
‘if he is going to hunt porpoise’

In (16), (a) demonstrates a word which contains a single ILT foot; in the ILT model, the syllable *taq* is an adjunct to the foot containing the first two syllables instead of being analyzed as unparsed or ‘skipped’. (b) is composed of two sequential ILT feet. (c) demonstrates that ILT feet can co-exist with simple binary feet within the same word; in terms of syllable skipping, the syllable *su* would be the skipped syllable. With ILT footing, however, it is clear that this syllable is contained within a layered, branching constituent, and is therefore not actually skipped, but rather accounted for in a more complex metrical structure. Unlike other types of layered (or ‘resolved’) feet, such as those identified in Dresher & Lahiri (1991) and Rice (1992), ILT feet are not flat with respect to prominence: while other accounts of layered feet presume that the obligatory syllables that make up the binary ‘nested’ foot are ‘flat’ relative to one another, in Chugach Alutiiq, the ILT’s innermost foot is described as a proper foot, consisting of a dependent and foot head.

For Martínez-Paricio & Kager (2016), foot construction is dependent on the number of syllables in the prosodic word. Disyllabic words are footed as iambs, as in a. in Table 4. In words with 3n syllables, in order to avoid leaving any one syllable unparsed, ternary feet are built iteratively starting at the left edge (see b. in Table 24 below). However, if there are 2n syllables between the first ILT foot and the right edge of the word, binarity is favored over ternarity, so as to avoid leaving one syllable unparsed or in a degenerate foot (see c. in Table 24). Lastly, if an ILT foot is constructed on the first three syllables of a word, and an even number of syllables remain between it and the right edge, simple iambs are built on the remaining syllable (see (d) in Table 24).

Table 24: ILT foot construction, adapted from Martínez-Paricio & Kager (2017:5).

Number of syllables	Example	Source (Leer 1985a)
a. 2	(pə̥.ˈn̥aq) ‘cliff’	p. 104
b. 3n	((a.ˈku).taq) ‘a food (ABSOLUTIVE)’	p. 84
	((pi.ˈsu).qu)((ta.ˈqu).ni) ‘if he is going to hunt’	p.113
c. 3n+1	(a.ˈku).(ta.ˈmək) ‘a food (ABLATIVE SG)’	p. 84
	((ma.ˈŋaʁ).su).(qu.ˈta).(qu.ˈni) ‘if he is going to hunt porpoise’	p.113
d. 3n+2	((a.ˈtu).qu).(ni.ˈki) ‘if he uses them’	p. 113

To compare, Leer (1994a) would foot *pisuqutaquni* ‘if he is going to hunt’ ((b) in the table above) as /(**p**i.ˈsu).qu.(**t**a.ˈqu).ni/, where *qu* and *ni* are left stray. This demonstrates an advantage of the Martínez-Paricio & Kager account, under the assumptions of metrical stress theory: namely, that it manages to satisfy exhaustivity while still acknowledging the ‘weak’ status of adjunct syllables. The Martínez-Paricio & Kager proposition requires the distinction only between the non-minimal foot (i.e. a foot that dominates another foot; an ILT foot) and the minimal foot (a simple binary foot)[20], both of which follow the same fundamental behaviors as traditional feet.

Martínez-Paricio & Kager assert that, in regards to heavy syllables, the Weight-to-Stress principle applies within the ILT framework. Heavy feet are always bimoraic, making a monosyllabic heavy foot in any position a valid minimal foot for the purposes of ILT foot construction. In these two examples, an ILT foot is constructed with a monosyllabic heavy foot occupying the minimal foot position: *an* in (17), heavy due to its closure and position, and *na:* in (18), heavy due to its vowel length.

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[20] The terms ‘minimal’ and ‘non-minimal’ are borrowed from Itô & Mester (2007, 2009, 2013).

(17) *anciqua* ((ˈan).tʃi).(ˈqua)
'I'll go out'

(18) *naaqumaluku* ((ˈnaː).qu)((ma.ˈlu)ku)
'apparently reading it'

One of the strongest aspects of the ILT model is its ability to account for the non-stress metrical phenomena of Alutiiq discussed in section 3.1.2 above. Firstly, for onset fortition, ILT feet share a major advantage with Leer's (1985c) superfoot: namely, that the ternary construction allows for the prediction of foot-initial fortition, where it is assumed that the left edge of every foot is the target of said fortition. For example in (19), (20), and (21), fortified onsets are marked in bold. Each aligns with the left edge of a foot, either an ILT foot or a minimal iamb. Notably, the 'skipped' (or unfooted) syllables, here the rightward adjuncts of a binary foot, do not have fortified onsets, and are instead immediately followed by them.

(19) *penaq* (**pə**.ˈnaq)
'cliff'

(20) *pisuqutaquni* ((**p**i.ˈsu).qu)((**t**a.ˈqu)ni)
'if he is going to hunt'

(21) *mangarsuqutaquni* ((**m**a.ˈŋaʁ).su)(**q**u.ˈta)(**q**u.ˈni)
'if he is going to hunt porpoise'

Secondly, the ILT foot proposal accounts for additional lengthening as it is described by Leer (1985a): additional lengthening is given to any syllable that heads an ILT foot. Compare the examples in (15) again, this time with ILT-style footing, as shown in (22).

(22) a. ((a.ˈkuː)taq)
b. (a.ˈku)(ta.ˈmək)

Here it is clear that the syllable *ku* in *akutaq* is the head of two foot projections: a minimal (binary) and non-minimal (binary + adjunct) foot ((Martínez-Paricio, 2012). This is the reason that *ku* attracts additional lengthening in (22), but not (22). This analysis further accounts for all additionally lengthened stressed syllables in Chugach Alutiiq as described by Leer (1985b, 1994). This analysis asserts that the three-way length distinction among underlyingly short vowels—between those that are unstressed; those that are stressed; and those that are stressed and lengthened—is metrically motivated.

Turning then to tone, the ILT is the only one of the various ternary foot types that have been proposed for Chugach Alutiiq that both accounts for H upstepping (¡H) and predicts the assignment of L tones without assuming a custom level above the foot. To illustrate this analysis, consider the examples in (23) and (24). In Chugach Alutiiq, upstepping occurs where two H tones occur in sequence, with no intervening L tones. Upstepping will not affect an H if the preceding H is already upstepped. Therefore, upstepping can be interpreted as an effect of the Obligatory Contour Principle (OCP), as suggested by Hewitt (1991), avoiding consecutive identical features by distinguishing H tones in sequence. Compare *anciqua* 'I'll go out' and *taataqa* 'my father':

(23) ((ˈan).tʃi).(ˈqua)
H L H
(24) (ˈtaː).(ta.ˈqa)
H ¡H

Both of these words contain three syllables, the first of which is heavy (bimoraic, constituting its own foot) and the second of which is light. An ILT foot, headed by a monosyllabic heavy foot, is formed in (23) because its third syllable is heavy, whereas a monosyllabic heavy foot and a disyllabic iamb are formed in (24), as its third syllable is light.[21] Accordingly, (23) has an L tone that intervenes between the H tones, and so the second H tone is not upstepped, while (24) has no intervening tone, and so the second H tone is upstepped. The footing of these two words demonstrates how L tones only dock onto unstressed syllables in adjunct positions that are directly dominated by a ternary foot, i.e. skipped syllables, while no specific tone is assigned to immediate dependents of a binary foot (Martínez-Paricio & Kager, 2016). Under this analysis, an L tone

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[21] If an ILT foot were present in *taataqa*, the foot structure would be *((taː)ta)qa*, violating exhaustivity. As demonstrated in this section, we would also expect a L tone on *ta*, which is not present in the surface form (that there is no L is further evidenced by the presence of upstepping, which would not occur if an L were present). The form given in the example is the most economical, and also explains the upstepped H on *qa* and the distribution of the fortified consonants that begin the syllables *taː* and *ta*.

cannot occur in a word that does not contain an ILT foot. In this way, the ILT foot predicts the distribution of L tones by distinguishing between types of foot dependents: those that are dominated by a non-minimal foot and those that are dependents of a minimal foot. Furthermore, upstep is not the result of higher-order prosody, but rather a natural process of dissimilation resulting from the binary branching of the ILT foot.

In summary, Martínez-Paricio & Kager's binary-ternary analysis of Chugach Alutiiq has three significant strengths that it shares in part with the analyses of other authors, including:

1. A strictly bimoraic foot (here, the minimal binary foot; also see the Foot in Leer, 1985c, and Hewitt, 1991, 1992);
2. Some type of recursive prosodic layer between the foot and the word to account for other metrical phenomena like tone and onset fortition (here, the ILT foot; also see the superfoot in Leer, 1985c; the bounded prosodic word in Hewitt, 1991, 1992);
3. Monomoraic righthand adjuncts in recursive categories.

Furthermore, this analysis manages to avoid two major pitfalls that other accounts face: non-unique heads (the flattened heads of Rice's, 1992, layered feet; the ambipodal syllables in Hyde, 2001, 2002) and superfluous categories (Pitch Group in Leer, 1985c; the maximal minimal word in Hewitt, 1991, 1992; flat surface feet in Kager, 1993). Of all of the proposals of Alutiiq stress models, the ILT foot is the most economical and accounts for the most data, and for this reason, the ILT framework was adopted as the predictive metrical model for the acoustic analyses presented in this article.

3.1.4. Hypotheses

To date, there have been no acoustic studies of Alutiiq stress production or other metrical phenomena. Studies on related languages, namely Central Alaskan Yup'ik and Central Siberian Yupik, have pointed to a ternary distinction in production between unstressed short, stressed short, and long vowels (Alden & Arnhold, submitted; Koo & Badten, 1974a). The same could be expected for Alutiiq, as hypothesized in (25a) below. Alutiiq, however, with its ternary footing and phonology that affects duration and F0 (additional lengthening, compression, and tone), has a more complex metrical structure than other Yupik languages (also compare the overview by Woodbury, 1984). The goal of this study, therefore, is to examine the effect of foot structure on the acoustics of Alutiiq syllables. A syllable's nucleus can be made more prominent by increasing its duration, increasing its amplitude, raising its pitch, or any combination thereof (Gordon & Roettger, 2017). Therefore, we predict that stressed syllables are made distinct from unstressed syllables via one or more acoustic correlates, including duration (25b), intensity (25c), and F0 (25d). Regarding F0, we investigated F0 maxima specifically (25d) to examine descriptions that stress is accompanied by a higher F0 (Leer, 1985a:92).

If it is true that long and short stressed vowels are equally affected by compression, then the length contrast between both vowel types and unstressed short vowels will be neutralized (25e). If additional lengthening is both meaningfully distinct from regular stress lengthening and associated with the heads of ILT feet, then we expect a significant difference in duration, and possibly other measures, between additionally lengthened vowels that are maximal (ILT) foot heads and stressed vowels that are minimal (iambic) foot heads (25f). Moreover, regarding length, if it is true that compression affects both underlyingly long vowels and vowels lengthened by stress, then we expect to see the durations of both types of vowels significantly shortened in closed and word-final syllables compared to all other environments. If it is true that tone is associated with positions within metrical feet, then we expect the F0 of syllables in the head position to be associated with H and ¡H tones and syllables in the adjunct position to be associated L tones. Furthermore, we expect that the three tone categories, H, ¡H, and L, to be distinct in terms of F0 (25). Finally, if onsets are fortified word-initially, and this fortification is observable in duration, then we expect that foot-initial onsets will surface as longer than non-initial onsets (15h).

Therefore, our hypotheses regarding the acoustic correlates of the metrical phenomena of Alutiiq are as follows:

(25) Hypothesis for the acoustic study of Alutiiq metrics

a. $H_{VowelLength}$: There is an acoustic distinction between long, stressed-short, and unstressed-short vowels, such that underlyingly long vowels are distinct from underlyingly short vowels, and the acoustic values of short vowels are increased by the presence of stress.

b. H_{DUR}: The presence of stress significantly increases the duration of a syllable's nucleus.

c. H_{INT}: The presence of stress significantly increases the intensity of a syllable's nucleus.

d. H_{F0MAX}: The presence of stress significantly increases the maximum F0 of a syllable's nucleus.

e. $H_{Compression}$: Compressed stressed vowels are shorter than non-compressed stressed vowels. Furthermore, the duration distinction between long vowels in a compression environment and short vowels is neutralized.

f. $H_{AddLength}$: There is an acoustic distinction between the heads of ILT feet and iambic feet, such that the head of an ILT foot has a significantly longer nucleus.

g. H_{Tone}: The presence of stress significantly alters the maximum F0 of a syllable's nucleus, such that there are three distinct tone categories (H, ¡H, and L).

h. H_{Onset}: A foot-initial onset is significantly longer than a non-initial onset.

Results of acoustic analyses assessing hypotheses (25) appear in section 3.3, while analyses testing hypotheses (25) are presented in section 3.4.

3.2. Materials and Methods

A set of recordings from the Alaska Native Language Archive were chosen for annotation (*Alaska Native Language Archive*, n.d.). The recordings were selected because they are available for public download, are high quality, and have written transcriptions. They included seven narratives from the Alaska Native Language Center's first Alutiiq publication, *Sugcestun Unigkuat* (or *Unigkua'it Paluwigmiut Nanwalegmiut-hlu*), collected from the people of Port Graham, AK, and recorded with speaker Derenty Tabios[22] (recording ANLA identifier: AS018, text ANLA identifier SUC972TL1973) (Tabios & Meganack, 1972). Due to the general scarcity of digitized recordings of Chugach Alutiiq, these narratives represent the only materials currently available in ANLA that are both transcribed by speakers and of a high enough quality for acoustic analysis.

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[22] Currently, some metadata surrounding these recordings is unclear. They were deposited into the archive as cassettes in the Leer Koniag Audio Collection, and were then digitized and made available through the archive web portal. Archive descriptions state that the speaker was mostly likely Derenty Tabios. As contributors to the stories, Sergus and Margaret Moonin and Walter Meganack are also credited with the production of the recordings.

The recordings were annotated in Praat (Boersma & Weenink, 2020) by the first author. The annotation tiers included the entire intonational phrase (IP), the word level, the syllable level, and the segment level. The criteria for isolating vowels included the onset of frication in the surrounding consonants and movement in the higher vowel formants (Turk et al., 2012). IP boundaries were determined by pauses between words, combined with clause- and sentence-denoting punctuation in the transcription. A word in isolation was defined as an IP unto itself.

The resultant dataset was composed of 719 IPs, 465 words ranging in length from one to eight syllables, 2,235 vowels, and 2,720 onset consonants. The distribution of vowels by stress, phonemic length, and syllable number of the containing word is given in Table 25

Table 25: Distribution of vowels by stress and phonemic length, and by the length of the containing word (in number of syllables).

Vowel	Quantity
Stressed Long	286
Stressed Short	891
Unstressed Short	1058
Word Length	**Quantity**
1σ	55
2σ	1154
3σ	1451
4σ	1471
5σ	1161
6σ	422
7σ	183
8σ	32

After annotation, underlying forms were derived based on orthography. Alutiiq orthography was designed to be phonemic, and so it was appropriate to begin reconstructing underlying forms from spelling. It should be noted that metadata surrounding the creation of the recordings is scarce; it is unclear exactly when the materials were made or what the state of Alutiiq orthography was at the time. While this did not affect the majority of segments, some specific phones, such as schwas and voicing distinctions among certain fricatives, were inconsistent with the modern writing system. Most of the time, the differences are minor representational changes, such as writing /ɬ/ as <hl> rather than <ll>. Sometimes, however, the difference in spelling has larger implications for the underlying form and its relationship to the surface form. For example, the word for 'see it' is written in the texts as *tangehrluku*, implying that the schwa surfaces and that the fricative <r> is devoiced. In modern orthography, this same word is written as *tang'rlluku,* closer to its production as [taŋʁɬuku], with the deleted schwa elided and the voicelessness associated with the /ʁl/ sequence accurately assigned to the approximant [ɬ] rather than the fricative [ʁ]. Where such orthographic discrepancies occurred, then, Qalirneq (English: Ivana Ash), a Chugach Alutiiq speaker from Nanwalek, AK, was consulted and the sound-spelling relationship, clarified.

Once underlying forms were determined, Martínez-Paricio & Kager's (2017) ILT model was applied to each word in the dataset (see section 3.1.3). The result of this process was that each vowel segment was assigned a label for stress (stressed/unstressed), additional lengthening (lengthened/not lengthened), and tone (H/¡H/L/N). Onset consonants were classified with respect to onset fortition (fortified/not fortified). These assignments were then corroborated with Qalirneq, who also consulted on translations, morphemic sequencing, and clarifying unclear words in the recordings.

Measurements were taken via a Praat script that recorded duration (in ms), intensity (in dB), and maximum fundamental frequency (F0; in Hz) (Arnhold, 2018). The F0 measure was then converted to semitones (ST) relative to a reference value of 100 Hz.

3.3. Stress Correlate Results

This section presents results regarding the potential acoustic correlates of stress, namely duration (section 3.3.1), intensity (section 3.3.2) and F0 (section 3.3.3). The goal of each of these analyses is to explore the hypotheses presented in (25a-d). Hypothesis (25b-d) correspond to each of these acoustic measured evaluated, while (25a), which asserts that length distinctions are preserved in stress environments, will be examined based on the results of the three correlate substudies together.

Each measure was separately analyzed as a dependent variable in linear mixed-effects modeling using the package lme4 in R (Baayen et al., 2008; Bates et al., 2015, 2020; R Core Team, 2020). The best models reported below for each dependent variable were chosen to be only as complex as justified by an improved fit to the data (Matuschek et al., 2017). Model selection began with a model containing only the most relevant predictor, the stress-length distinction (stressed long, stressed short, and unstressed short), as a fixed effect, with file and phoneme as the random intercepts. When coding phonemes in vowels, diphthongs were coded for the quality of their first segment, e.g. /au/ was simplified to /a/, but retained its long specification.

The predictor variables were then forward fitted and added to the model if they were shown to improve model fit via ANOVA comparison between models with or without each added variable. The predictor variables tested in each model included syllable position (calculated as the distance from the left edge); whether the vowel was compressed; IP position (final/non-final); and whether there was an onset or coda present. Tone could not be included as a fixed-effects variable in models of duration, intensity or F0, as tone (especially H/¡H) is determined exclusively by stress, meaning both variables are highly correlated and could not appear in the same model. Therefore, results accessing F0 correlates of tone are presented separately in Section 3.4.3. Similarly, compression and additional lengthening only apply to stressed vowels, and so results for acoustic correlates of each are presenting in 4.1 and 4.2, respectively.

The random effects included in each model included file and phoneme. By-subjects random slopes for each of the predictor variables were tested for each of the random effects in the models. However, none of the models with random slopes converged. Finally, we tested whether all random intercepts significantly contributed to model fit via backwards-fitting and simplified models where appropriate. The fixed effects for each resulting best model are specified in the individual subsections below. After model selection, the residuals were plotted and datapoints with residuals more than 2.5 standard deviations from zero were trimmed. Information about the number of trimmed data points for each model is presented in the table captions for each model. P-values for fixed effects were obtained with the package lmerTest (Kuznetsova et al., 2017).

3.3.1. Duration

Table 26 shows the fixed effects of the best model for duration. All tested predictor (fixed-effects) variables improved model fit and were included in the final duration model. The intercept for the model in Table 26 is a short, stressed vowel which is the sole syllable of a monosyllabic word, is not IP-final, and has both an onset and coda (CVC). All other factor levels are compared to the intercept.

Table 26: Fixed effects summary of best linear mixed-effects model of duration (in ms). Trimming removed 44 data points (1.92%).

Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept	52.9843	7.2996	3.3117	7.2585	0.0038
Vowel Length (Long Vowel, Stressed)	32.7295	1.9358	2172.705	16.9077	<2e-16
Vowel Length (Short Vowel, Unstressed)	-12.7909	1.3765	2172.1648	-9.292	<2e-16
2σ from Left	28.3486	1.6592	2171.5632	17.0857	<2e-16
3σ from Left	27.2611	1.7953	2174.585	15.1845	<2e-16
4σ from Left	27.7427	2.1274	2176.3537	13.0409	<2e-16
5σ from Left	24.7742	2.8146	2177.0671	8.802	<2e-16
6σ from Left	34.6765	4.4638	2172.5751	7.7683	1.22E-14
7σ from Left	22.0627	8.2384	2171.1687	2.678	0.0075
8σ from Left	-0.6935	18.9154	2174.0411	-0.0367	0.9708
IP Position (Final)	3.1465	1.7908	2175.0495	1.757	0.0791
Onset (No onset)	6.3223	2.1302	2172.3197	2.9679	0.003
Coda (No coda)	21.866	1.4228	2177.2928	15.368	<2e-16

The top section of Table 26 shows the results for the general effect of stress and length on vowel duration. There is a significant difference in duration among stressed short and long vowels, such that long vowels are longer than stressed short vowels. There is further a distinction between stressed short and unstressed short vowels, with unstressed short vowels being significantly shorter. The range of durations for each stress-length type is differs, but all of the categories overlap to some degree, as illustrated in Figure 9.

The bottom section of Table 26 shows how the non-metrical characteristics of syllables affect duration. Distance from the left edge consistently had a significant effect, such that syllables further from the left edge (or, alternatively, closer to the right edge) became longer. This effect was significant up to seven syllables away compared to the first syllable. Most likely, the comparison with the eighth syllable was not significant due to a relative lack of such exceptionally long words (recall Table 25). Phrase position significantly affected duration, with the vowels of IP-final syllables surfacing as longer than non-final vowels. The presence of both an onset and a coda affected duration, such that vowels without an onset were longer than those with one, and vowels in open syllables were longer than those in closed syllables.

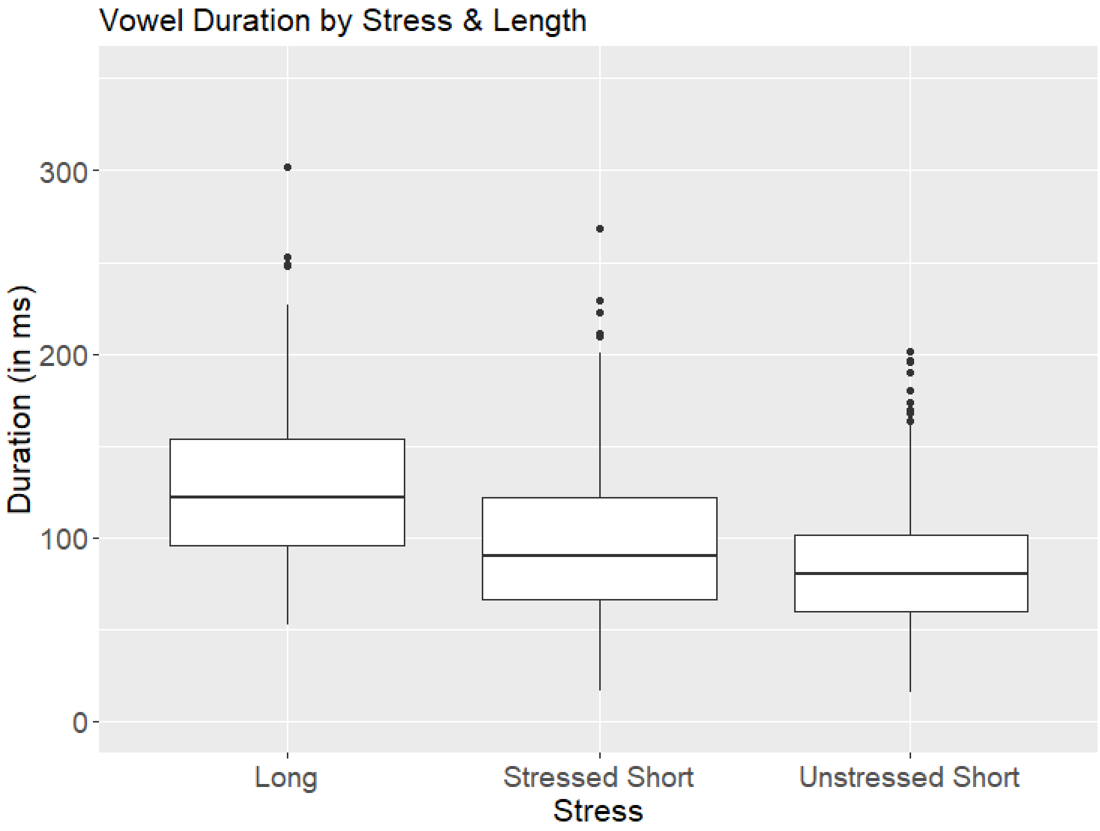

Figure 9: Boxplot of the vowel durations for each of three different stress-length combinations.

3.3.2. Intensity

All of the tested fixed effects improved model fit for intensity; however, word length was excluded following backwards-testing. As indicated by the final model, intensity was significantly affected by underlying length, such that stressed long vowels were significantly louder than stressed short vowels (cf. Table 27). Intensity was also affected by stress: unstressed short vowels were quieter than stressed short vowels (see Figure 10).

Table 27: Fixed effects summary of best linear mixed-effects model of intensity (in dB). Trimming removed 30 data points (1.34%).

Intensity Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept	68.7405	0.6882	4.9635	99.8905	2.16E-09
Vowel Length (Long Vowel, Stressed)	1.9127	0.2572	2187.9845	7.4373	1.47E-13
Vowel Length (Short Vowel, Unstressed)	-1.3514	0.1863	2184.5074	-7.2519	5.68E-13
2σ from Left	2.0777	0.2238	2184.5011	9.2833	<2e-16
3σ from Left	0.5051	0.2418	2185.3763	2.089	0.0368
4σ from Left	-0.8452	0.2853	2187.0393	-2.9627	0.0031
5σ from Left	-1.9048	0.3814	2188.0556	-4.9948	6.36E-07
6σ from Left	-2.619	0.6107	2184.9836	-4.2882	1.88E-05
7σ from Left	-2.6123	1.1143	2184.0554	-2.3444	0.0191
8σ from Left	-4.3821	2.56	2184.742	-1.7118	0.0871
IP Position (Final)	-2.4255	0.2405	2186.7565	-10.086	<2e-16
Onset (No onset)	-2.646	0.2922	2185.1006	-9.0542	<2e-16
Coda (No coda)	0.7448	0.1917	2175.3522	3.8851	1.00E-04

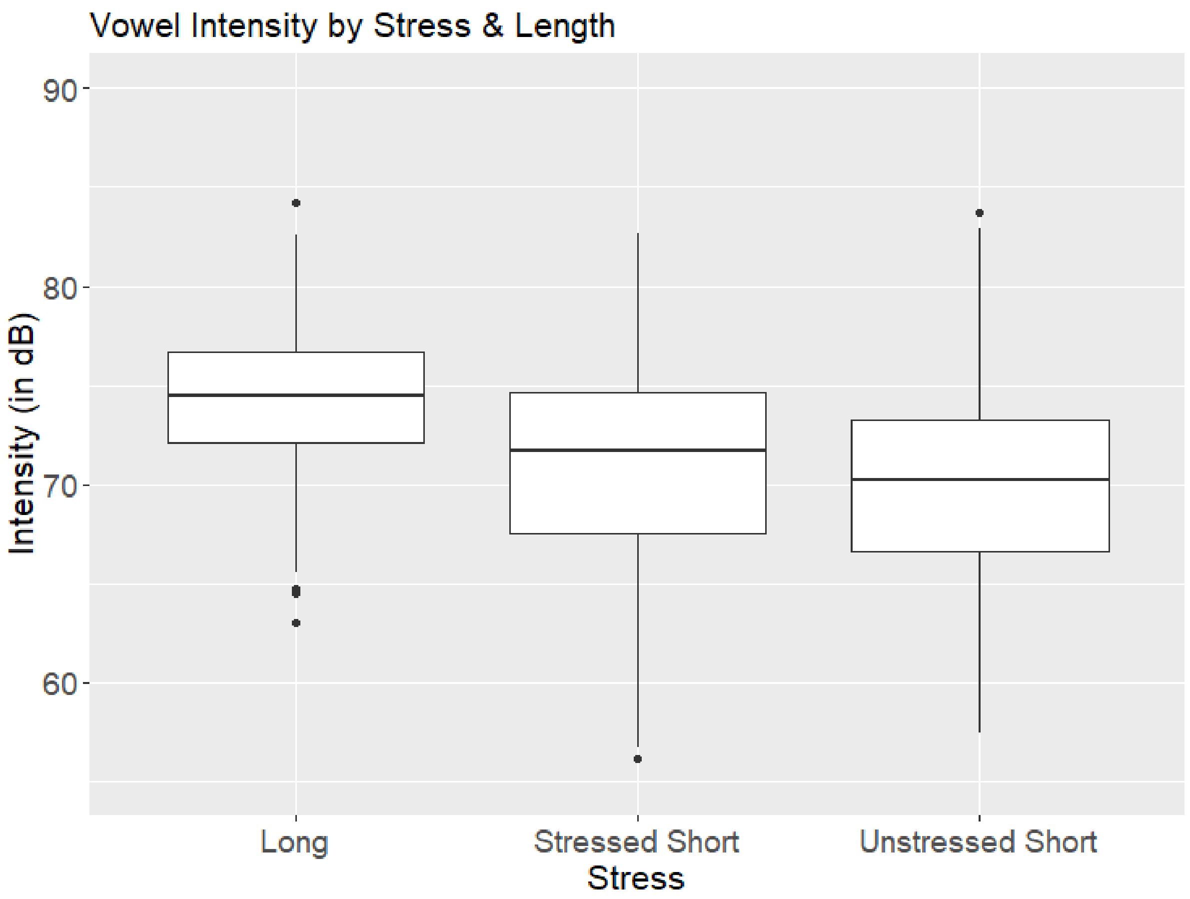

Figure 10: Boxplot of the vowel intensities for each of three different stress-length combinations.

In terms of syllable characteristics, distance from the left edge always affected intensity, such that, based on the model estimates, syllables seemed to peak in intensity near the left edge and then taper off. The second and third syllable had significantly higher intensity than the first, whereas following syllables had significantly lower intensity (except, again, the eighth syllable, which was represented by few instances in the data set). Unsurprisingly, IP-final vowels were significantly quieter than non-final vowels. Lastly, the presence of an onset or a coda significantly affected the intensity of that syllable's vowel, where a vowel in a syllable without an onset was quieter than a vowel in a syllable with one, and a vowel not followed by a coda was louder than one that was followed by a coda.

3.3.3. Maximum F0

For the maximum F0 model, IP finality, and the presence of an onset did not significantly improve model fit and were excluded from the final model; see Table 28. While adding word length did initially improve model fit, it was excluded after backwards-testing. Note that due to missing values due to non-modal voice quality, the dataset used here was composed of 2072 vowels, rather than the full 2235 of the duration and intensity models.

Table 28: Fixed effects summary of best linear mixed-effects model of maximum F0 (in ST). Trimming removed 34 data points (1.64%).

Maximum F0 Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept	1.7526	0.2132	25.5884	8.2192	1.20E-08
Vowel Length (Long Vowel, Stressed)	1.0538	0.1938	2016.7382	5.4376	6.05E-08
Vowel Length (Short Vowel, Unstressed)	-0.4755	0.1416	2008.265	-3.3586	8.00E-04
2σ from Left	0.4493	0.161	1995.1168	2.7912	0.0053
3σ from Left	-0.3828	0.1785	1914.8245	-2.1444	0.0321
4σ from Left	-1.1779	0.2118	1838.6389	-5.5611	3.07E-08
5σ from Left	-2.2856	0.2876	1804.8101	-7.9458	3.37E-15
6σ from Left	-2.147	0.4563	1976.103	-4.7048	2.72E-06
7σ from Left	-3.0933	0.9079	2017.9543	-3.4072	7.00E-04
8σ from Left	-2.9439	1.9056	2019.3041	-1.5449	0.1225
Coda (No coda)	-0.1869	0.1364	717.5339	-1.3699	0.1711

Table 28 shows that long vowels were significantly higher in F0 and unstressed short vowels are significantly lower in F0 compared to the intercept, short stressed vowels, as illustrated in Figure 11. Similar to the results in Section 3.1, there is considerable overlap among the boxplots, but their median lines are distinct.

Figure 11: Boxplot of the vowel maximum F0s for each of three different stress-length combinations.

The lower portion of Table 28 shows that distance from the left edge was significant for nearly all syllables (except 2σ and 8σ from the left), indicating a consecutive lowering of pitch the further away the syllable is. Lastly, the absence of a coda did not significantly affect maximum F0, although the inclusion of this predictor improved model fit.

3.4. Other Metrical Phenomena

The results given in Section 3.3 describe the general behaviors of the three potential correlates of stress in Alutiiq. This section concentrates on processes that further affect how vowels surface, such as compression, and the non-stress metrical phenomena associated with footing. Section 3.4.1 examines compressed and uncompressed stressed vowels in terms of duration. Section 3.4.2 presents the results for comparing additionally lengthened stresses and non-additionally lengthened stresses in terms of duration, intensity, and F0. Section 3.4.3 shows the results for duration, intensity, and F0 among the four tone categories described in the literature.

Finally, Section 3.4.4 examines duration differences among onsets that are simple, fortified and geminated.

The statistical analysis methods for these sub-studies were the same as for the models presented in section 3.3, except for the variables tested. The sections below list the tested fixed effects for each reported model. For models that tested interactions between two factors, where those interactions were significant, pairwise comparisons were performed with the lsmeans function from the package emmeans (Lenth et al., 2022), using the Tukey method for p-value adjustments and the (default) Kenward-Roger method for calculating degrees of freedom.

3.4.1. Compression in Stressed Vowels

That duration appears to indicate both stress and underlying length, as reported in section 3.3.1, is a surprising result given Alutiiq's tendency to compress long and stress-lengthened short vowels in closed syllables or word finally, as described by Leer (1985b). It is not clear from the results in 3.1, however, how this compression affects vowel duration. Leer's descriptions of compression state that length of stressed vowels in closed and word-final syllables is reduced to such a degree that the distinction between long, lengthened, and short (i.e. unstressed) vowels is neutralized. The goal of this section is then to explore the hypothesis given in (25e): compressed stressed vowels are shorter than non-compressed stressed vowels, and moreover, compression neutralizes the difference between unstressed and compressed stressed vowels. If length distinctions are neutralized by compression, such that both long and stress-lengthened vowels are shortened to the duration of an unstressed short vowel, then we expect there to be no significant difference in duration between compressed vowels and unstressed short vowels.

In order to address both parts of this hypothesis, a simple linear mixed-effects model was run. This model contained only a predictor variable that encoded stress, length, and compression (Stressed-Long-Compressed, Stressed-Long-Uncompressed, Stressed-Short-Compressed, Stressed-Short-Uncompressed, and Unstressed-Short). The model was first fit with a stressed, long, compressed vowel as the intercept and then releveled around a stressed, short, compressed intercept. The fixed effects for each model are given in Table 29 and Table 30, respectively.

Table 29: Fixed effects summary of linear mixed-effects model of vowel length and compression. Trimming removed 34 data points (1.52%).

Stress-Length-Compression Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Long Compressed)	101.619	8.742	3.556	11.625	0.00059
Stressed Long Uncompressed	26.239	3.587	2193.156	7.315	3.60E-13
Stressed Short Compressed	-20.896	2.889	2193.671	-7.233	6.49E-13
Stressed Short Uncompressed	5.821	3.26	2193.063	1.786	0.07429
Unstressed Short	-25.722	2.788	2193.424	-9.227	<2E-16

Table 30: Fixed effects summary of linear mixed-effects model of vowel length and compression. Trimming removed 34 data points (1.52%).

Stress-Length-Compression Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Short Compressed)	80.723	8.407	3.043	9.602	0.00226
Stressed Long Compressed	20.896	2.889	2193.671	7.233	6.49E-13
Stressed Long Uncompressed	47.135	2.730	2193.909	17.264	<2E-16
Stressed Short Uncompressed	26.717	2.291	2194.104	11.664	<2E-16
Unstressed Short	-4.826	1.500	2193.456	-3.218	0.00131

The model results confirm that compression significantly affects the duration of both long (Table 29) and stressed short (Table 30) vowels, as illustrated in Figure 12. As Table 29 shows, an uncompressed long vowel was significantly longer than a compressed long vowel. A compressed short vowel was still significantly shorter than a compressed long vowel, but an uncompressed stressed short vowel was longer than a long compressed vowel. Lastly, an unstressed short vowel was shorter than a long compressed vowel. Similarly, Table 30 shows that long vowels were always longer than short compressed vowels, whether the long vowel was compressed or not. Importantly, a stressed short uncompressed vowel was significantly longer than a stressed short compressed vowel, and again, an unstressed short vowel was significantly shorter than a stressed short compressed vowel.

In general, these results demonstrate that compressed vowels in general are shorter than uncompressed vowels. Among uncompressed vowels, there is a ternary stress-length distinction, and among compressed vowels, long vowels are still longer than short vowels. In other words, the phonemic length distinction is preserved even when vowels are compressed: there is no evidence of neutralization. Furthermore, the difference in duration between unstressed and stressed compressed short vowels is significant—that is, stress distinctions are also preserved in compression. In sum, while compression does consistently affect duration, it does not have a fully neutralizing effect.

Figure 12: Boxplot of the vowel durations among the stress-length categories for compression.

Following up on the compression results, a further model was run to examine the extent to which syllable closure has a measurable effect on vowel duration independent of stress and compression. The model tested the duration of vowels by stress, phonemic length, and whether or not a coda was present in the syllable, with filename and vowel phoneme as random effects. The fixed effects additionally included an interaction between vowel length and presence/absence of a coda, which significantly improved model fit. The distribution of the data is given in Table 31 and the results of the model are given in Table 32.

Table 31: Distribution of data for the closure-length duration model.

	Syllable Closure	
Stress-Length Category	Closed	Open
Stressed Long	100	186
Stressed Short	383	508
Unstressed Short	242	816

Table 32: Fixed effects summary of linear mixed-effects model of syllable closure, vowel stress and length, and duration. Trimming removed 41 data points (1.83%).

Length-Closure Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Short Vowel, Coda Present)	67.6618	6.8995	3.1592	9.8067	0.0018
Vowel Length (Stressed Long)	23.8882	3.2667	2186.887	7.3126	3.66E-13
Vowel Length (Unstressed Short)	8.4245	2.3036	2185.473	3.657	3.00E-04
Syllable Closure (Open)	38.1229	1.9793	2187.943	19.2612	0.000261
Vowel Length (Stressed Long) : Syllable Closure (Open)	-0.7988	4.0715	2186.373	-0.1962	0.8445
Vowel Length (Unstressed Short) : Syllable Closure (Open)	-37.768	2.7952	2185.07	-13.5115	<2E-16

Since the model included a significant interaction between the stress-length categories and closure, pairwise comparisons were run in order to investigate the effect of closure within each underlying stress-length category, and then the differences among stress-length categories within closure categories. The results of these tests are given in Table 33 and visualized in Figure 13.

Table 33: Pairwise comparison results for closure within length categories and vice versa. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Category	Contrast	Estimate	SE	df	t ratio	p value
Stressed Long Vowels	Closed vs. Open	-37.324	3.56	2185	-10.491	<.0001
Stressed Short Vowels	Closed vs. Open	-38.123	1.98	2188	-19.241	<.0001
Unstressed Short Vowels	Closed vs. Open	-0.355	2.13	2188	-0.166	0.8679
Closed Syllables	Stressed Long vs. Stressed Short	23.89	3.27	2187	7.310	<.0001
	Stressed Long vs. Unstressed Short	15.446	3.47	2188	4.461	<.0001
	Stressed Short vs. Unstressed Short	-8.42	2.30	2186	-3.657	0.0008
Open Syllables	Stressed Long vs. Stressed Short	23.09	2.43	2185	9.500	<.0001
	Stressed Long vs. Unstressed Short	52.43	2.30	2185	22.812	<.0001
	Stressed Short vs. Unstressed Short	29.34	1.60	2185	18.368	<.0001

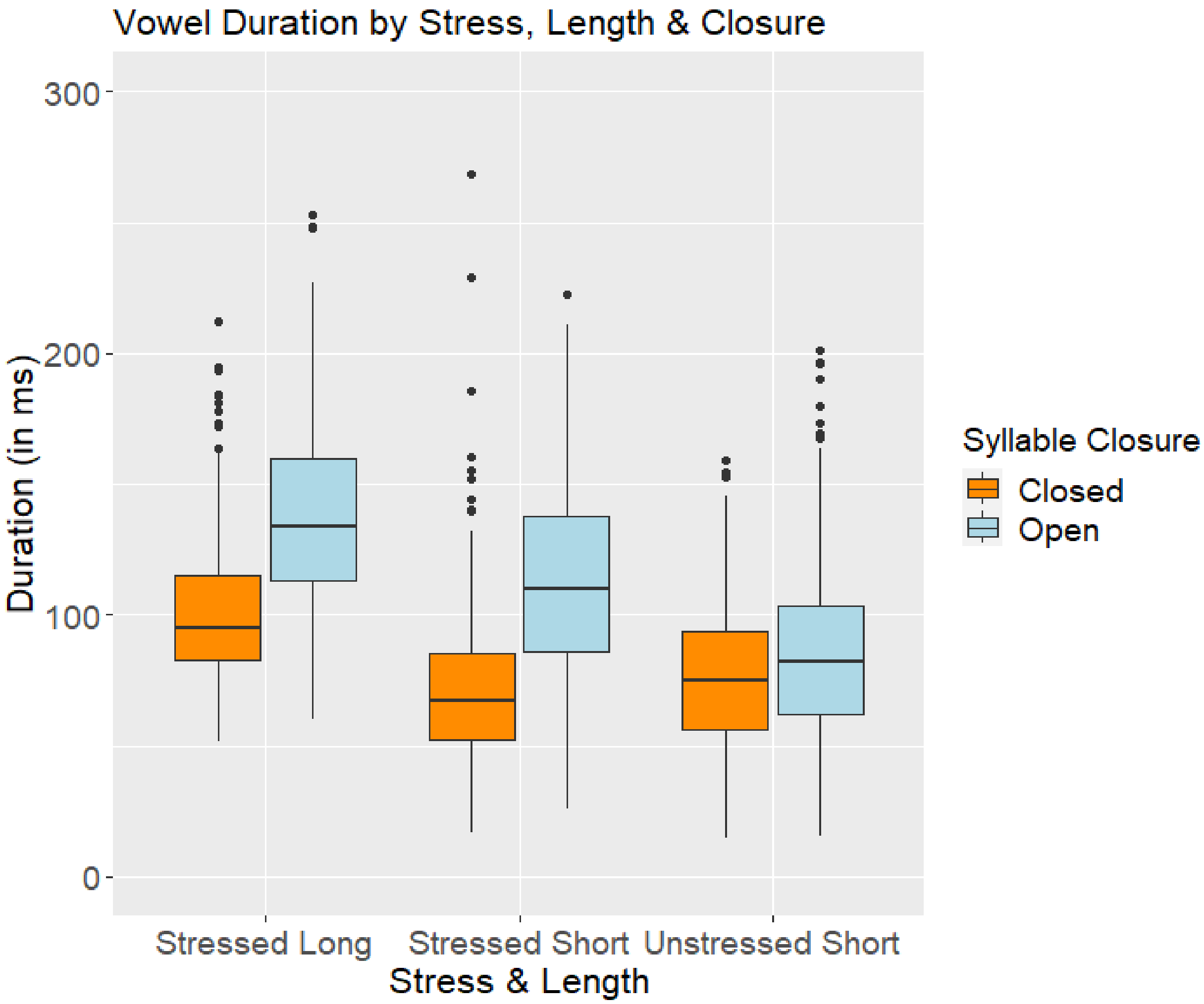

Figure 13: Boxplot of the vowel durations among vowels in open and closed syllables.

The results in Table 33 indicate that syllable closure significantly affected duration in both short and long stressed vowels: for both long and short stressed vowels, those in closed syllables were shorter than their open counterparts. However, closure did not significantly affect duration in unstressed short vowels. In both the open and closed categories, meanwhile, the difference in duration between stressed long and stressed short vowels, as well as the difference between the two stressed categories and unstressed vowels, remained significant. This result is evidence that there is a relationship between syllable closure and duration independent of stress and shows again that length is not wholly neutralized in compression environments.

3.4.2. Additional Lengthening in Stressed Syllables

As described in the literature, additional lengthening only affects stressed syllables (Krauss, 1985; Leer, 1985a, 1985b, 1985c, 1994; Martínez-Paricio & Kager, 2016). In order to examine the hypotheses proposed in (25f), we tested the effect of additional lengthening in a dataset consisting only of stressed long and stressed short vowels (N=1177). In this dataset, syllables that were the heads of internally-layered ternary (ILT) feet were labelled as additionally lengthened (see distribution in Table 34). In order to examine the relationship between additional lengthening and the stress-length categories, a model was built containing filename and vowel phoneme as random effects and an interaction between the phonemic length distinction and whether or not the syllable is additionally lengthened as fixed effects. In this section, the degree to which additional lengthening affects each stress-length category is examined in terms of duration, intensity, and maximum F0.

Table 34: Distribution of data for the length-additional lengthening duration model.

	Syllable Additionally Lengthened (ILT Head)	
Phonemic Length	Not Lengthened	Lengthened
Stressed Long	145	141
Stressed Short	627	264

Table 35 gives the fixed effects for the model of the effect of additional lengthening on duration. The intercept is a stressed long vowel that does not receive additional lengthening (i.e. is not the head of an ILT foot). The interaction between the phonemic length category and additional lengthening was not significant, so the main effects in the model can be interpreted directly without the calculation of pairwise comparisons. There was a significant difference in duration between stressed long and stressed short vowels, with short vowels having shorter durations than long ones. There was, however, no significant difference in duration between stressed vowels that receive additional lengthening and those that do not. This result indicates that, in spite of the label ‘additional lengthening’ for this process in the literature, vowels in syllables that are attested to undergo this process are not differentiated by duration.

Table 35: Fixed effects summary of linear mixed-effects model containing an interaction between phonemic length and additional lengthening in stressed vowels in terms of duration. Trimming removed 18 data points (1.53%).

Length-Lengthening Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Long, not lengthened)	113.3620	11.2445	3.3427	10.082	0.00129
Stress-Vowel Length (Stressed Short)	-26.6602	3.2942	1153.0247	-8.093	1.47e-15
Lengthening (Lengthened)	2.1035	4.2876	1152.7952	0.491	0.62380
Stress-Vowel Length (Stressed Short) : Additional Lengthening (Lengthened)	-0.8829	4.9731	1152.4147	-0.178	0.85911

Given that additional lengthening did not affect a vowel's duration, in order to see whether it affected intensity and maximum F0 instead, the same model as in Table 35 was run for each. The intensity model is summarized in Table 36. It shows a significant interaction between the stress-length category and additional lengthening, which was followed up with pairwise comparisons, reported in Table 37.

Table 36: Fixed effects summary of linear mixed-effects model containing an interaction between phonemic length and additional lengthening in stressed vowels in terms of intensity. Trimming removed 2 data points (0.17%).

Length-Lengthening Intensity Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Long, not lengthened)	71.1815	0.6544	5.5668	108.768	1.77e-10
Stress-Vowel Length (Stressed Short)	-2.7866	0.3851	1164.9907	-7.236	8.36e-13
Lengthening (Lengthened)	0.6805	0.4998	1164.8456	1.362	0.17358
Stress-Vowel Length (Stressed Short) : Additional Lengthening (Lengthened)	1.5382	0.5813	1163.9321	2.646	0.00826

Table 37: Pairwise comparison results for additional lengthening and phonemic length categories in terms of intensity. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Category	Contrast	Estimate	SE	df	t ratio	p value
Stressed Long Vowels	Not lengthened vs. Lengthened	-0.68	0.500	1165	-1.360	0.1742
Stressed Short Vowels	Not lengthened vs. Lengthened	-2.22	0.307	1164	-7.219	<.0001
Lengthened	Long vs. Short	1.25	0.435	1164	2.868	0.0042
Not Lengthened	Long vs. Short	2.79	0.386	1165	7.225	<.0001

The first results in Table 37 indicate that additional lengthening did not affect the intensity of long vowels. However, there was a significant difference among short vowels: an additionally-lengthened stressed short vowel was louder than a non-additionally-lengthened stressed short vowel. Thus, there was a difference between stressed long and short vowels in terms of additional lengthening. Secondly, within all additionally lengthened vowels, the distinction in intensity between long and short vowels was significant. An additionally-lengthened (stressed) long vowel was significantly louder than a lengthened (stressed) short vowel, and the same is true of stressed long and short vowels without additional lengthening.

It is possible, however, that the apparent difference between long and short stressed vowels with respect to the effect of additional lengthening was due to the fact that the dataset contained notably fewer long vowels than short ones (recall Table 34). Figure 14 suggests that long vowels were affected by additional lengthening as well, even though the effect was not significant according to the pairwise comparison (note that the figure includes unstressed short vowels for comparison, even though they are not included in the models reported in this section).

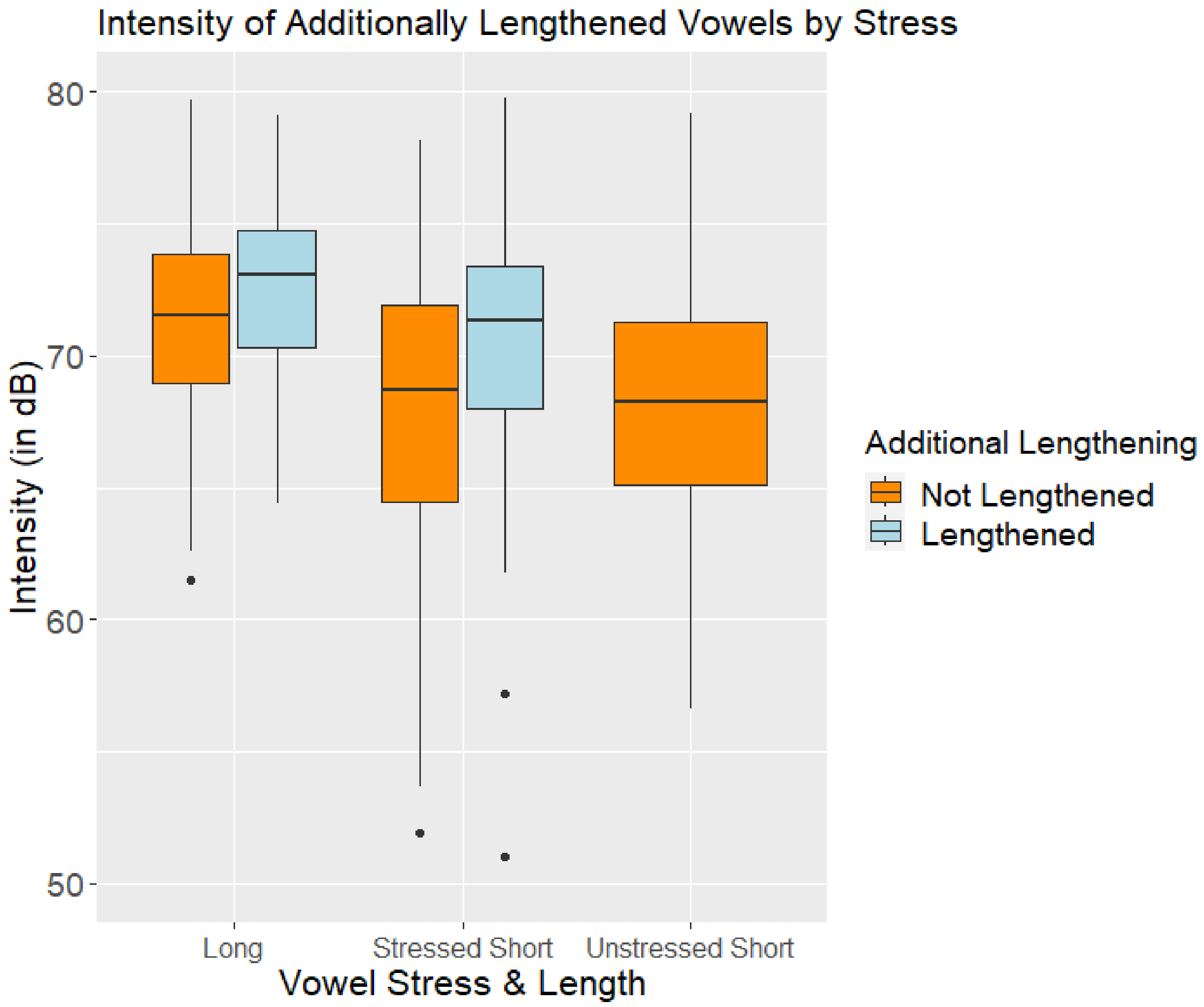

Figure 14: Boxplot of the vowel intensities among the stress-length categories for additional lengthening.

In sum, intensity is correlated with additional lengthening, but only reliably so for stressed short vowels. Together with the result that the phonemic length distinction is preserved among syllables in ILT heads, the result is a hierarchy of intensity, such that long vowels were louder than additionally lengthened stressed short vowels, which were in turn louder than stressed short vowels without additional lengthening, followed by (unlengthened) unstressed short vowels (recall Table 27 for that last comparison).

The final model examined the effect of additional lengthening on maximum F0. The fixed effects of the linear mixed-effects model are given in Table 38; as with the previous F0 model, instances where F0 could not be measured, such as octave jumps, were removed, resulting in a dataset where N=1122.

Table 38: Fixed effects summary of linear mixed-effects model of containing an interaction between phonemic length and additional lengthening in stressed vowels in terms of maximum F0. Trimming removed 2 data points (0.18%).

Length-Lengthening Maximum F0 Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Stressed Long, not lengthened)	2.4327	0.2698	20.3033	9.018	1.53e-08
Stress-Vowel Length (Stressed Short)	-1.3839	0.2575	1087.1593	-5.375	9.39e08
Lengthening (Lengthened)	0.2542	0.3311	1054.0927	0.768	0.4429
Stress-Vowel Length (Stressed Short) : Additional Lengthening (Lengthened)	0.8800	0.3883	1096.3729	2.266	0.0236

Table 38 shows that the interaction between phonemic vowel length and additional lengthening was significant; the pairwise results are given in Table 39. Table 39 shows that there was no effect of additional lengthening on maximum F0 among stressed long vowels. There was a significant difference, however, for stressed short vowels, where additionally-lengthened stressed short vowels had higher F0 than non-lengthened stressed short vowels. Interestingly, there was no significant difference in phonemic length among lengthened vowels, meaning that short vowels, when ILT heads, were raised to roughly the same F0 as long vowels. This is illustrated in Figure 15: the distributions of long and short vowels with additional lengthening overlap almost completely. Note also that, unlike for intensity (compare Figure 14), Figure 15 provides no indication that long vowels with and without additional lengthening differ in maximum F0.

Table 39: Pairwise comparison results for additional lengthening and phonemic length categories in terms of maximum F0. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Category	Contrast	Estimate	SE	df	t ratio	p value
Stressed Long Vowels	Not lengthened vs. Lengthened	-0.254	0.335	1053	-0.759	0.4478
Stressed Short Vowels	Not lengthened vs. Lengthened	-1.134	0.209	1096	-5.437	<.0001
Lengthened	Long vs. Short	0.504	0.291	1100	1.734	0.0833
Not Lengthened	Long vs. Short	1.384	0.259	1087	5.347	<.0001

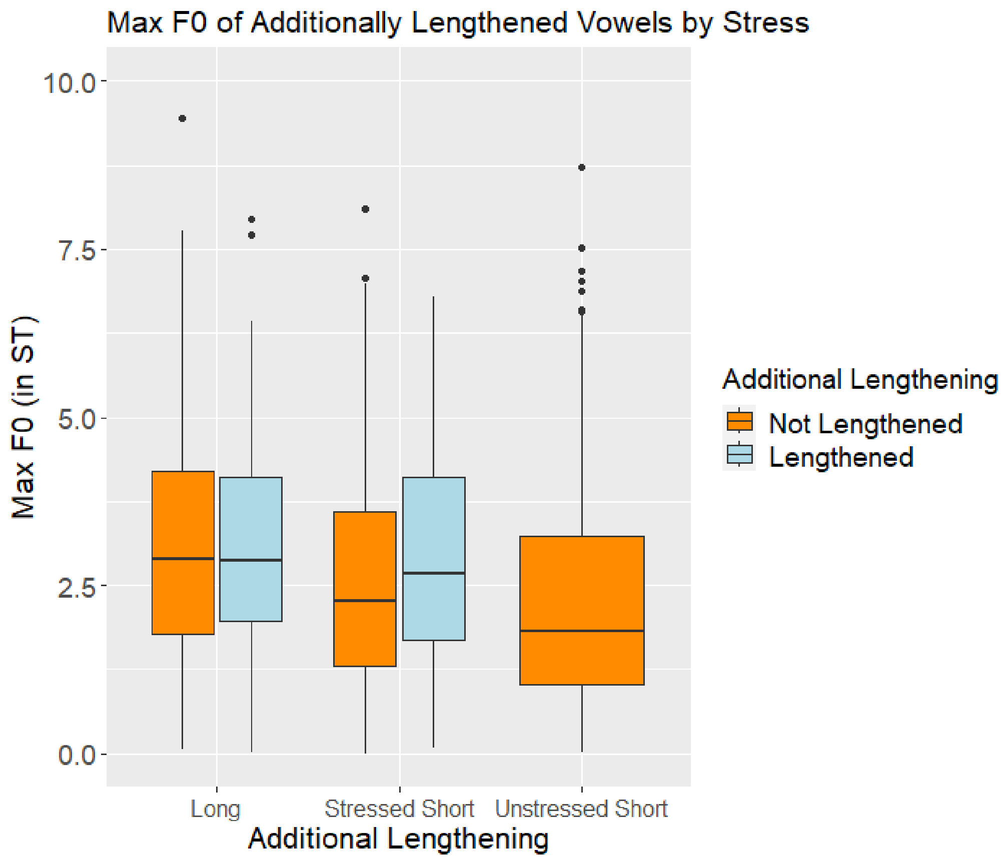

Figure 15: Boxplot of vowel F0s among the stress-length categories for additional lengthening.

Altogether, the results in this section paint a very nuanced picture of additional lengthening. While previous literature has asserted a distinction among foot heads, such that the head of an ILT foot is longer than the head of a non-maximal iamb, these results show that this is not the case. Rather, duration does not factor into distinguishing ILT and iambic foot heads. The conclusion is that additional *prominence* affects short vowels, such that a short vowel that is the head of a (maximal) ILT foot is generally louder and higher than a short vowel that is the head of a minimal iamb. In contrast, there is no meaningful difference between a long vowel that is the head of an ILT foot and one that heads a maximal iamb.

3.4.3. Tone

The literature describes tone in Chugach Alutiiq as metrical, determined by a syllable's position in a foot. According to the literature, the head of a foot is assigned an H, the adjunct of an

ILT foot is assigned an L, and when two H tones are in sequence without an intervening L tone, the second is upstepped. All other syllables have a neutral tone (N) that changes based on the surrounding syllables (cf. section 3.2.). This section presents the results of linear mixed-effects models with tone as a predictor variable for maximum F0, duration, and intensity, in order to examine, in accordance with hypothesis (25g), the ways in which H and ¡H tones surface on stressed long and stressed short syllables and the ways L and N tones surface on unstressed short syllables. All of the models in this section include filename and phoneme as random effects. The distribution of the tone data analyzed here is given in Table 40.

Table 40: Distribution of data by tone, phonemic length, and stress.

	Tone			
	¡H	H	L	N
Stressed Long	122	164	0	0
Stressed Short	184	707	0	0
Unstressed Short	0	0	393	665

The first model, given in Table 41, examined the effects of tone on F0. In this model, the intercept is a vowel with an N tone. As this is an F0 model, instances of measurement failure were removed, resulting in a dataset of N=2072. The model shows that the differences in maximum F0 were significant between N and H, as well as between N and ¡H, so that the H tones were always higher in F0 than the N tones. Interestingly, the difference between N and L, however, was not significant in terms of maximum F0. To determine if the difference between H and ¡H was significant, the model was releveled around H, see Table 42. This indicated that the difference in F0 between H and ¡H was not significant, but the difference between H and L was.

Table 41: Fixed effects summary of linear mixed-effects model of tone in terms of maximum F0 (ST). Trimming removed 28 data points (1.35%).

Tone F0 Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (N)	0.7574	0.2178	9.0242	3.478	0.00693
Tone (¡H)	0.9603	0.2029	2033.3611	4.733	2.37e-06
Tone (H)	0.8317	0.1525	2034.7909	5.453	5.54e-08
Tone (L)	0.1753	0.1928	2020.5325	0.910	0.36318

Table 42: Fixed effects summary of linear mixed-effects model of tone in terms of maximum F0, releveled around H. This model is releveled from Table 41, and was trimmed to the same specifications.

Tone F0 Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (H)	1.5891	0.2086	7.6413	7.616	7.92e-05
Tone (¡H)	0.1286	0.1940	2031.0472	0.663	0.507350
Tone (L)	-0.6564	0.1820	2031.7508	-3.607	0.000317
Tone (N)	-0.8317	0.1525	2034.7909	-5.453	5.54e-08

The results in Table 41 and Table 42 are unexpected given that literature clearly describes four levels of tone distinction. Here, there is only evidence of two tone categories that are reliably distinct in terms of F0: a general high tone, which includes H and ¡H and only attaches to stresses, and a general non-high tone, which includes N and L and is only associated with non-stresses.

A second model was run to examine if there was a significant difference in duration among the tone categories. This model and the intensity model that follows were both run on the full dataset, wherein N=2235. For duration, the model with N as the intercept is given in Table 43 and the model releveled around H is given in Table 44. They show that duration was significantly different among different tone categories, such that vowels with L tones were longer than N tones and ¡H tones were longer than H tones. Additionally, both H and ¡H tones had significantly longer durations than N. Interestingly, the difference in duration between L and H was only marginally significant, with H tones slightly longer than L tones.

Table 43: Fixed effects summary of linear mixed-effects model of tone in terms of duration (ms). Trimming removed 45 data points (2.01%).

Tone Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (N)	68.543	10.828	3.042	6.330	0.00764
Tone (¡H)	36.089	2.135	2183.265	16.902	< 2e-16
Tone (H)	18.888	1.583	2183.020	11.930	< 2e-16
Tone (L)	15.223	1.957	2172.566	7.777	1.14e-14

Table 44: Fixed effects summary of linear mixed-effects model of tone in terms of duration, releveled around H. This model is releveled from Table 43, and was trimmed to the same specifications.

Tone Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (H)	87.431	10.813	3.026	8.086	0.00383
Tone (¡H)	17.200	2.069	2180.890	8.314	< 2e-16
Tone (L)	-3.665	1.869	2183.488	-1.961	0.04998
Tone (N)	-18.888	1.583	2183.020	-11.930	< 2e-16

Lastly, Table 45 and

Table 46 show the effects of tone on intensity. Here, the differences between N and H, and between N and ¡H were significant, with H and ¡H both being louder than N. Furthermore, the difference between N and L was marginally significant, with L-toned vowels slightly louder than N-toned vowels. In

Table 46, there was no significant difference in intensity between H and ¡H, but it confirms that H was louder than both L and N.

Table 45: Fixed effects summary of linear mixed-effects model of tone in terms of intensity (dB). Trimming removed 23 data points (1.03%).

Tone Intensity Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (N)	67.8508	0.7573	4.0587	89.597	7.62e-08
Tone (¡H)	1.5197	0.2847	2201.8663	5.339	1.03e-07
Tone (H)	1.6615	0.2119	2201.1823	7.840	6.97e-15

Tone (L)	0.5054	0.2642	2204.0816	-1.913	0.0559

Table 46: Fixed effects summary of linear mixed-effects model of tone in terms of intensity, releveled around H. This model is releveled from Table 45, and was trimmed to the same specifications.

Tone Intensity Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (H)	69.5123	0.7531	3.9690	92.306	9.19e-08
Tone (¡H)	-0.1418	0.2748	2201.2015	-0.516	0.606
Tone (L)	-2.1669	0.2514	2202.6170	-8.621	<2e-16
Tone (N)	-1.6615	0.2119	2201.1823	-7.840	6.97e-15

In summary, the results of examining the expression of tone revealed that H and ¡H tones were significantly different from N in every measure: H tone was longer, louder, and higher than an N. This is the expected result, given that H is assigned based on stress; in this way, these results reinforce the previous stress correlate results in Section 3. The only significant difference between H and ¡H, surprisingly, was in their duration, where ¡H was longer than H. N and L, meanwhile, were not different in terms of F0, but L tones were significantly longer and marginally louder than N tones. These results indicate that all four levels were distinctly produced in addition to their role in the metrical system, e.g. L preventing upstepping.

3.4.4. Onset Fortition

The final prominence-adjacent phenomenon examined here is onset fortition. According to previous literature, onsets in Alutiiq can be fortified (foot-initially), geminated (lexically marked or in a #V.CVV environment), both geminated and fortified (a combination of the former two environments), or neither (referred to below as ‘neutral’). The goals of this inquiry are to examine whether or not there is evidence of foot-initial strengthening observable in onsets, and how this foot-initial strengthening is comparable in terms of its effect on duration to geminated and neutral consonants. The goal is not to exhaustively describe the articulatory or acoustic mechanisms that result in fortition. An observable effect on duration alone would sufficiently attest the existence of fortition, hence the hypothesis presented in (25h): that a foot-initial onset is significantly longer than a non-initial onset.

Table 47: Distribution of data for the onset fortition model.

Strengthening	Voiced	Voiceless
Neutral	613	789
Fortified	346	833
Geminated	24	50
Geminated-Fortified	24	41

A linear mixed-effects model was run on the onsets contained in the present data set as shown in Table 47 (N=2720) in order to determine whether duration was significantly affected by an onset's strengthening type. The model contained phoneme and filename as random intercepts and strengthening type and voicing as predictor variables (since Leer, 1985b describes voicing as having a role in onset fortition); however, voicing did not improve model fit and was excluded after backwards testing. An interaction was tested but did not converge, possibly due to the small size of the dataset. The summary of the fixed effects for the onset model is given in Table 48.

Table 48: Fixed effects summary of linear mixed-effects model of onset consonants in terms of duration (ms). Trimming removed 73 data points (2.68%).

Approximant Duration Model	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (Neutral)	64.7274	5.4189	25.6635	11.9449	5.55E-12
Strengthening (Fortified)	6.6819	0.7794	2613.3416	8.5737	<2E-16
Strengthening (Geminated)	28.537	2.3465	2607.6826	12.1613	<2E-16
Strengthening (Fortified-Geminated)	36.9224	2.5267	2607.9754	14.613	<2E-16

This result shows that fortified, geminated, and fortified-geminated onsets were all significantly longer than neutral onsets. The result that geminated onsets are longer than non-geminated onsets is a litmus test that affirms that the model is accurate. The key result is that the difference between fortified and neutral onsets was significant. This constitutes evidence firstly, that onset fortition is in fact distributed along foot boundaries, such that a foot-initial onset is longer than a non-initial one, and secondly, that duration is a correlate of this fortition. Releveling the model in Table 28 to have an intercept that is fortified reveals that fortified onsets are significantly different from geminated onsets, where geminated onsets are significantly longer (estimate = 21.8551; SE = 2.3452; df = 2607.2323; t= 9.319; p < 2e-16), implying that the two onset strengthening processes are not identical in their effects.

The goal of this inquiry was to determine the degree to which consonant duration indicates foot boundaries. Specifically, onset fortition was cited by Leer (1985a, b) as an expression of metrical structure in Alutiiq, and Martinez-Paricio & Kager (2016) justified their model by accounting for the distribution of fortified onsets within their binary-ternary footing schema. The brief investigation into onset fortition given here has provided evidence that onset fortition does indeed occur where the Internally-Layered Ternary foot model predicts.

3.5. Summary and Discussion

Table 49: Summary of the effects of stress and length on each examined acoustic correlate.

Comparison	Duration	Intensity	Maximum F0
A stressed vowel is ___ than an unstressed vowel	Significantly Longer	Significantly Louder	Significantly Higher
A long vowel is ____ than a short vowel	Significant Longer	Significantly Louder	Significantly Higher

In Chugach Alutiiq, a syllable's stress and phonemic vowel length are differentiated by duration, intensity, and maximum F0 of its vowel nucleus, as indicated by the results of the present study (see summary in Table 49). These results imply a ternary vowel hierarchy of prominence wherein (obligatorily stressed) long vowels are the longest, loudest, and highest, followed by stressed short vowels, with unstressed short vowels being the least prominent. In relation to the hypotheses given in section 3.1.4, the results presented in Table 49 affirm $H_{\mathrm{VowelLength}}$ (25a), H_{DUR} (25b), H_{INT} (25c), and H_{F0MAX} (25d). These results are consistent with the acoustic correlates of stress and length in the closely-related languages Central Siberian Yupik (Koo & Badten, 1974b) and Central Alaskan Yup’ik (Alden & Arnhold, submitted). However, unlike in these other two Yupik languages, Alutiiq features two additional processes that may affect a vowel’s length: additional lengthening and compression.

The results for compression and additional lengthening are summarized in Table 50. These are presented by their effects on long and short vowels separately. Recall that additional lengthening only affects syllables that are able to bear stress, and compression operates on both vowels that are underlyingly long and those that are lengthened by stress; in short, the results in Table 50 exclude short unstressed vowels from consideration.

Table 50: Summary of the effects of compression and additional lengthening on each examined acoustic correlate.

Metrical Effect	Duration	Intensity	Max F0
A compressed short vowel is ____ than an uncompressed short vowel	Significantly shorter	N/A	N/A
A compressed long vowel is ____ than an uncompressed long vowel	Significantly shorter	N/A	N/A
An additionally lengthened short vowel is _____ than a non-lengthened short vowel	Not significantly different	Significantly louder	Significantly higher
An additionally lengthened long vowel is _____ than a	Not significantly different	Not significantly different	Not significantly different

non-lengthened long vowel			

The results of the pairwise comparisons of compression showed that vowels that are underlying long and stress-lengthened short vowels are both affected by compression. However, the underlying length distinction and the difference between stressed and unstressed vowels are preserved even when vowels are compressed, indicating that compression is more of a near-neutralization of length rather than a full neutralization. The hypothesis around compression, given in (15e) and based on descriptions in Leer (1985b), should therefore be rejected, at least in part: while compressed vowels are shorter than non-compressed vowels, the duration distinction between phonemically long and short vowels, relative to the length of unstressed vowels, is not neutralized.

There is some nuance to be had surrounding the conditions that drive compression. Namely, it is unclear whether compression as it is described in the literature is actually at work in both contexts that produce a compressing effect on long vowels: syllable closure and open word-final syllables. While the literature largely conflates these as being two environments for compression, it may instead be the case that these two environments for vowel shortening are driven by different factors. In the case of long nuclei in closed syllables, the observed shortening effect could be a result of syllable isochrony. The word-final effect, meanwhile, may be prosodic-boundary induced, parallel to IP-final destressing in Yup'ik (see Sections 2.2.-2.3.; for a description of IP-final destressing in Yup'ik, see Jacobson, 1985; Jacobson and Jacobson, 1995; and Woodbury, 1987). Further research into both isochronic effects and phrase boundary marking in Alutiiq might tease out this distinction.

Leer claimed that phonemic vowel length in Alutiiq has become largely redundant, with the contrast being predictable by stress, closure, and syllable position rather than duration alone (Leer, 1985a:88). These results have shown instead that long and short stressed vowels are produced distinctly, except where both are additionally lengthened; furthermore, the length distinction is maintained even when vowels are compressed (or targeted for other vowel-shortening phonology, if compression is not the sole cause of vowel shortening). In our data, duration is the acoustic correlate that bears the heaviest burden: it is associated with stress, underlying length, compression, upstep, distinguishing ILT foot adjuncts, and differentiating H and N tones (see discussion of adjuncts and tones below). Independent of other correlates and contextual information, it is difficult to determine a vowel's identity, and indeed a syllable's structure, based on duration alone. Difficult, however, is not impossible: the length contrast remains significant among both compressed and additionally lengthened vowels, indicating that it has not been completely neutralized.

Martínez-Paricio and Kager (2016) connect Leer's additional lengthening to the additional prominence given to ILT foot heads, as compared to other iambic heads. The results for additional lengthening in Table 50 provide evidence that ILT foot heads are significantly prominent—however, only in terms of intensity and maximum F0, and not duration. Therefore, we can partially accept hypothesis (25f): additionally 'lengthened' vowels are phonetically distinct, but not in terms of duration. As established, duration already carries a significant burden, so this might explain why additional *prominence* would surface with other correlates. Technically, this result does mean that $H_{AddLength}$ should be rejected; however, the hypothesis can be accepted if the wording is changed to a broader "there is an acoustic distinction between the heads of ILT feet and iambic feet, such that the head of an ILT foot is more prominent by some acoustic correlate (duration, intensity, or F0)". Together with the conclusion that adjuncts are distinguished from syllables in other metrical positions (see section 3.4.3), this outcome provides evidence for the existence of ILT feet as a distinct foot shape: within a span of three syllables, there are acoustic differences between each syllable, such that the unstressed and stressed syllables within the internally layered iamb and the adjunct to the right of that iamb are produced differently.

Next, in terms of onset fortition, the results in section 3.4.4 provide evidence that foot-initial onsets are indeed longer than non-initial onsets. While there is still room for research on the exact nature of the relationship between gemination, preclosure, and fortition, these results allow us to accept hypothesis (15h) and corroborate prior attestations of foot boundary demarcation in onsets. These results are interesting and warrant a follow-up study focused on onset production in Alutiiq. A follow-up investigation could reveal other acoustic and articulatory correlates of onset strengthening in Alutiiq, such as examining the role of voicing in a larger, more curated dataset. However, as stated above, the goal in this article was to provide evidence that onset fortition occurs where the ILT model predicts, not to describe the acoustic details of onset strengthening in general.

Table 51: Summary of the effects of tone on each examined acoustic correlate

Metrical Effect	Duration	Intensity	Maximum F0
The high tones (H and ¡H) are ____ than the low tones (N and L).	Significantly Longer	Significantly Louder	Significantly Higher
An L tone is ____ than an N tone.	Significantly Longer	Marginally Louder	Not Significant
An ¡H tone is ____ than an H tone.	Significantly Longer	Not Significant	Not Significant

Lastly, Table 51 summarizes the results for tone. These results do not give adequate evidence to support the hypothesis H_{Tone} in (25g), namely because F0 is not as significant a factor in differentiating attested tone categories as expected. The acoustics of tone are more complex than just changes to F0: in fact, F0 is only significant in differentiating the generally lower spectrum of tones, N and L, from the generally higher ones, H and ¡H. Given that only the difference between H and N is correlated with F0, then it is more technically correct to assert that Alutiiq has two tone categories: a non-high tone and a high tone that anchors to stress. Within those tone categories, there are further distinctions. Among the non-high tones, there is a difference between non-adjuncts (which bear an N tone if they are not the head of a foot, and an H if they are) and adjuncts (labelled L in previous descriptions, following Leer, 1985b), which are longer and louder, but not higher in F0. Among the H tones, there is a distinction between H and ¡H, the latter of which are also longer, but not higher in F0. These relationships are illustrated in Table 52.

Table 52: Relationships among tone categories and ILT foot positions.

Distinguished by F0	Non-High		High	
Distinguished by Duration & Intensity	L	N	H	¡H
Metrical Position	Adjunct	Non-Head	Iamb/ILT Head	Upstepped H: HH > H¡H

The tone results are particularly interesting because they do not support the claim that there are four distinct levels of tone in Alutiiq. Rather, H tones, which are assigned only to stresses (recall that F0 was found to be a stress correlate), are lengthened rather than made higher when in an upstep position. L tones, which are assigned only to ILT foot adjuncts, are distinguished from other non-high tones not by their F0, but rather by their duration and intensity. This implies that adjunct vowels are longer and louder than unstressed vowels, but not as loud, long, or high as stressed vowels, a result that matches their metrical positions: that is, that maximal foot heads are the most prominent syllable, followed by the maximal foot dependent (the adjunct), followed by the minimal foot dependent.

Whether or not the effects that acoustically distinguish head and adjunct vowels from other vowels can be formally classified as tone depends on whether or not one allows for tone to be defined by correlates other than F0, and further, whether tone can be metrically, rather than lexically or morphologically, conditioned. Hyman (2006) gives the following definition of tone:

(26) “A language with tone is one in which an indication of pitch enters into the lexical realisation of at least some morphemes.” (Hyman, 2006:229)

This implies that F0 is central to tone, and furthermore, that tone is a lexical specification, rather than a metrical behavior. It may be more appropriate, then, to call the observed ‘tones’ in Alutiiq *accents*: an “abstract mark where a culmination of prosodic features occurs, marking that syllable […] with greater salience than surrounding syllables” (Hyman, 1977:4). Using the term accent to describe tones in Alutiiq allows for their distribution to be metrically conditioned, as accent has been loosely described as a tone that “acts like stress” (Hyman, 2006:234). In other words, the evidence presented in this study does not support attestations of salient tones in Alutiiq: rather, head syllables are accented and made more prominent than non-head syllables, and adjunct syllables are accented and made more prominent than the dependent of a minimal foot.

In terms of accent on foot head syllables, there are two possibilities that account for the prominence behaviors associated with high accents. Firstly, it is possible that an F0 peak is only associated with stress, and not with accent, which is to say, there is no high accent in Alutiiq; or, alternatively, that both stress and accent affect F0, and that the effects of the two combine to create the observed effects. In either instance, if it is the case that F0 is an expression of stress, and thereby a correlate of metrical headedness, then F0 would also be expected to distinguish between adjuncts (L) and minimal dependents (N). This is not the case, as adjuncts are not significantly distinguished from minimal dependents via F0. Furthermore, the fact that so-called upstep occurs to distinguish H tones in sequence indicates that there is some additional process that differentiates head vowels. Notably, if F0 is associated solely with stress effects, upstep would also be expected to use F0 to distinguish between high accents in sequence. This is also not substantiated by the acoustic evidence in Section 3.4.3. However, if upstep is seen as a more general dissimilatory process, as explicitly described in Leer (1994), then F0 may be linked to stress after all, as dissimilation is not inherently marked by a change in F0 in the way that upstep is expected to. We consider the observation made in this study that so-called upstep does not involve F0 to be additional evidence that it is in fact dissimilation, and another application of the Obligatory Contour Principle, as suggested by Hewitt (1991).

Secondly, it is possible that F0 is only affected by accent, and not by stress. This interpretation divorces F0 effects on the syllable head from stress and attributes them to the presence of an obligatory H* accent. F0 is an indicator of phonemic length, such that long vowels have a higher F0 than short vowels. It may be the case that F0 is also a correlate of metrically-bound accent, thus distinguishing the acoustic correlates of length and stress while also explaining the effect of accent on a foot head. As it is impossible in Alutiiq for a stressed syllable to not bear an accent, however, this is not empirically demonstrable. Nonetheless, this option both explains the effect of H* on F0 and sidesteps the complexities that surface when F0 is connected to metrical headedness—namely, that while it would be expected that F0 would distinguish adjuncts and minimal dependents if it were associated with stress, it does not.

Regarding the non-high accents, it appears that L accents function as expressions of embedded structure, giving the vowels of the syllables to which they are assigned prominence via duration and intensity in order to mark the layered internal structure of the ILT foot. In terms of the definition of accent adopted here from Hyman (1977), L-assigned vowels have greater salience than unaccented syllables, but not greater salience than H*-assigned vowels. Technically speaking, then, since L accents only ever appear following H* accents, they are not more salient than all surrounding syllables, but are instead only more salient than unaccented syllables. The result is a ternary hierarchy where adjuncts, as maximal head dependents, are more prominent than minimal head dependents, but less so than either minimal or maximal foot heads (which are distinguished from one another via additional lengthening/prominence; see Section 3.4.2). Perhaps, then, the term ‘accent’ is not ideal for describing the relationship between H and L specifications. They are somewhat reminiscent of a primary/secondary stress distinction, where foot heads are primary and adjuncts are secondary. However, describing L accents as secondary stresses is not accurate either, as adjuncts are not stressed, but rather unstressed dependents, and are also not obligatory, only appearing in ILT feet. Moreover, a definitional criterion of primary stress is that there can be only one within each word, whereas all foot heads in an Alutiiq word carry an H* accent. For these reasons, ‘accent’, due to the broadness of its interpretation, is the best option for describing ILT adjunct expression.

With regards to typological classification, two observations about Alutiiq can be established: that Alutiiq has neither a prototypical tone nor a prototypical stress system. Regarding tone, Alutiiq does not have a tone system, as discussed above. While it does distinguish two types of accent via F0, the subcategories of ‘tones’ within the accent categories are not distinguished by F0 and cannot be formally classified as tones (cf. Table 34). Moreover, the distribution of accents is metrically-bound, without any lexical specification. Regarding stress, Alutiiq is certainly a stress language, insofar as it has clear, measurable stress marking that reflects metrical structures. This stress exhibits some, but not all, features commonly associated with stress systems. According to

Hyman (2006) (see also Hayes, 1995 and Jun, 2014), culminativity and obligatoriness are fundamental to stress: it is highly unusual for a stress language to not express culminativity within some phonological domain no larger than the prosodic word. In Alutiiq, stress is indeed obligatory, such that there is a minimum of one stress per prosodic word (Leer, 1985b, 1985c, 1985d, 1994). However, its stress system is non-prototypical, since stress in Alutiiq, similar to other languages in its family, has been attested to not be culminative (Jacobson, 1984, 1990; Leer, 1985b; Mithun, 1996; Woodbury, 1995). Furthermore, the distribution of stress and accent is atypical—unlike European intonation languages, all stressed syllables in Alutiiq bear the same accent (H*), while a second type (L*) appears on unstressed syllables (see overviews of several intonation languages in Féry, 2016; Gussenhoven, 2004; Jun, 2010; but also see Jun, 2014 who describes languages with only a single accent type as head-prominence languages with strong macro-rhythm). Alutiiq can therefore be compared to other languages that are neither prototypical stress nor accent languages, but have some characteristics of both. Further languages with metrically-bound accents, i.e. with neither an inventory of contrastive pitch accents nor an inventory of contrastive tones, include Creek (Haas, 1977), Nubi (Gussenhoven, 2006), and Seneca (Chafe, 1977, 1996; Melinger, 2002) (see Hyman, 2006, and Jun, 2014, for broader discussions of prosodic typology and non-prototypical stress languages/tone systems; see also Agostinho & Hyman, 2023).

In Creek, tone is obligatory and attaches to foot heads, but is non-culminative, differentiating it from a more prototypical stress-accent system. Like Alutiiq, Creek tone is metrical: Creek often has an accent on the ultimate syllable. However, if the ultimate is heavy, then the placement of the tonal accent is no longer automatic, and morphological rules determine the location of the accent (Haas 1977:204). There has not been, to date, extensive research into Alutiiq morphophonology, and so the effects that the admittedly complex morphosyntax of the polysynthetic Alutiiq word has on its prosody are not clear; however, there are no instances where morphosyntax appears to override the metrical prescriptions of stress or accent. In this way, Creek is somewhat closer to a classical tone language as defined in (16) than Alutiiq, as its tone has more morphological and lexically-determined behaviors than Alutiiq accent does.

In Seneca, tones are distributed based on both foot boundaries and syllable shape: the head of a trochee receives an H, so long as either syllable in the trochee is closed (Melinger, 2002). If multiple feet within the word meet this criteria, then multiple H tones will be assigned, thereby violating culminativity in a similar way as Alutiiq. If neither syllable is closed, however, then no

H is assigned, meaning that H is not obligatory. This differs from Alutiiq, where accent is obligatory: there is no foot whose constituent syllables are not marked as either H*-bearing (head), L*-bearing (adjunct), or unaccented. Furthermore, Seneca tones are sensitive to conditions other than a syllable's metrical position, as the closure of non-head syllables may be taken into account when determining a head syllable's tone. In Alutiiq, however, there are no such considerations, as accents are strictly assigned by feet and cannot be moved.

Gussenhoven (2006:194) describes Nubi as exhibiting a combination of characteristics of tone, stress-accent, and non-stress-accent (pitch-accent, per Beckman, 1986) languages. As in Alutiiq, all Nubi words bear an accent; obligatoriness is fulfilled. This accent is not purely metrical, however, as Gussenhoven claims that it is assigned in the verbal morphology and is further subject to deaccenting in gerunds and unique accent behaviors in phrases with premodifying adjectives (212). Furthermore, the reason Gussenhoven claims that Nubi is not a prototypical stress language differs sharply from Alutiiq: Alutiiq is not a prototypical stress language because of its ternary foot structure and lack of culminativity, but Nubi is not a stress language because of its accent-neutralizing phonology. As shown in Section 4.1, even where neutralization is attested in Alutiiq, it is not complete neutralization, and is also not connected to morphosyntax. In this way, Alutiiq is more of a prototypical stress language than Nubi.

In summary, in Alutiiq, accent is obligatory, insofar as all foot heads and adjuncts are assigned a high or non-high specification, but not culminative, as multiple H accents can be assigned in a given word (and furthermore, upstep has been shown to not significantly affect F0, and so even words with both H and !H could be said to violate culminativity in terms of relative pitch). In this way, Alutiiq accent behaves more like stress than like prototypical tone. Beckman's (1986) definition of *stress accent* offers perhaps the best summary of the Alutiiq stress-tone relationship, as stress accent 'differs phonetically from non-stress [pitch-] accent in that it uses to a greater extent material other than pitch' (Beckman, 1986:1). As shown by the results of the acoustic studies here, both stress and accent in Alutiiq use duration, intensity, and F0 to varying degrees. Furthermore, the processes that go beyond the regular expression of stress within Alutiiq, such as upstep, utilize non-F0 correlates.

3.6. Conclusion

The goal of this study was to examine the acoustics correlates of metrical structure in Chugach Alutiiq. Alutiiq features a complex system of stress wherein both binary iambic feet and internally-layered ternary (ILT) feet form from left to right. In this system, codas do not contribute to weight, but the metrical system is sensitive to weight as determined by syllable length (and syllable closure, word-initially). Furthermore, Alutiiq employs three prosodic phenomena to express metrical structures in vowels: stress and high accents on foot heads, additional prominence on ILT foot heads, and non-high accents on ILT foot adjuncts. The results of this study show that an Alutiiq vowel's stress and phonemic vowel length affect its duration, intensity, and F0, such that vowels can be arranged in a scale from unstressed short to stressed long. This demonstrates that in Alutiiq, there is a ternary relationship between stress and length: in general, unstressed short vowels will always be the least prominent, followed by stressed short vowels, and stressed long vowels will always be the most prominent. Furthermore, these categories maintain their distinctions even in instances of strengthening or weakening: within the category of stressed vowels, compressed vowels are always shorter than uncompressed vowels, but compressed long vowels are still longer than uncompressed short vowels. Similarly, where it applies, additionally 'lengthened' vowels are always louder and higher than non-lengthened vowels, but non-'lengthened' long vowels are still louder and higher than lengthened short vowels.

In conclusion, this project corroborates the claims that Leer's (1985a, b, c; 1994) descriptions and Martínez-Paricio and Kager's (2016) ILT model, which is based on them, make regarding the distributions of stress, tone, additional prominence, and onset fortition, while clarifying how these phenomena are realized acoustically. In terms of stress, we found that ILT foot heads, iambic foot heads, and unstressed syllables are all acoustically distinct. While the literature describes ILT foot heads as bearing additional lengthening, the results of this study showed that syllables in this position are louder and higher, but not longer—hence, the term additional prominence is preferred over additional lengthening. We further found that high and non-high tones are distinguished by F0, where stressed vowels are assigned a high tone and unstressed vowels are assigned a non-high tone. Unexpectedly, the two other tone categories described in the existing literature, !H and L, are not significantly distinguished by F0. Rather, so-called upstep surfaces as extra duration on dissimilated H tones, and L-toned syllables, which are ILT foot adjuncts, surface as louder and longer than N tones, but not as long or as loud as H tones.

We therefore argue that these tonal events are better analyzed as accents rather than tone: H*, L* and unaccented.

In sum, Alutiiq in general, and Chugach Alutiiq in particular, has been described as having a uniquely complex prosodic system. Many authors have sought to describe which elements of the prosody and the phonology at large are directly tied to metrical structure. The result is a variety of theoretical perspectives that detail a clockwork-like network of interconnected phonological processes. Until now, however, there has been no acoustical corroboration of the assumptions and assertions made by the theoretical models. This study has demonstrated in thorough detail that the metrical system of Alutiiq is indeed as intricate as Leer's descriptions—moreso even, as claims surrounding additional prominence, compression and length neutralization, and 'tone' have proven more complex than expected. While this project is a broad evaluation of Alutiiq prosodic behaviors, it is far from complete, setting the stage for future inquiries into the morphophonology of this complex language.

4. Is stress in Chugach Alutiiq and Central Alaskan Yup'ik actually non-culminative?

4.1. Introduction

It is generally considered a principle of stress languages that stress is culminative: that is, that stressed vowels within a word arrange themselves hierarchically, such that there is a distinction between primary and secondary stressed vowels, with each word having exactly one primary stress (Hayes, 1995:24-25; Liberman & Prince, 1977:262). This distinction surfaces as a trichotomy of prominence, such that vowels that receive primary stress are the most prominent (the loudest, longest, or highest in F0, in accordance with the stress correlates of the language), followed by secondary stressed vowels, followed in turn by unstressed vowels. For many phonologists, including Hayes (1995), Hyman (2006), and Liberman & Prince (1977), culminativity is definitional of stress. As critical as culminativity is to the description of prosodic behaviors in stress languages, however, certain non-prototypical stress languages have been attested to not be culminative: where there are multiple stressed vowels per word, there is no primary-secondary distinction (Bogomolets, 2014; de Chene & Hyman, 1981; Dixon, 1977; Molineaux, 2018; Stacy, 2004; Voegelin, 1935; Woodbury, 1987). The studies presented in this paper seek to examine two such languages, exploring acoustic evidence in order to evaluate the degree to which either stress system is demonstrably culminative.

This article concerns the Chugach dialect of Alutiiq (*Sugt'stun/Sugcestun*; henceforth Alutiiq) and the General Central dialect of Central Alaskan Yup'ik (*Yugtun*; henceforth Yup'ik),[23] two languages of the Yupik branch of the Inuit-Yupik-Unangan family. Most literature describing these two languages attests both stress systems are non-culminative at the word level (Jacobson, 1984, 1985a; Jacobson & Jacobson, 1995; Krauss, 1985; Mithun, 1996; Reed et al., 1977; Woodbury, 1987, 1995). This claim is not completely unanimous. For Yup'ik, Miyaoka (1971, 1985, 2012) claims that the rightmost stress, as in the final stress of the word, closest to the right

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[23] We recognize that, due to a history of violent colonization against the Alaska Native peoples, an individual's relationship to the various terms for their community's traditional language is complex and deeply personal. Preferred terms, and even autonyms themselves, may differ across dialects, regions, generations, and social groups. In choosing to use the terms *Yup'ik* and *Alutiiq*, our intention is to use the most accessible terminology for the broadest audience.

word edge, is the most prominent. Alutiiq stress, meanwhile, has only ever been described as non-culminative (Leer, 1985a, b, c; 1994). Importantly, no acoustic study to date has explored how culminativity may surface among stressed syllables in either language.

Yup'ik and Alutiiq are, to a large degree, mutually intelligible, sharing many words and grammatical structures. They are both polysynthetic languages with strict metrical parameters for stress assignment, leading to exceptionally long words (10+ syllables) with large quantities of stressed vowels (generally half as many stressed vowels as there are syllables in the word). In some ways, their metrical systems are similar: they share basic metrical parameters, namely left-to-right, weight-sensitive, iterative iambic foot construction, and certain idiosyncrasies, such as word-initial closed syllables being heavy, where closed syllables may not be heavy elsewhere in the word (Alden & Arnhold, submitted, 2022; Halle, 1990; Hayes, 1995a; Jacobson, 1984, 1985a, 1990; Jacobson & Jacobson, 1995; Leer, 1985a, 1985c; Miyaoka, 1970, 1971, 1985, 2012; Reed et al., 1977; Woodbury, 1987). They also share stress correlates, with stress in both languages expressed via longer duration, louder amplitude, and higher F0, with an acoustically marked ternary distinction between (obligatorily stressed) long, stressed short, and unstressed short vowels (Alden & Arnhold, submitted, 2022).

Their systems also show important differences. Whereas in Alutiiq, codas never contribute to syllable weight outside of the initial syllable, in Yup'ik, syllable weight can be indeterminate, with codas only contributing to syllable weight when not in double-clash (i.e. between two stressed vowels or a stress and the end of the word) (Hayes, 1995). Together with frequent gemination that closes word-medial syllables, this makes the Yup'ik weight system more nuanced than Alutiiq's. However, Alutiiq features both minimal (binary, or bimoraic) and maximal (ternary, or trimoraic) feet (Alden & Arnhold, n.d.; Martínez-Paricio & Kager, 2017), giving the language a different rhythm than its sister. Furthermore, where stress is the only expression of metrical structure in Yup'ik, Alutiiq also expresses foot boundaries via onset fortition, foot constituency via accent, and two stress types (stress on minimal heads vs. additionally-prominent stress on maximal heads) (Alden & Arnhold, n.d.; Leer, 1985b, 1994; Martínez-Paricio & Kager, 2017).

If it is true that culminativity is a principle of stress, then it is surprising to find a family of languages that do not adhere to that principle. As stated, the Yupik languages have been described as non-culminative, despite exhibiting clear stress behaviors (Arnhold, n.d.; Jacobson, 1985, 1990; Leer, 1985a, 1994; Woodbury, 1984). The two parallel studies presented here seek to explore the degree to which stress in Yup’ik and Alutiiq is culminative by comparing the production of stressed syllables within words. A comparison of these two languages in particular is interesting because of the ways their stress systems differ despite the similarities in their fundamental characteristics. Section 4.2 introduces theoretical perspectives on culminativity and our hypotheses. Section 4.3 reviews the materials and methods for the two culminativity studies reported on here before section 4.4 presents the Yup’ik results and section 4.5 presents the Alutiiq results. Section 4.6 discusses implications of the findings for the issue of culminativity before section 4.7 concludes.

4.2. Background & Hypotheses

Hyman (2006) defines culminativity as a defining characteristic of stress languages, such that in a stress language, every lexical word has at most one syllable marked for the highest degree of metrical prominence. The central role of culminativity can be traced back to earlier literature. For example, Liberman & Prince (1977) assert that the feature [stress] is not strictly binary, as other phonological features are, but rather n-ary, as multiple stress values are often distinguishable in stress languages, e.g. primary and secondary stress (or [1 stress] and [2 stress], in the original notation) (p.262). They propose that unlike other non-binary features, which have some defined quantity of distinct values above 2, [stress] is arbitrarily limited—presumably, by prosodic or morphosyntactic boundaries (also see Chomsky & Halle (1991 [1968]).

Critically, Liberman and Prince (1977) assert that the non-primary stressed vowels are defined syntagmatically—that is, they are only defined relative to the primary stress elsewhere within the sequence (or domain). In this way, this conception of culminativity asserts that secondary stressed vowels are distributed relative to the primary stress. The reason, then, for the relative prominence of a primary stress is not that it enjoys a privileged position within the string, but rather because it is the first stress assigned in a cyclical derivation and the cornerstone by which all other stressed vowels are determined (see van der Hulst, 2010, for a more recent suggestion along those lines). In Yup’ik and Alutiiq, however, authors have traditionally only distinguished between stressed and non-stressed categories, implying that in these languages, the stress feature is binary, and the first stress assigned in derivation is the left-most, not the primary. This is more similar to the view of Hayes (1995) and other more contemporary authors, who assert that a set of all stressed syllables in the word is defined first, and one is projected up from the rest, becoming the primary stress and rendering the rest secondary. In the case of Yup'ik and Alutiiq, however, where words would not ostensibly have a head syllable, this projection to the word level would be absent.

Since Liberman and Prince (1977), culminativity has been framed in the surrounding literature in two different ways: as a principle of stress and as a parameter that can differ between languages. In the discussion of culminativity as a principle, it has an intrinsic relationship with obligatoriness, another principle of stress languages that requires that every word contain *at least* one stress. In Hyman's (2006) definition, culminativity is independent, but parallel to, obligatoriness, and a language must fulfill both in order to be considered a prototypical stress language. Hayes (1995), on the other hand, presents the conjoined view of culminativity and obligatoriness: that culminativity is a phonological characteristic of stress in which a single, strongest syllable in a given domain bears main stress (also see Hyman, 2009, 2014). Both Hyman and Hayes shift the focus of defining culminativity away from the distribution of secondary stressed vowels relative to the primary during derivation and towards a definition that accounts for the distribution of stress levels in surface forms, where the primary stress serves as the head of the word domain, above the foot domains of the secondary stressed vowels.

A handful of languages have been attested to be exceptions to culminativity, among them Arapaho (Bogomolets, 2014), Yidiɲ (Dixon, 1977), Cayuga, Seneca, and Sierra Miwok (Hayes, 1995), Mapudungun (Molineaux, 2018), Blackfoot (Stacy, 2004), Tübatulabal (Voegelin, 1935), Yup'ik (Woodbury, 1987), among others (see de Chene & Hyman, 1981:38-39). Hayes (1995:25) allows for some flexibility in his definition of culminativity in these cases, asserting that such languages still parse words into metrical feet, thereby displaying culminativity at, at bare minimum, the foot level. He concedes that while culminativity may be universal to all stress languages, the domains in which it is expressed may be parametric. Even in languages that are attested to be culminative at only the foot level, or entirely non-culminative, including Cayuga, Seneca, Sierra Miwok, and Yup'ik, Hayes maintains that there is head-marking at the word level in the form of tonal association, implying that he does find it to be an important criterion for culminativity (also see van der Hulst, 2023:572-3, on the claim that words have heads in all languages).

With these definitions of culminativity in mind, the studies presented here seek to evaluate the degree to which stress is culminative in Yup'ik and Alutiiq, centering on the questions of whether stress is culminative in the word domain, and if so, where the primary stress falls. Although descriptions across the literature for both the languages and the language family point to both languages being non-culminative, for sake of testability, we hypothesize that Yup'ik and Alutiiq stressed vowels are both culminative at the word level.

While the majority of the literature on Yup'ik describes a non-culminative stress system, Miyaoka (1971, 1985, 2012) claims that Yup'ik stress is in fact culminative, and that primary stress is expressed on the rightmost stress in the word. This finding is partially corroborated in Gabas (1996), who proposes, based on a sample of 135 Yup'ik words, that "short" words, six syllables or less, are produced distinctively from "long" words, seven syllables or more. Short words exhibit falling intensity and a pitch peak on the right-most stressed syllable. Long words feature falling pitch and intensity, and while the rightmost stressed syllable is slightly higher in pitch, it is notably louder than surrounding syllables. However, Gabas' sample size is relatively small and does not account for intonation, finality or syllable closure effects. Moreover, the difference between "long" and "short" words was not corroborated in a recent more controlled acoustic study (Alden & Arnhold, submitted), which did not yet address the question of culminativity.

If Yup'ik is found to distinguish primary stress, we predict that it will be the rightmost stress in the word, which is usually the penultimate or ultimate syllable. However, there is nothing in the literature that informs an equivalent prediction for Alutiiq, and so again, for the sake of having a positive hypothesis to test, we extend Miyaoka's suggestion of penultimate primary stress to Alutiiq.

(27) Hypotheses for Yup'ik and Alutiiq:

H_{Culm}: Stress is culminative: there is a distinction between primary and secondary stressed vowels within the prosodic word. Specifically, the rightmost stress is the most prominent stress in a prosodic word.

The hypothesis in (27) will be tested through substudies in both languages that examine the relationship between the three acoustic correlates of stress and a stressed syllable's distance from the right edge. In this way, these studies initially only compare stressed syllables within the same word to one another. Follow-up analyses taking unstressed syllables into account are presented as a second step for both languages, see sections 4.4.5 and 4.5.5. Alden & Arnhold (submitted, n.d.) found that duration, intensity, and maximum F0 are acoustic correlates of both Yup'ik and Alutiiq stress. If stress is culminative at the word level, then it would likely be observable as a statistically significant increase in one or more of these correlates at a given position relative to the right edge of the word. If, however, there is no significant relationship between distance from the right edge and any of the three correlates, then stress may indeed not be culminative at the word level. This leads to three more sub-hypotheses for each language, given in (28)a-c.

(28) In Yup'ik and Alutiiq:

a. $H_{Duration}$: The primary stressed syllable is longer (in ms) than secondary stressed syllables.
b. $H_{Intensity}$: The primary stressed syllable is louder (in dB) than secondary stressed syllables.
c. H_{F0}: The primary stressed syllable is higher in F0 (in ST) than secondary stressed syllables.

4.3. Materials & Methods

In order to measure differences among stressed vowels within words, the same recordings analyzed in the acoustic stress studies in Alden & Arnhold (submitted, n.d.) were analyzed here. The recordings were chosen because they are housed at the Alaska Native Language Archive (Alaska Native Language Archive, n.d.), are available for public download, are high quality, and have written transcriptions. The six Yup'ik recordings included four supplementary recordings (ANLA identifiers: ANLC3111a, ANLC3111b, ANLC3112a, and ANLC3113a) to a language textbook (Reed et al., 1977) and narratives from Paschal Afcan's *Napam Cuyaa* (Afcan & Hofseth, 1972) and Annie Blue's *Cikmiumalria Tan'gaurluq Yaqulegpiik-llu*, from the book *Cungauyaraam Qulirai: Annie Blue's Stories* (Blue, 2007) (ANLA identifiers CY(SCH)967A1972g and CY970B2007, respectively). In total, there were four different Yup'ik speakers across the recordings. The seven Alutiiq recordings included seven narratives by Sergius and Margaret Moonin and Walter Meganack, collected by Seraphim Meganack and Derenty Tabios, and recorded by Derenty Tabios (text ANLA identifier: AS018, recording ANLA identifier SUC972TL1973) (Tabios & Meganack, 1972).

The first author annotated all recordings in Praat (Boersma & Weenink, 2020). The transcription tiers included the intonational phrase (IP) and the word, syllable, and segment levels. Vowel boundaries were placed around the onset of frication in the surrounding consonants and the movement of higher vowel formants (Turk et al., 2012). Pauses between words and punctuation cues in the written narratives indicated IP boundaries; a word in isolation constituted its own IP. After transcription, a script was used to obtain measurements for duration (in ms), intensity (in dB, scaled to a reference level of 70 dB), and maximum F0 (in Hz, converted to ST relative to 100 Hz) (Arnhold, 2018) for each vowel. For the Yup'ik study, the dataset contained a total of 458 IPs, 440 word tokens and 2,282 vowel tokens. For the Alutiiq study, the dataset contained 719 IPs, 465 word tokens and 2,235 vowel tokens.

Each vowel was then assigned a value that corresponded to its distance from the right edge of the word. Because the Yup'ik and Alutiiq feet are built from left to right, in the studies presented in Alden & Arnhold (submitted, n.d.), a syllable's position within the word was coded based on its proximity to the left edge. In this project, we measure syllables by their proximity from the right edge of the word in order to assess the hypothesis in (1). A value of 1 indicated that the stressed syllable was on the right edge (ultimate); a value of 2 indicated that the syllable was the second syllable counting from the right edge (penultimate); and so on. Each vowel was further labelled as either stressed or unstressed according to the stress diagnostic models for each language; these annotations were validated as predicting consistent acoustic stress cues in the previous studies (see Alden & Arnhold, 2022 for more information on Yup'ik stress diagnosis, and Alden & Arnhold, n.d. and Martínez-Paricio & Kager, 2017 on Alutiiq). In the interest of examining culminativity, which is expressed among stressed syllables, the unstressed vowels were subtracted from the dataset of all vowels in the recordings, resulting in 1,280 stressed vowels in the final Yup'ik data and 1,155 stressed vowels in the final Alutiiq data.

Analysis was done via linear mixed-effect models using the package lme4 in R (Baayen et al., 2008; Bates et al., 2015, 2020; R Core Team, 2020). The best models reported in the results sections for each dependent variable were chosen to be only as complex as justified by an improved fit to the data (Matuschek et al., 2017). Improved model fit was determined by ANOVA comparison between models with or without each individual variable. Model comparisons started with a model including the fixed effects variables that were significant in the previous acoustic studies on stress correlates (Alden & Arnhold n.d., submitted), including underlying vowel length (long or short), total word length (in number of syllables), IP-finality[24] (yes/no), presence of an onset, and syllable closure, as well as phoneme as a random intercept (/a, i, u/ or /ə/; diphthongs were coded for the quality of their first segment, e.g. /au/ was coded as /a/). For the Yup'ik recordings, which contained multiple speakers and genres, both speaker and genre (educational or narrative) were also included as random intercepts. The Alutiiq models additionally included whether the stressed vowel was the head of a minimal or maximal foot as a fixed effects variable. Note that dependent variables differed in the variables included in the previous best models; the initial fixed effects in each individual model are specified in their respective sections.

Starting from the previous best models, we then tested whether models were improved by adding a fixed effect coding the vowel's distance from the right edge, as well as whether by an interaction between this measure and vowel length. The random-effects structure was then forward fitted by stepwise adding by-subjects random slopes for each of the fixed effects variables. However, none of the models with random slopes converged, so all models below contain only random intercepts. Finally, we tested whether all fixed effects and random intercepts significantly contributed to model fit and simplified models where appropriate. The dependent and independent variables for each resulting best model are specified in the results.

After model selection, the residuals were plotted and datapoints with residuals more than 2.5 standard deviations from zero were trimmed. Information about the number of trimmed data points for each model can be found in the table captions for each model below. Additionally, p-values for fixed effects were obtained with the package lmerTest (Kuznetsova et al., 2017). For the models whose interactions were significant, pairwise comparisons were performed with the lsmeans function from the package emmeans (Lenth et al., 2022) in order to further examine the interactions between stress contrasts and the penultimate position in terms of duration, intensity,

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[24] Yup'ik features IP-final destressing, wherein any stressed syllable loses its stress IP-finally (Jacobson, 1985a; Jacobson & Jacobson, 1995). In derivational terms, stress is assigned to word-final syllables, but removed by a later process if said syllable is also IP-final. For this reason, IP-final syllables were still annotated as stressed, but additionally marked as IP-final.

and F0. In these pairwise comparisons, the Tukey method was used for p-value adjustments and the (default) Kenward-Roger method was used for calculating degrees of freedom.

4.4. Results for Yup'ik

The goal of this section is to describe the distribution of duration, intensity and maximum F0 across stressed syllables in Yup'ik. The analyses in sections 4.4.1-4.4.3 are intended to illustrate general trends and highlight patterns across stressed vowels within a word, while specifically examining if the relationship between underlying length and the proximity of a stressed vowel to the right edge affected its acoustic production. As will be seen, the results of these models reveal a window of interesting stress behaviors at the right edge of the word. Section 4.4 tests the hypothesis that rightmost stressed vowels specifically are more prominent than stressed vowels elsewhere in the word.

The distribution of stressed vowels analyzed in sections 4.4.1-4.4.3 is given in Table 1, with respect to vowel length, two right-edge proximity measures and the presence of codas. The Yup'ik corpus contained insufficient data (<5 tokens) for stressed syllables more than eight syllables away from the right edge, and furthermore, there were no stressed long vowels more than six syllables away from the right edge. As the models test for interactions between right-edge categorization and vowel length, only vowels 1-6 syllables from the right edge were included (N=1280). Where an interaction was found to be significant, pairwise comparisons explored the differences among syllables of varying right-edge proximities within each length category (e.g. comparing ultimate and penultimate stressed long vowels).

Table 53: Data distribution for the acoustic investigation of potential differences among stressed syllables in Yup'ik, organized by right-edge proximity.

		Long Vowels	Stressed Short Vowels
Distance from Right Edge	1	189	195
	2	203	245
	3	62	155
	4	26	96
	5	18	56
	6	7	28
Rightmost	Rightmost	362	359
	Not Rightmost	143	416
Syllable Closure	Closed	168	485
	Open	337	290

4.4.1. Duration

The durations of Yup'ik stressed vowels, stratified by distance from the right edge and categorized by phonemic length, are shown in Figure 16. Generally, the graph shows that both long and short vowels appear to lengthen towards the right edge, an effect that is especially pronounced on the last two syllables. There is a small peak for long vowels in the 5th syllable from the edge (i.e. 5th-syllable vowels), and a notable jump in duration for word-final long vowels.

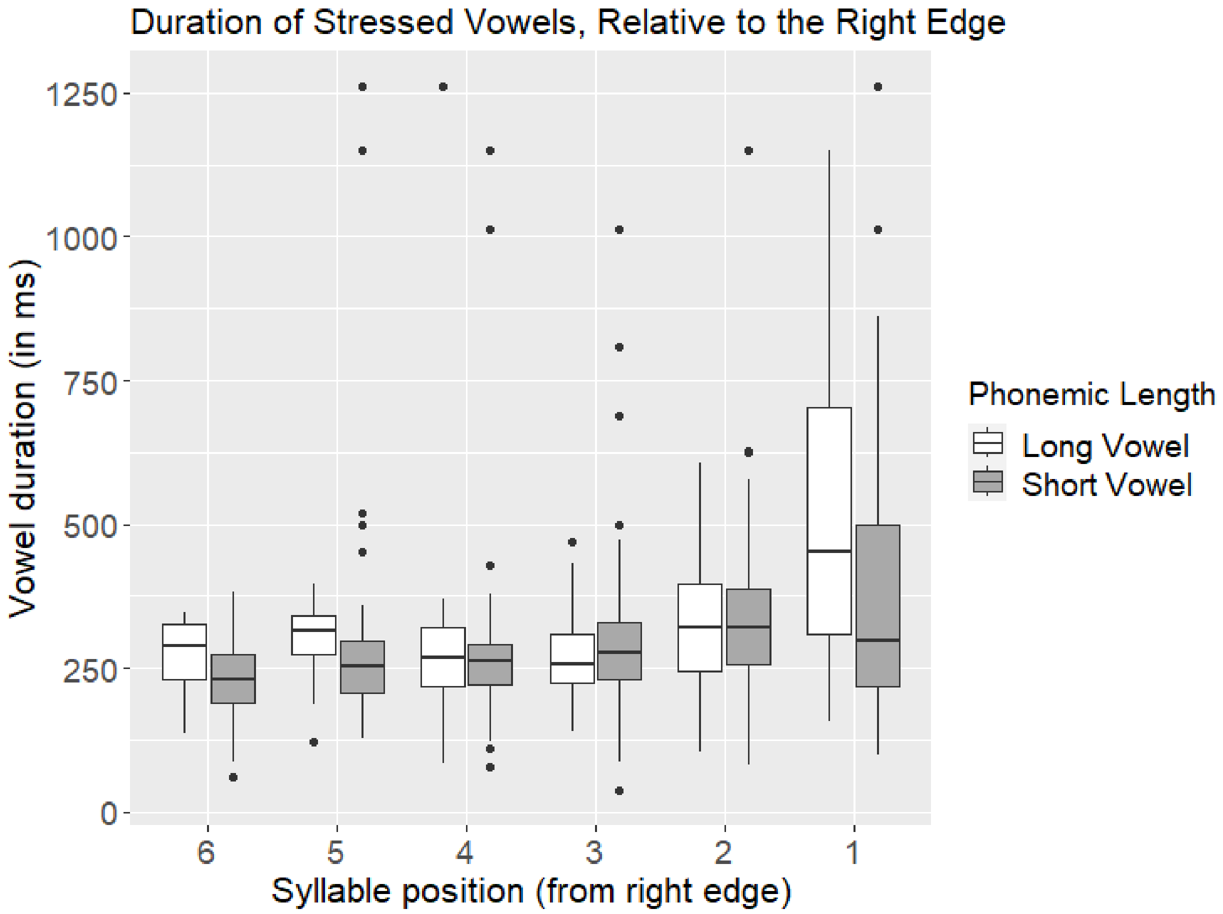

Figure 16: Stressed vowel durations in various positions within a Yup'ik word, by phonemic vowel length.

Table 54 shows the fixed effects summary of the best model of duration among stressed vowels in the dataset. The fixed effects for duration that improved model fit in Alden & Arnhold (submitted) included phonemic vowel length (long or short); IP finality; syllable closure; and the sum total of syllables in the word. Per backwards-fitting, these predictors all improved the model in this study as well. The interaction between right edge proximity and vowel length also had a significant effect on Yup'ik stressed vowel duration. In order to examine the interaction more closely, then, pairwise comparisons were done; the significant results are given in Table 55 (for the full table, see Table 85 in Appendix B).

Table 54: Fixed effects summary of the model examining duration and right-edge proximity among Yup'ik stressed vowels. Trimming removed 64 data points (2.98%).

Yup'ik Duration Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	118.9267	14.04753	9.530272	8.466024	9.76E-06
Right Edge Proximity (2nd syllable)	23.80079	5.084236	1223.789	4.681291	3.17E-06
Right Edge Proximity (3rd syllable)	24.07334	5.932097	1221.218	4.058151	5.26E-05
Right Edge Proximity (4th syllable)	25.07319	6.688268	1221.988	3.748832	0.000186
Right Edge Proximity (5th syllable)	30.60111	8.33071	1222.436	3.67329	0.00025
Right Edge Proximity (6th syllable)	13.71042	11.2147	1222.937	1.22254	0.221739
Vowel Length (Long)	91.70694	5.428532	1221.17	16.89351	<2E-16
Right Edge Proximity (2 syllables) * Vowel Length (Long)	-20.8533	7.590347	1223.253	-2.74734	0.006096
Right Edge Proximity (3 syllables) * Vowel Length (Long)	-57.1352	9.60808	1221.968	-5.94658	3.57E-09
Right Edge Proximity (4 syllables) * Vowel Length (Long)	-71.2942	12.39831	1218.873	-5.75031	1.13E-08
Right Edge Proximity (5 syllables) * Vowel Length (Long)	-58.4475	14.64155	1219.704	-3.9919	6.95E-05
Right Edge Proximity (6 syllables) * Vowel Length (Long)	-49.3396	22.25836	1219.594	-2.21668	0.026829
IP Final (Yes)	33.57741	7.124245	1222.652	4.713118	2.72E-06
Syllable Closure (Open)	59.89115	3.440559	1210.687	17.40739	<2E-16
Word Length (2 syllables)	-30.5413	8.807012	1221.962	-3.46784	0.000543
Word Length (3 syllables)	-39.2458	8.823237	1220.197	-4.44801	9.46E-06
Word Length (4 syllables)	-49.196	9.173376	1222.118	-5.36291	9.79E-08
Word Length (5 syllables)	-48.5054	9.268351	1220.204	-5.23344	1.96E-07
Word Length (6 syllables)	-46.2001	10.31928	1221.38	-4.47706	8.27E-06
Word Length (7 syllables)	-53.3764	11.74585	1220.733	-4.54428	6.06E-06
Word Length (8 syllables)	-43.0544	12.09986	1222.452	-3.55825	0.000388
Word Length (9 syllables)	-63.6446	16.96516	1219.905	-3.75149	0.000184
Word Length (10 syllables)	-80.2224	30.78211	1218.939	-2.60614	0.009269
Word Length (11 syllables)	-65.122	19.50449	1220.484	-3.33882	0.000867

Table 55: Pairwise comparison results for right edge proximity and phonemic length categories in terms of duration of Yup'ik stressed vowels (significant differences only, see text). Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (3)	33.06189	8.100202	1223.646	4.081612	0.000677
Right Edge Proximity (1) vs. Right Edge Proximity (4)	46.221	11.11362	1221.318	4.15895	0.000489
Right Edge Proximity (2) vs. Right Edge Proximity (3)	36.00942	7.845033	1221.748	4.590091	7.15E-05
Right Edge Proximity (2) vs. Right Edge Proximity (4)	49.16854	11.06937	1221.183	4.441856	0.000141
Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-23.8008	5.094535	1223.888	-4.67183	4.87E-05
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-24.0733	5.948149	1222.151	-4.0472	0.000781
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-25.0732	6.694457	1222.499	-3.74537	0.00259
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-30.6011	8.340782	1222.753	-3.66885	0.003458

The results in Table 55 show that among long vowels, ultimate and penultimate vowels were significantly longer than 3rd-syllable or 4th-syllable vowels (as counted from the right edge). However, ultimates and penultimates were not significantly different from one another. Interestingly, long 5th-syllable vowels were not significantly different from any other long vowels, despite the small peak at the fifth position observed in Figure 16. Among short vowels, only ultimates were significantly different from other stressed vowels, insofar as they were significantly shorter than 2nd-syllable to 5th-syllable vowels, even though this is not clearly visible in Figure 16, which does however show a relatively low median and a wide distribution for short ultimates. The difference grows the further away a short stress gets from the right edge, as indicated by the estimates in Table 55. It is likely that ultimates were not significantly shorter than six-syllable vowels because of their low representation in the data (see Table 53 for the data distribution).

The lower half of Table 54 describes how the other fixed effects in the model affect duration. IP final vowels were significantly longer than non-final vowels. Vowels in open syllables were significantly longer than those in closed syllables. Lastly, the stressed vowels in every word longer than one syllable were significantly shorter than the vowel of a monosyllabic word.

4.4.2. Intensity

The intensity of Yup'ik stressed vowels by distance from the right edge and vowel length is illustrated in Figure 17, which displays a distinctive pattern for both long and short vowels, where intensity peaks on the penult. The intensity model began from the best model as reported in Alden & Arnhold (submitted), containing phonemic length, word length, IP finality, the presence of an onset, and the presence of a coda as fixed effects and speaker, genre of the recording, and vowel as random effects. While an interaction between right-edge proximity and vowel length was tested, its inclusion did not improve model fit for intensity—not surprising, given that the same pattern seems to hold for long and short vowels. For this reason, the model results presented in Table 56 do not include this interaction.

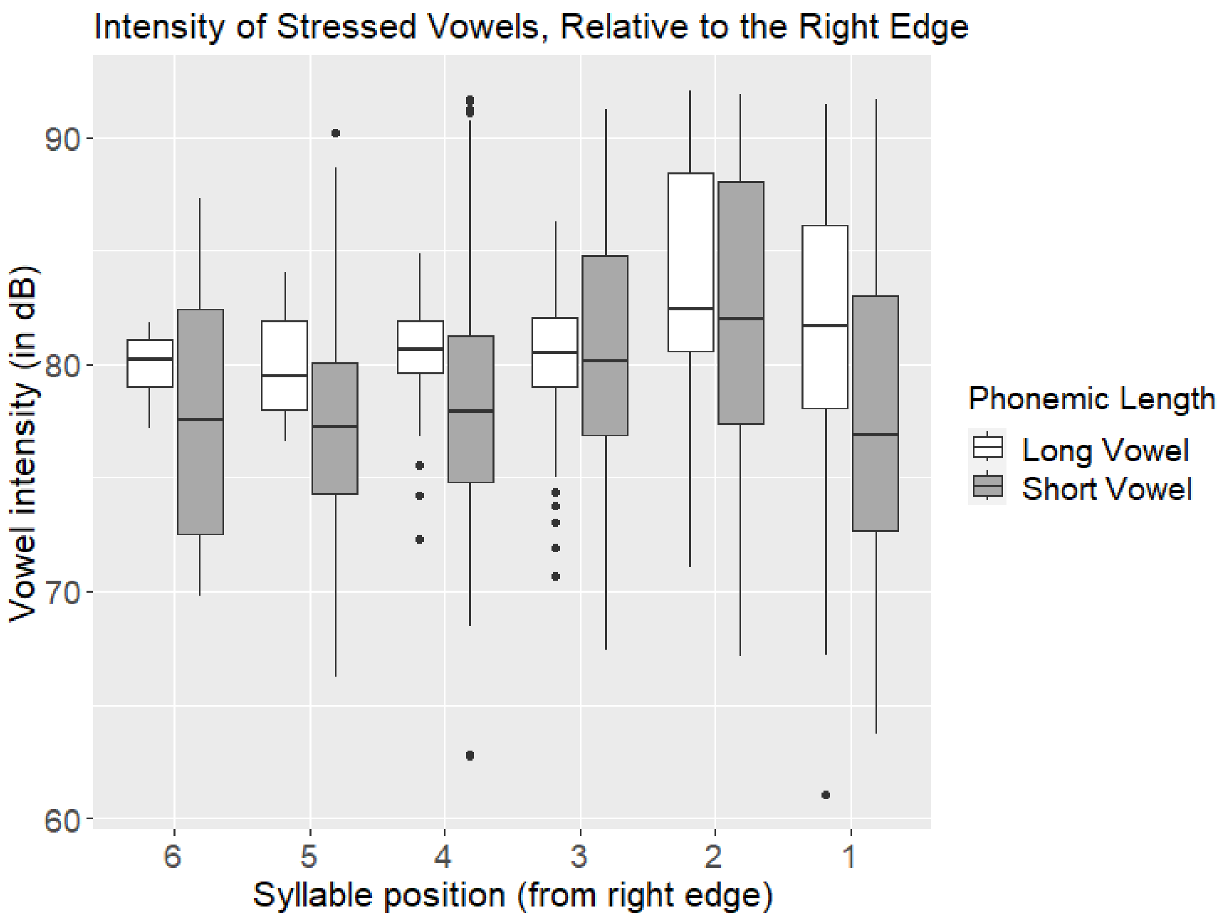

Figure 17: Stressed vowel intensity in various positions within a Yup'ik word, by phonemic vowel length.

The model summary in Table 56 shows that stressed vowels in all earlier positions were significantly louder than an ultimate stressed vowel. Long vowels were significantly louder than short stressed vowels. Vowels in all words longer than one syllable were significantly lower in intensity than vowels in monosyllabic words. Vowels in IP-final syllables were significantly quieter than non-final ones. Vowels that were not preceded by an onset were significantly quieter than vowels in syllables with an onset. Finally, vowels in open syllables were significantly louder than those in closed syllables.

Table 56: Fixed effects summary of the model examining intensity and right-edge proximity among Yup'ik stressed vowels. Trimming removed 24 data points (1.88%).

Yup'ik Intensity Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	82.38868	4.586163	1.124887	17.96462	0.025404
Right Edge Proximity (2nd syllable)	1.860812	0.259817	1231.222	7.162017	1.36E-12
Right Edge Proximity (3rd syllable)	2.95297	0.316847	1230.512	9.319853	<2E-16
Right Edge Proximity (4th syllable)	3.328435	0.381774	1230.096	8.718329	1.00E-17
Right Edge Proximity (5th syllable)	2.684453	0.468691	1230.406	5.727558	1.28E-08
Right Edge Proximity (6th syllable)	2.443916	0.643051	1230.417	3.8005	0.000151
Vowel Length (Long)	1.600829	0.204244	1231.743	7.837831	9.86E-15
Word Length (2 syllables)	-2.16132	0.532156	1230.184	-4.06144	5.19E-05
Word Length (3 syllables)	-3.60981	0.538885	1230.212	-6.69866	3.19E-11
Word Length (4 syllables)	-4.8971	0.558719	1230.832	-8.76487	1.00E-17
Word Length (5 syllables)	-4.64791	0.569495	1230.248	-8.16146	8.10E-16
Word Length (6 syllables)	-5.5577	0.632226	1230.303	-8.79068	<2E-16
Word Length (7 syllables)	-5.1465	0.728111	1230.126	-7.06829	2.62E-12
Word Length (8 syllables)	-7.64521	0.755175	1230.91	-10.1238	<2E-16
Word Length (9 syllables)	-4.80503	1.05454	1230.2	-4.55652	5.72E-06
Word Length (10 syllables)	-5.62377	1.884776	1229.966	-2.98379	0.002903
Word Length (11 syllables)	-6.89911	1.217019	1230.644	-5.66886	1.79E-08
IP Final (Yes)	-0.91388	0.434077	1230.323	-2.10535	0.035463
Onset Present (No onset)	-1.86912	0.288752	1230.464	-6.4731	1.38E-10
Syllable Closure (Open)	0.749464	0.208175	1231.609	3.600162	0.000331

In the absence of an interaction, in order to examine potential differences between stressed vowels in other positions (such as the distinct spike in intensity values on the penult in Figure 17), the predictor right edge proximity in the model summarized in Table 56 was releveled several times, setting each distance from the right edge as the intercept in a series of follow-up models. The results are given in Table 57; note that, because the minimum word length requirement for a penultimate syllable is two syllables, the model was also releveled around disyllabic words. Table

57 only presents the significant differences, and moreover, only those that are not redundant with Table 56 (i.e. it does not include comparisons between any intercept and ultimate vowels). For the full table see Table 86 in Appendix B.

Table 57: Fixed effects summary of the Yup'ik intensity model, releveled (significant differences only, see text).

Relevelled Yup'ik Intensity Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (2nd syllable)	82.0882	4.5657	1.1053	17.979	0.026722
Right Edge Proximity (3rd syllable)	1.0922	0.2956	1230.8945	3.695	0.000229
Right Edge Proximity (4th syllable)	1.4676	0.3713	1230.4262	3.953	8.17E-05

Upon releveling, the only additional significant differences in intensity were between penultimates and vowels 3-4 syllables from the right edge. A critical takeaway from Table 57 is that while according to Table 56, penultimates were significantly louder than ultimates, they were significantly quieter than 3rd- and 4th-syllable vowels. The visualization in Figure 17 is thus misleading: while ultimate stressed vowels are indeed significantly quieter than all preceding stressed vowels, there is no statistical support for a notable spike in intensity values on penultimates when the effects of other relevant factors are taken into account in mixed-effects modelling.

4.4.3. F0

Figure 18 visualizes the F0 values of stressed vowels. There appears to be a slight rise in F0 throughout the word, with a notable rise in F0 on the penult and a word-final drop. As with duration, there appears to be a slight peak in F0 for long vowels five syllables from the right edge.

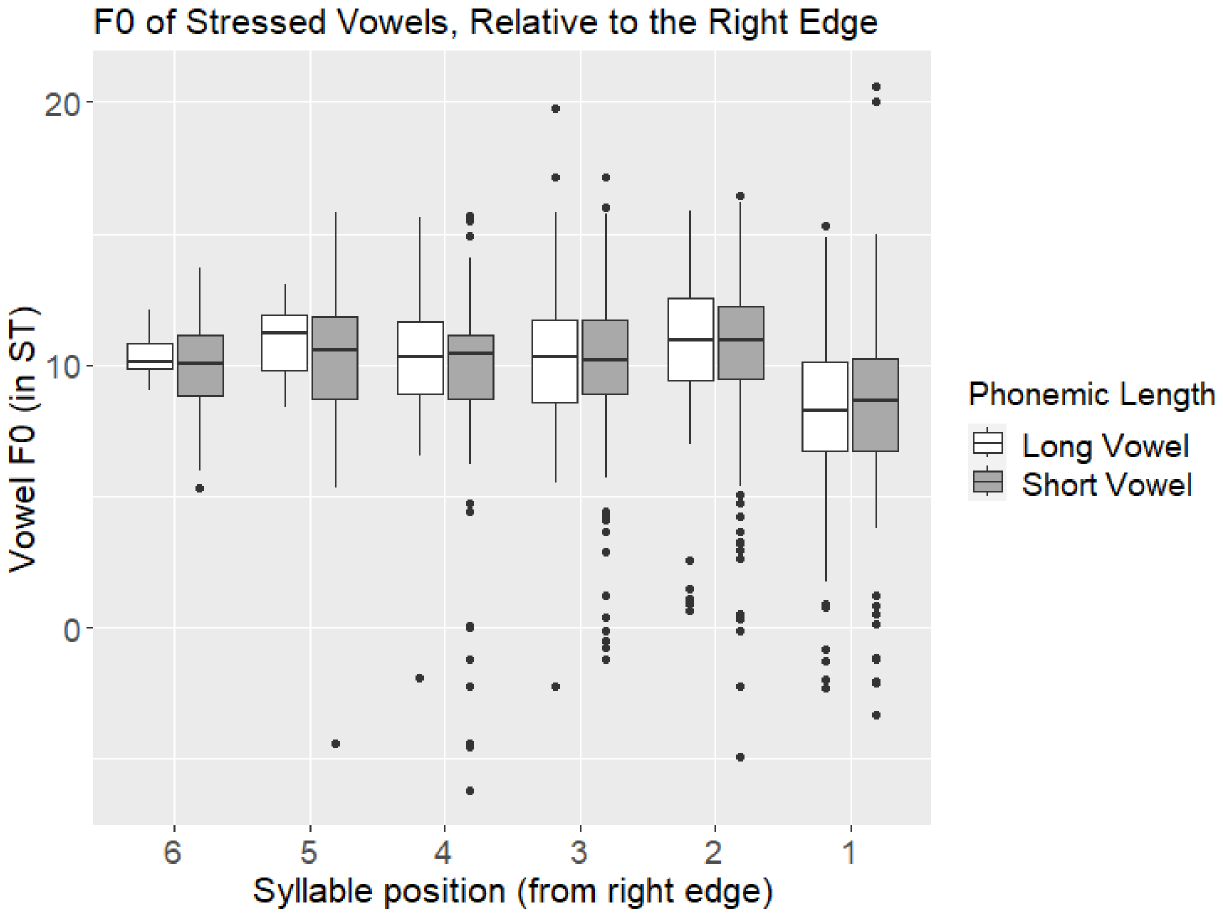

Figure 18: Stressed vowel F0 across various positions within a Yup'ik word, by phonemic vowel length.

The statistical model was based on the F0 model in Alden & Arnhold (submitted), which included the presence of a coda, IP finality, phonemic length, and distance from the left edge as its fixed effects. We first tested whether replacing distance from the left edge, which was in the Alden & Arnhold (submitted) F0 model, with distance from the right edge improved the fit of the model for maximum F0. It did not make a significant difference, and so for the purposes of addressing the present research question, as well as for consistency with the other analyses presented here, distance from the right edge was kept as a fixed effect in the F0 model. Further fixed effects testing resulted in the addition of word length as a fixed effect, and the presence of a coda was removed in backwards testing. In the original model, the fit was improved by adding phonemic length as a slope for the random effect 'speaker'. In this study, subsetting the data to only the stressed vowels caused the previous model to not converge until the slope was removed. The resulting best model for the dataset in this study contained an interaction between the right edge proximity and phonemic length. It additionally included IP finality, and total word length as fixed effects, with speaker and vowel as random effects (see Table 58). Since the interaction between right-edge proximity and vowel length significantly affected F0, the significant results of the follow-up pairwise comparison are given in Table 59; for the full results, see Table 87 in Appendix B.

Table 58: Fixed effects summary of the model examining F0 and right-edge proximity among Yup'ik stressed vowels. Trimming removed 64 data points (2.98%).

Yup'ik F0 Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	9.484783	1.463006	4.129891	6.483078	0.002611
Right Edge Proximity (2nd syllable)	1.599264	0.275306	1192.99	5.809043	8.05E-09
Right Edge Proximity (3rd syllable)	1.263363	0.319246	1193.041	3.957334	8.03E-05
Right Edge Proximity (4th syllable)	0.411495	0.367209	1191.213	1.120602	0.262683
Right Edge Proximity (5th syllable)	1.321831	0.442435	1192.639	2.987624	0.002869
Right Edge Proximity (6th syllable)	0.795217	0.591112	1192.296	1.345291	0.178787
Vowel Length (Long)	-1.08627	0.284395	1193.496	-3.81959	0.000141
Right Edge Proximity (2 syllables) * Vowel Length (Long)	1.090335	0.386608	1192.65	2.820261	0.004878
Right Edge Proximity (3 syllables) * Vowel Length (Long)	1.093342	0.503154	1191.208	2.172979	0.029978
Right Edge Proximity (4 syllables) * Vowel Length (Long)	1.673101	0.659824	1190.381	2.535678	0.01135
Right Edge Proximity (5 syllables) * Vowel Length (Long)	1.543213	0.766159	1191.02	2.014219	0.044211
Right Edge Proximity (6 syllables) * Vowel Length (Long)	1.629106	1.164992	1190.631	1.398384	0.162258
IP Final (Yes)	-0.82743	0.348418	1192.046	-2.37481	0.017715
Word Length (2 syllables)	-1.75221	0.451721	1191.96	-3.87897	0.000111
Word Length (3 syllables)	-2.10887	0.45283	1191.002	-4.65709	3.57E-06
Word Length (4 syllables)	-2.30746	0.471273	1191.316	-4.89624	1.11E-06
Word Length (5 syllables)	-2.43512	0.479588	1190.928	-5.07751	4.43E-07
Word Length (6 syllables)	-2.37204	0.528975	1191.043	-4.48423	8.02E-06
Word Length (7 syllables)	-1.56786	0.614076	1190.894	-2.5532	0.010798
Word Length (8 syllables)	-2.30054	0.620155	1192.472	-3.70962	0.000217
Word Length (9 syllables)	-0.82621	0.882196	1191.202	-0.93653	0.349189
Word Length (10 syllables)	-2.19337	1.607268	1190.738	-1.36465	0.172619

Word Length (11 syllables)	-2.78455	1.00521	1191.28	-2.77011	0.005691

Table 59: Pairwise comparison results for right edge proximity and phonemic length categories in terms of the F0 of Yup'ik stressed vowels (significant differences only, see text). Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowels					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-2.6896	0.298557	1192.338	-9.00867	<.0001
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-2.35671	0.421358	1192.295	-5.59311	4.13E-07
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-2.0846	0.588287	1191.371	-3.5435	0.00548
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-2.86504	0.683719	1192.211	-4.19038	0.000428
Short Vowels					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-1.59926	0.275525	1193.242	-5.80442	1.24E-07
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-1.26336	0.319524	1193.245	-3.95389	0.001144
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-1.32183	0.442731	1192.925	-2.98563	0.034246
Right Edge Proximity (2) vs. Right Edge Proximity (4)	1.187769	0.353993	1192.354	3.355346	0.010576

Table 59 shows that among long vowels, ultimate stressed vowels were significantly lower in F0 than 2nd-syllable to 5th-syllable vowels. Among short vowels, ultimates were significantly lower in F0 than 2nd-syllable, 3rd-syllable, and 5th-syllable vowels. Short penultimates, meanwhile, were significantly higher in F0 than short 4th-syllable vowels.

The lower half of Table 58 describes the remainder of the fixed effects not involved with the interaction. It shows that stressed vowels in IP-final syllables were significantly lower in F0 than non-final ones. Finally, vowels in all words longer than one syllable, except for nine- and ten-syllable words, were significantly lower in F0 than vowels in monosyllables. Presumably, this is due to the relative low representation of words with more than eight syllables in the data.

4.4.4. Summary of Results

These models have shown that in Yup'ik, there are marked differences among stressed vowels at the end of the word. However, there are few discernable differences between stressed vowels elsewhere in the word. In duration and F0, where the interaction between right edge proximity and vowel length was significant, pairwise comparisons showed somewhat different behaviors for long and short stressed vowels on the right edge. Where they were significantly different from vowels in stressed syllables in other positions, ultimate long vowels were longer than other long stressed vowels, but lower in F0. Penultimate long vowels were also significantly longer than long vowels in 3rd or 4th positions, although not longer than ultimates. The duration model results thus point to a general window of lengthening on long stressed vowels in the penultimate and ultimate positions, whereas for short stressed vowels, those in final position where shorter than all others. In terms of F0, word-final stressed vowels were generally lower than preceding stressed vowels, except for short stressed penultimates, which were higher in F0 than a stress in the 4th position.

In terms of intensity, the interaction between right edge distance and vowel length was not significant: both long and short vowels showed a sharp decrease in intensity in final position. While the intensity figure (Figure 17) appeared to show an intensity peak on penultimate stressed vowels, this was not corroborated by releveling the model, which showed that penultimates were significantly higher in intensity than ultimates, but lower than preceding stressed vowels.

Based on Miyaoka's (1971, 1985, 2012) impressionistic observations that rightmost stress in Yup'ik is primary, we would expect a rise in values for all three acoustic values in either the penultimate or ultimate positions, as these are the only two positions that a rightmost stress can occupy because of binary foot structure. The results given here do not appear to corroborate this claim. Especially unexpected is the difference in behavior between long vowels and stressed short vowels, since it had not been mentioned in the literature. However, the combination of lengthening on ultimate stressed vowels and the apparent F0 peak on penultimate short stressed vowels justifies a more targeted approach to testing Miyaoka's hypothesis by comparing rightmost ultimate and penultimate stressed vowels both to other stressed vowels (to determine if they are uniquely affected by virtue of being rightmost) and to non-stressed vowels (to determine if the observed effects are specific to stressed syllables, or are general word-final effects on all syllables). This analysis is presented in the next section.

4.4.5. Follow-up: Testing the Rightmost Hypothesis in Yup'ik

To investigate whether rightmost stressed vowels exhibited significantly distinctive behaviors from non-rightmost stressed vowels, each token in the dataset was assigned a label that corresponded to whether it was the rightmost stress in its respective word. Rightmost stressed vowels were limited to the penultimate or ultimate position. Unstressed vowels were also included, so as to determine if any observed effect was a stress effect in particular (in which case unstressed vowels would be unaffected) or a general word-final effect (which would affect all vowels regardless of stress). The goal of the following investigations is to determine if, and the extent to which, a vowel's position as rightmost interacts with its stress and underlying length (coded as a single factor with three levels: stressed long, stressed short and unstressed short). In order to allow testing for such interactions, unstressed vowels in both penultimate and ultimate positions were considered rightmost while those in earlier positions were classified as non-rightmost.

The distribution of data is given in Table 60 (totaling 2,215 vowels):

Table 60: Distribution of rightmost and non-rightmost vowels by stress-length distinction in the Yup'ik dataset.

	Rightmost	Non-Rightmost
Stressed Long	361	144
Stressed Short	359	416
Unstressed Short	579	356

The first model tested the effect of the interaction between stress-length and rightmost categorization on duration in Yup'ik vowels. For this model, the same fixed effects as in the duration model in Table 54 above were included, except that right edge proximity was replaced with rightmost categorization. The model summary is given in Table 61. The interaction between rightmost and stress-length categories had a significant effect on vowel duration. Accordingly, this result was followed up with pairwise comparisons, given in

Table 62. The bottom half of Table 61 contains the remainder of the fixed effects, which are the same as in Table 54 and will not be discussed further here.

Table 61: Fixed effects summary of the model examining the interaction between stress-length and rightmost categories and its effect on duration of Yup'ik vowels. Trimming removed 48 data points (2.17%).

Yup'ik Rightmost Duration Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	120.5346	14.33827	3.952734	8.406494	0.001154
Rightmost (Not Rightmost)	13.15929	3.445122	2143.974	3.819686	0.000137
Stress-Length Category (Stressed Long)	86.26679	3.590583	2143.602	24.02585	<2E-16
Stress-Length Category (Unstressed Short)	-20.8749	3.087298	2142.714	-6.76153	1.75E-11
Rightmost (Not Rightmost) * Stress-Length Category (Stressed Long)	-44.677	5.659247	2142.466	-7.89451	4.61E-15
Rightmost (Not Rightmost) * Stress-Length Category (Unstressed Short)	-23.2291	4.600644	2142.872	-5.0491	4.81E-07
Word Length (2 syllables)	-23.399	7.279638	2142.398	-3.21431	0.001327
Word Length (3 syllables)	-27.9899	7.38996	2142.623	-3.78755	0.000156
Word Length (4 syllables)	-39.8285	7.645988	2143.918	-5.20907	2.08E-07
Word Length (5 syllables)	-39.8858	7.684825	2143.477	-5.19021	2.30E-07
Word Length (6 syllables)	-37.2923	8.153468	2143.553	-4.5738	5.06E-06
Word Length (7 syllables)	-41.4205	8.842963	2143.111	-4.68401	2.99E-06
Word Length (8 syllables)	-32.6434	9.137037	2143.728	-3.57264	0.000361
Word Length (9 syllables)	-52.7132	12.06912	2142.751	-4.36761	1.32E-05
Word Length (10 syllables)	-55.5534	19.76804	2142.142	-2.81026	0.004995
Word Length (11 syllables)	-49.6922	13.18839	2144.225	-3.76787	0.000169
IP Position (Final)	48.02753	4.160975	2144.869	11.54237	<2E-16
Syllable Closure (Open)	44.17424	2.316633	2144.398	19.0683	<2E-16

Table 62: Pairwise comparison results for rightmost and stress-length categories in terms of duration of Yup'ik vowels. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Stressed Long Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	-31.5177	4.758823	2142.99	-6.623	4.44E-11
Stressed Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	13.15929	3.44669	2144.157	3.817949	0.000138
Unstressed Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	-10.0698	3.404151	2143.334	-2.9581	0.003129

The pairwise comparisons in Table 62 show that, within each stress-length category, rightmost vowels were distinct from non-rightmost vowels. Interestingly, non-rightmost long and unstressed short vowels were shorter than their rightmost counterparts, while non-rightmost stressed short vowels were longer than their rightmost counterparts. This reflects general word-final lengthening, except for stressed short vowels, which are shorter when rightmost. This result does not immediately imply that rightmost categorization uniquely affects the duration of stressed vowels in a consistent manner. While the longer durations among rightmost long vowels and rightmost unstressed vowels appears to be a general final lengthening effect, it is unclear at this point why this lengthening effect would not affect rightmost short stressed vowels. To summarize the duration results, there is not adequate evidence to show that all stressed vowels behave predictably differently when rightmost.

To address intensity, the same method as for duration was followed: the model as given in Section 4.4.2 was rerun on the dataset that included unstressed vowels, and right edge distance was replaced in the interaction with rightmost category. Moreover, recording genre as a random effect had to be removed for the model to converge. Like the model in section 4.4.2, the interaction between stress-length and rightmost categories did not have a significant effect on vowel intensity. The model summary is given in Table 63.

Table 63: Fixed effects summary of the model examining the interaction between stress-length and rightmost categories and its effect on intensity of Yup'ik vowels. Trimming removed 47 data points (2.1%).

Yup'ik Rightmost Intensity Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	82.29484	2.654941	3.895019	30.99686	8.27E-06
Rightmost (Not Rightmost)	1.475762	0.174941	2146.171	8.435757	6.00E-17
Stress-Length Category (Stressed Long)	1.69213	0.209883	2145.239	8.062254	1.23E-15
Stress-Length Category (Unstressed Short)	-1.38582	0.178085	2146.008	-7.78175	1.10E-14
Word Length (2 syllables)	-1.35747	0.52967	2145.14	-2.56286	0.010449
Word Length (3 syllables)	-2.55763	0.537585	2145.083	-4.75763	2.09E-06
Word Length (4 syllables)	-3.37217	0.556471	2145.221	-6.05993	1.60E-09
Word Length (5 syllables)	-3.67684	0.560873	2145.296	-6.55556	6.92E-11
Word Length (6 syllables)	-4.30265	0.593443	2145.299	-7.25031	5.78E-13
Word Length (7 syllables)	-4.12636	0.647136	2145.206	-6.37635	2.21E-10
Word Length (8 syllables)	-7.00804	0.672153	2145.096	-10.4263	<2E-16
Word Length (9 syllables)	-4.36581	0.890694	2145.099	-4.90158	1.02E-06
Word Length (10 syllables)	-5.69223	1.46485	2145.026	-3.88588	0.000105
Word Length (11 syllables)	-6.57572	0.974485	2145.121	-6.7479	1.92E-11
IP Position (Final)	-2.42539	0.29988	2146.254	-8.08785	1.00E-15
Onset Present (No Onset)	-0.69262	0.211186	2148.033	-3.27967	0.001056
Syllable Closure (Open)	1.122563	0.16834	2145.736	6.668428	3.28E-11

Table 63 shows that the general patterns of intensity as seen in Section 4.4.2 were maintained. When compared to a short stressed vowel, stressed long vowels were significantly higher in intensity, while unstressed short vowels were significant lower in intensity. Importantly, non-rightmost vowels were significantly higher in intensity than rightmost ones. The other fixed effects in Table 63 are the same as in the corresponding model in Section 4.4.2 (cf. Table 56). Overall, then, these results imply that rightmost vowels are lower in intensity than non-rightmost vowels, regardless of stress. Lastly, when the F0 model in Section 4.4.3 was rerun with rightmost categorization replacing right edge distance in its interaction, the interaction no longer had a significant effect on F0. In other words, the relationship between right edge distance and length had an effect on F0, whereas the relationship between rightmost and stress-length categories did not. The other fixed effects in the resulting F0 model (see Table 64) are the same as in the corresponding model in Section 4.4.3 (see Table 58), except that 11-syllable words did not differ significantly from the monosyllabic intercept in the present model. As before, this is likely due to the dearth of words of exceptional length. Note that because of instances where the measurement script was unable to return values for F0, this model was run on a dataset containing 2,147 vowels, rather than 2,215.

Table 64: Fixed effects summary of the model examining the interaction between stress-length and rightmost categories and its effect on F0 of Yup'ik vowels. Trimming removed 64 data points (2.98%).

Yup'ik Rightmost F0 Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	7.539778	1.416184	4.06017	5.324011	0.005743
Rightmost (Not Rightmost)	0.860236	0.154431	2064.972	5.570372	2.87E-08
Stress-Length Category (Stressed Long)	0.999168	0.174944	2056.355	5.711351	1.28E-08
Stress-Length Category (Unstressed Short)	1.15179	0.151594	2064.937	7.597867	4.54E-14
IP Position (Final)	-1.67261	0.259057	2062.531	-6.45653	1.33E-10
Word Length (2 syllables)	-0.16292	0.460519	2062.749	-0.35378	0.723536
Word Length (3 syllables)	-0.84919	0.468004	2062.378	-1.81449	0.069747
Word Length (4 syllables)	-0.95034	0.485323	2063.056	-1.95816	0.050346
Word Length (5 syllables)	-1.27477	0.488265	2062.986	-2.61081	0.009098
Word Length (6 syllables)	-1.09272	0.518287	2063.202	-2.10832	0.035124
Word Length (7 syllables)	-0.96419	0.572146	2062.754	-1.68522	0.092097
Word Length (8 syllables)	-0.94802	0.578786	2062.871	-1.63795	0.101585
Word Length (9 syllables)	0.022962	0.792903	2062.455	0.028959	0.9769
Word Length (10 syllables)	-0.98982	1.288673	2061.869	-0.76809	0.442522
Word Length (11 syllables)	-0.25916	0.899559	2062.705	-0.28809	0.773304

Interestingly, the summary in Table 64 shows that non-rightmost vowels were significantly higher in general than rightmost vowels, meaning this effect pertained to all three stress-length categories. Stressed long and unstressed short vowels were both significantly lower in F0 than stressed short vowels. Like intensity, then, these results do not imply that rightmost stressed vowels are produced in any distinctive way from non-rightmost stressed vowels, over and above general positional effects.

In summary, this follow-up investigation comparing rightmost and non-rightmost vowels has not provided evidence to support Miyaoka's hypothesis that rightmost stressed vowels are the most prominent in Yup'ik. Rightmost stressed vowels are generally less prominent than stressed vowels that come earlier in the word by having lower intensity and F0, though they often show final lengthening. In conclusion, then, this study has not shown that any given stress in Yup'ik is produced more consistently prominent than any other stress.

4.5. Results for Alutiiq

The same general methodology used in the Yup'ik study in Section 4 was followed for Alutiiq: the best linear mixed-effects models of stress, as described in Alden & Arnhold (n.d.), were applied to a subset containing only the stressed vowels in the Alutiiq dataset. In Alutiiq, length neutralization and accent are predictable by stress, length, and syllable closure (Leer 1985b, c; Alden & Arnhold n.d.); maximal/ternary head marking is not. There is a difference in production between maximal and minimal head marking wherein maximal heads are louder and higher than minimal heads, a phenomenon which in the literature is described as 'additional lengthening' (see Alden & Arnhold n.d.). For this reason, each stressed vowel was labelled for whether or not it is in a maximal head position, i.e. whether it received additional prominence. From there, for the sake of comparison between the two languages, the fixed variable that described distance from the right edge was tested, as well as its interaction with phonemic length.

Table 65 represents the distribution for the analyzed stressed syllables from the Alutiiq corpus. The data was inadequate (<5 tokens) for stressed syllables more than six syllables away from the right edge, and there were few long vowels further than five syllables away, and so only stressed vowels up to five syllables away from the right edge were included in this study. The resultant dataset was composed of 1,155 vowels.

Table 65: Data distribution for the acoustic investigation of potential differences among stressed syllables in Alutiiq, organized by right-edge proximity.

		Long Vowels	Stressed Short Vowels
Distance from Right Edge	1	56	357
	2	113	217
	3	58	158
	4	39	99
	5	17	14
Rightmost	Rightmost	96	506
	Not Rightmost	187	366
Syllable Closure	Closed	99	376
	Open	184	496

4.5.1. Duration

Figure 19 shows that stressed short vowels appear to be relatively equal in duration, with a slight rise throughout the word, which peaks at the penultimate. Long vowels, meanwhile, appear shorter word-initially, with a clear peak in duration word-finally.

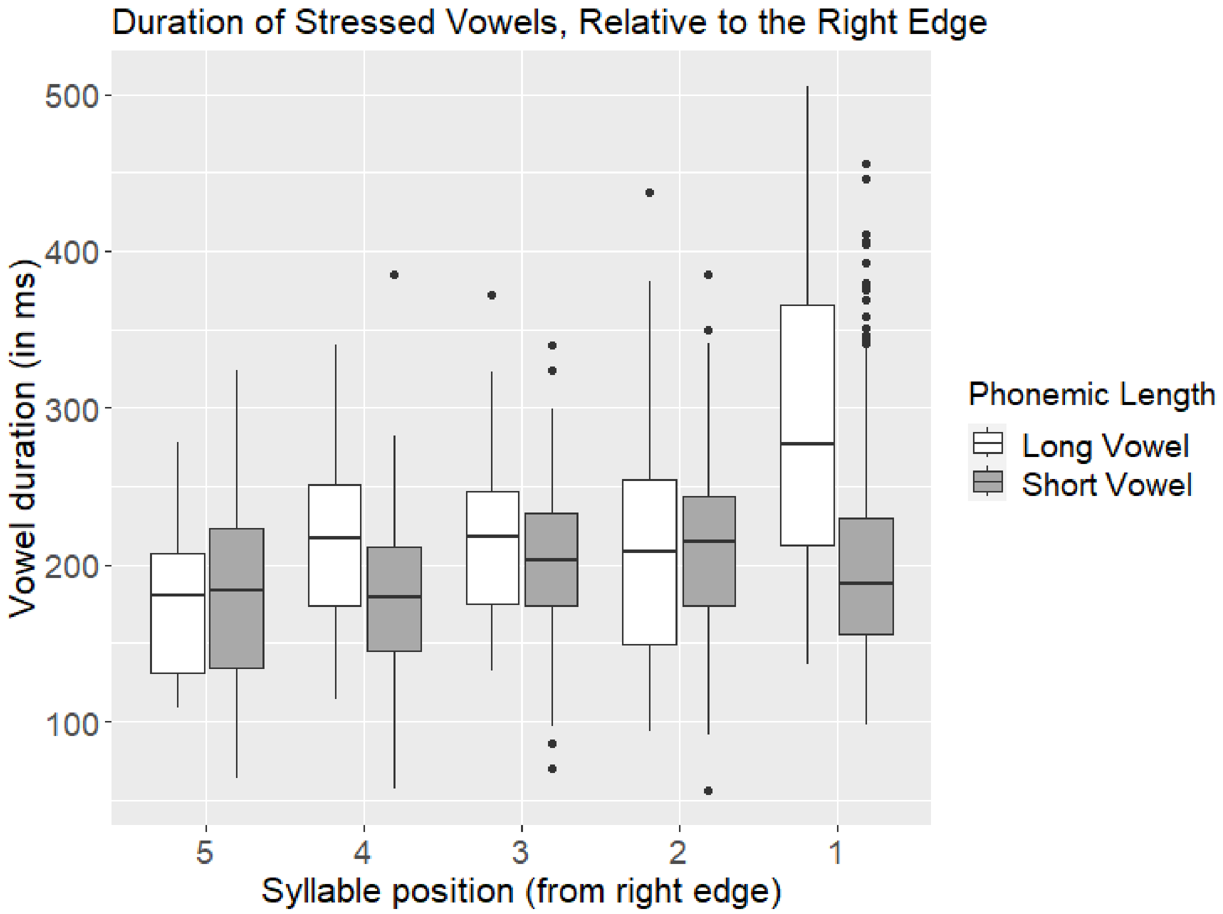

Figure 19: Stressed vowel durations in various positions within an Alutiiq word, by phonemic vowel length.

The best model for duration in Alden & Arnhold (n.d.) included filename and phoneme as random effects, and phonemic length, distance from the left edge, IP finality, and the presence of an onset and a coda as fixed effects. With the subset of stressed vowels used for this study, the inclusion of filename as a random effect resulted in a convergence failure, so it was removed. Next, distance from the left edge was replaced with distance from the right edge, which significantly improved the model. The inclusion of additional prominence as a fixed effect did not improve model fit. This matches the finding in Alden & Arnhold (n.d.) that showed that additional prominence (previously referred to in the literature as additional *lengthening*) did not affect a vowel's duration. The interaction between right edge proximity and vowel length had a significant effect on duration, and so was followed up with a pairwise comparison. The significant results are given in Table 67; for the full table, see Table 88 in Appendix B.

Table 66: Fixed effects summary of the model examining duration and right-edge proximity among Alutiiq stressed vowels. Trimming removed 20 data points (1.73%).

Alutiiq Duration Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	79.5738	7.882208	3.587781	10.09537	0.000923
Right Edge Proximity (2nd syllable)	-7.6966	3.798518	1114.173	-2.02621	0.042981
Right Edge Proximity (3rd syllable)	-11.7502	4.038554	1117.489	-2.9095	0.003692
Right Edge Proximity (4th syllable)	-27.4584	4.496929	1119.424	-6.10604	1.41E-09
Right Edge Proximity (5th syllable)	-25.676	5.671693	1121.704	-4.52704	6.62E-06
Vowel Length (Long)	32.05204	4.583264	1121.913	6.993279	4.60E-12
Right Edge Proximity (2 syllables) * Vowel Length (Long)	-18.8668	5.792536	1121.034	-3.25709	0.001159
Right Edge Proximity (3 syllables) * Vowel Length (Long)	-9.79028	6.459031	1120.11	-1.51575	0.129865
Right Edge Proximity (4 syllables) * Vowel Length (Long)	7.422182	7.362302	1120.586	1.008133	0.313608
Right Edge Proximity (5 syllables) * Vowel Length (Long)	-17.4266	9.817877	1119.894	-1.77499	0.076171
IP Final (Yes)	-21.8365	4.150408	1116.17	-5.26128	1.71E-07
Onset Present (No onset)	2.933317	3.631472	1120.005	0.807749	0.419407
Syllable Closure (Open)	43.95327	2.361966	1121.005	18.60876	<2E-16

Table 67: Pairwise comparison results for right edge proximity and phonemic length categories in terms of duration of Alutiiq stressed vowels (significant differences only, see text). Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	26.56342	5.707393	1121.295	4.654213	3.58E-05
Right Edge Proximity (1) vs. Right Edge Proximity (3)	21.54043	6.202633	1120.605	3.472789	0.004849
Right Edge Proximity (1) vs. Right Edge Proximity (4)	20.03624	6.976182	1120.391	2.872093	0.033736
Right Edge Proximity (1) vs. Right Edge Proximity (5)	43.10261	8.780638	1119.841	4.908825	1.04E-05
Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (3)	11.75015	4.05397	1117.702	2.898432	0.031249
Right Edge Proximity (1) vs. Right Edge Proximity (4)	27.45842	4.511803	1119.546	6.08591	1.59E-08
Right Edge Proximity (1) vs. Right Edge Proximity (5)	25.67597	5.684568	1121.718	4.516784	6.80E-05
Right Edge Proximity (2) vs. Right Edge Proximity (4)	19.76182	3.648956	1119.068	5.415747	7.43E-07
Right Edge Proximity (2) vs. Right Edge Proximity (5)	17.97936	5.092762	1119.07	3.530376	0.003944
Right Edge Proximity (3) vs. Right Edge Proximity (4)	15.70827	3.87317	1119.07	4.055662	0.000512

Table 67 shows that among long vowels, ultimates were significantly longer than all vowels further away from the right edge. Among short vowels, meanwhile, ultimates were significantly longer than 3rd-syllable, 4th-syllable, and 5th-syllable vowels, but there was no significant difference between ultimates and penultimates. Additionally, penultimates were longer than 4th-syllable and 5th-syllable vowels, and antepenultimates were longer than 4th-syllable. Altogether, these results imply that stressed vowels lengthen incrementally across the Alutiiq word rather than any individual position being made distinct.

Returning then to the bottom half of Table 66, a vowel in an IP-final syllable was significantly shorter than a non-final vowel. This diverges from Yup'ik, where IP-final stressed vowels were longer in duration than non-IP final one. Recall that the dataset for this study included only stressed vowels: the apparent lack of IP-final lengthening here does not necessarily indicate broader trends across all syllables. While the inclusion of the presence of an onset as a fixed effect did improve model fit, it did not significantly affect vowel duration. Finally, vowels in open syllables were significantly longer than vowels in closed syllables.

4.5.2. Intensity

Figure 20 shows that, generally, intensity seems to be similar across syllable positions, although there is a slight trend for intensity to decrease across the word. There is a visible drop in values word-finally, which is more obvious for stressed short vowels than long vowels. Lastly, there appears to be a relative peak in intensity among long vowels at the 4th syllable.

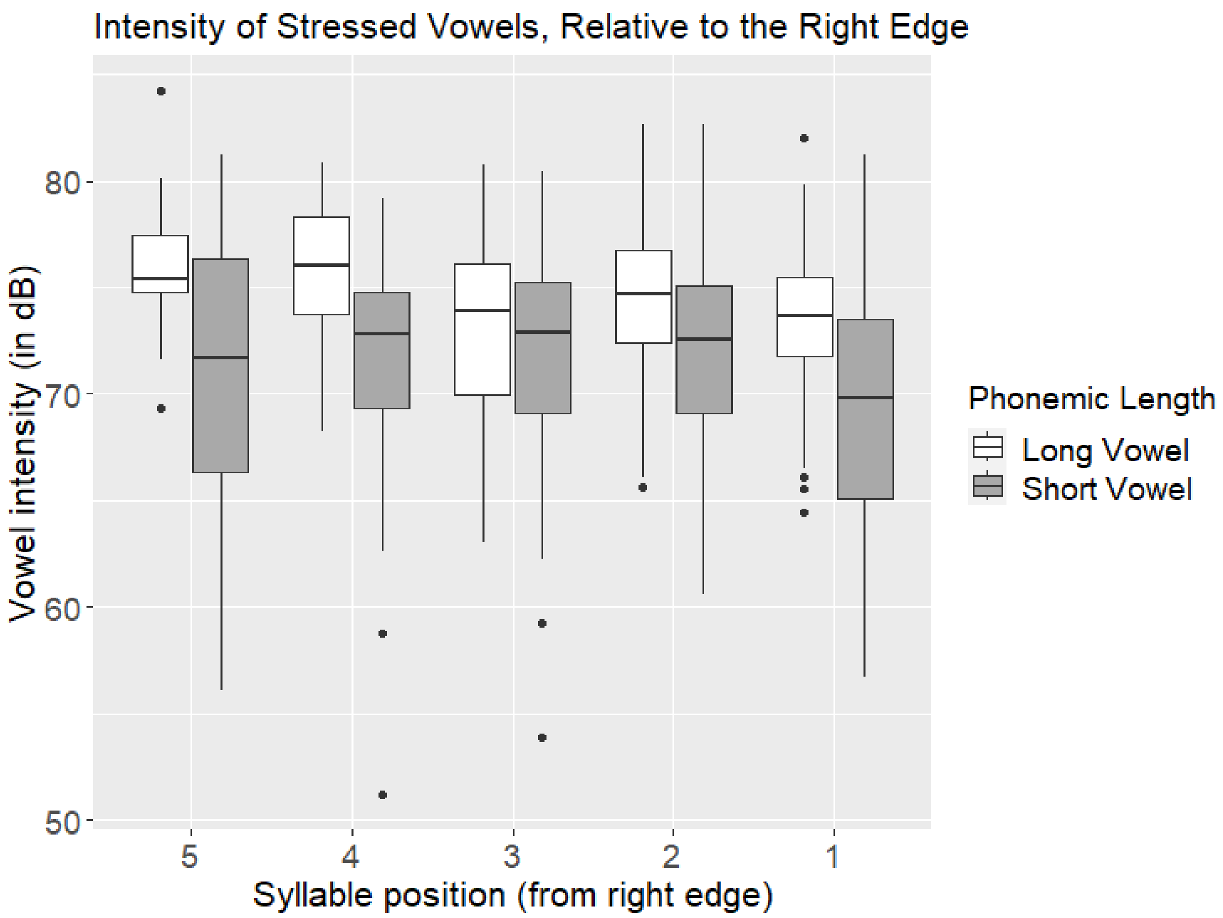

Figure 20: Stressed vowel intensity in various positions within an Alutiiq word, by phonemic vowel length.

The intensity model started from the previously reported model that included distance from the left edge, phonemic vowel length, IP finality, syllable closure, the sum total of syllables in the word, and the presence of an onset and coda. First, distance from the left edge was replaced with distance from the right edge, which was shown to improve the model. All of the tested fixed effects, except for IP finality, improved model fit. The findings in Alden & Arnhold (n.d.) also showed that there is a difference in intensity between maximal and minimal foot heads, so the present model contained additional prominence as a predictor as well. The interaction between this predictor and length, as well as a three-way interaction with right edge proximity were tested, but did not improve model fit.

The interaction between right edge proximity and vowel length had a significant effect on stress intensity, and so pairwise comparisons were done to explore this relationship. The significant results are given in Table 69; see Table 89 in Appendix B for the full table.

Table 68: Fixed effects summary of the model examining intensity and right-edge proximity among Alutiiq stressed vowels. Trimming removed 15 data points (1.3%).

Alutiiq Intensity Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	71.66944	1.212536	89.46049	59.10707	<2E-16
Right Edge Proximity (2nd syllable)	1.966658	0.483812	1116.362	4.06492	5.14E-05
Right Edge Proximity (3rd syllable)	3.411968	0.409051	1115.468	8.341178	2.10E-16
Right Edge Proximity (4th syllable)	4.174016	0.549654	1114.141	7.5939	6.55E-14
Right Edge Proximity (5th syllable)	4.155759	0.772126	1119.053	5.382228	8.96E-08
Vowel Length (Long)	3.507236	0.591863	1119.847	5.925757	4.13E-09
Right Edge Proximity (2 syllables) * Vowel Length (Long)	-3.8756	0.76316	1119.965	-5.07836	4.46E-07
Right Edge Proximity (3 syllables) * Vowel Length (Long)	-1.71627	0.848167	1118.433	-2.0235	0.043259
Right Edge Proximity (4 syllables) * Vowel Length (Long)	-1.08247	0.973689	1119.979	-1.11172	0.266496
Right Edge Proximity (5 syllables) * Vowel Length (Long)	-0.13621	1.303354	1119.55	-0.1045	0.916787
Word Length (2 syllables)	-0.28493	1.118184	1117.637	-0.25481	0.798914
Word Length (3 syllables)	-2.74914	1.123296	1118.13	-2.44739	0.014543
Word Length (4 syllables)	-3.43734	1.123673	1118.874	-3.05902	0.002273
Word Length (5 syllables)	-4.29353	1.14913	1119.236	-3.73633	0.000196
Word Length (6 syllables)	-4.39044	1.213323	1118.72	-3.61852	0.00031
Word Length (7 syllables)	-5.0185	1.376089	1118.41	-3.64693	0.000278
Word Length (8 syllables)	-7.03529	2.070459	1117.6	-3.39794	0.000703
Onset Present (No onset)	-4.49462	0.495321	1119.181	-9.07417	<2E-16
Syllable Closure (Open)	0.853845	0.270308	963.9474	3.158784	0.001634
Additional Prominence (Yes)	1.253277	0.3856	1119.046	3.250201	0.001188

Table 69: Pairwise comparison results for right edge proximity and phonemic length categories in terms of intensity of Alutiiq stressed vowel (significant differences only, see text). Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-22.4614	6.490947	1118.936	-3.46042	0.005066
Right Edge Proximity (3) vs. Right Edge Proximity (4)	18.20882	4.719561	1117.74	3.85816	0.00114
Right Edge Proximity (3) vs. Right Edge Proximity (5)	19.87339	6.54281	1117.705	3.03744	0.020584

Interestingly, there were no significant differences in intensities among long vowels. Among short vowels, meanwhile, ultimates were significantly quieter than 3rd-syllable vowels. 3rd-syllable vowels were in turn significantly louder than 4th-syllable and 5th-syllable vowels. Together, these results imply that stress intensity peaks word-medially and falls word-finally.

In the remainder of Table 68, the bottom half of the table shows that stressed vowels in words containing three or more syllables were significantly quieter than the stress of a monosyllable, an effect that seems larger the longer the word becomes. Lacking an onset resulted in a significantly quieter stress than a syllable with an onset, while an open syllable was significantly louder than a closed one. Finally, an additionally prominent stress was significantly louder than a non-prominent stress, corroborating the results in Alden & Arnhold (n.d.).

4.5.3. F0

As Figure 21 shows, there appears to be a slight fall in F0 values over the course of a word for both long and short vowels. Long and short values largely overlap in their F0, apart from word-finally where long vowels appear to be notably higher in F0 than short vowels.

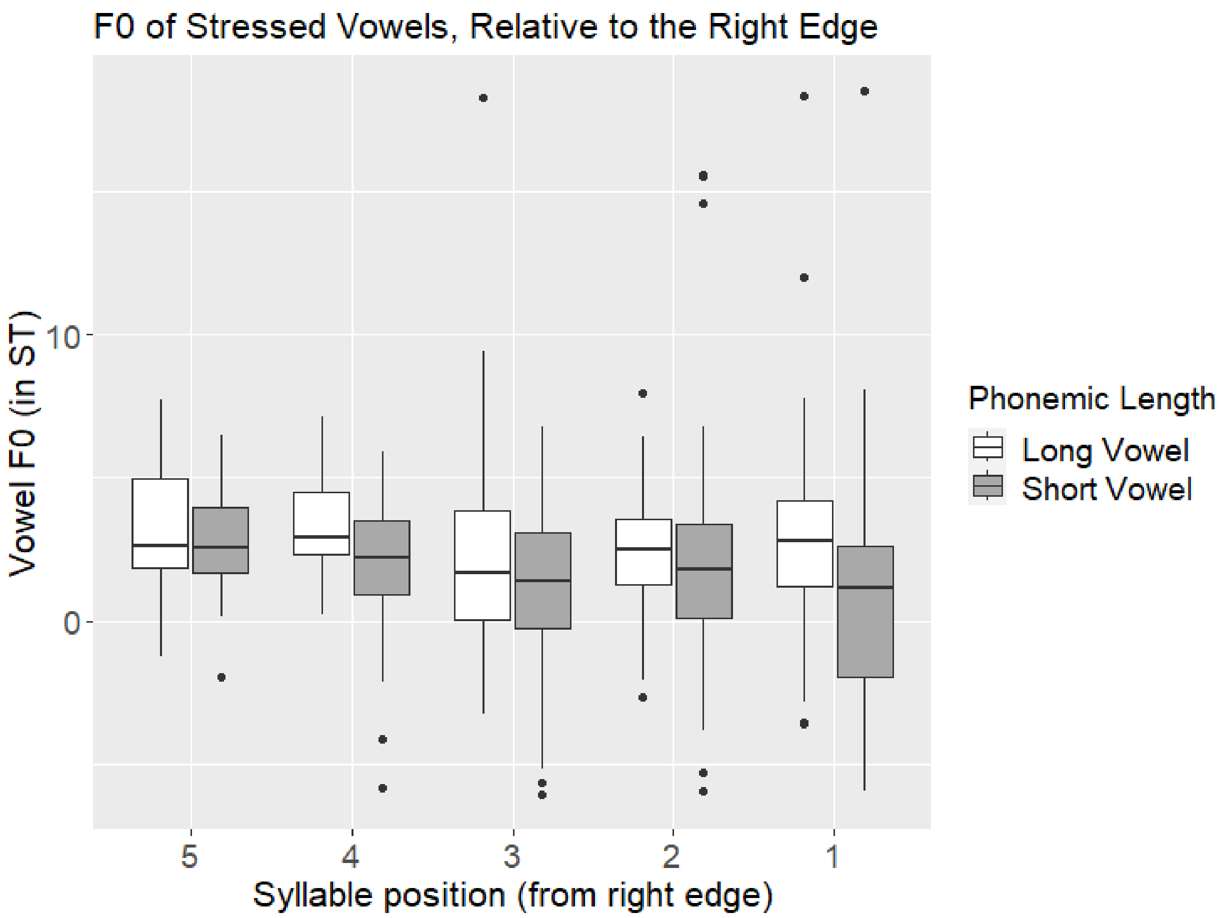

Figure 21: Stressed vowel F0 in various positions within an Alutiiq word, by phonemic vowel length.

There were 55 instances where F0 could not be measured; their removal resulted in a slightly smaller dataset (N =1100). The best model for F0, as reported in Alden & Arnhold (n.d.), included distance from the left edge, underlying length, and syllable closure as fixed effects, and file and phoneme as random effects. Here, distance from the left edge was replaced with distance from the right edge. This replacement resulted in an improved fit. Syllable closure was additionally included as a fixed effect and, again, additional prominence was included, as well (see Table 70).

The interaction between right edge proximity and vowel length did not significantly improve model fit, and so it was not included in this model. The model summary in Table 70 shows that 2nd-syllable and 3rd-syllable were not significantly different from an ultimate vowel. 4th-syllable and 5th-syllable vowels, however, were significantly higher in F0 than ultimates, implying that in Alutiiq, stressed vowels earlier in the word tend to be higher. Long vowels were significantly higher than short vowels. While the inclusion of syllable closure did improve model fit, there was no significant difference in F0 between a vowel in an open or closed syllable. Finally, vowels receiving additional prominence (i.e. the heads of maximal feet) were significantly higher in F0 than those not receiving it. As with intensity above, because this effect was significant, an interaction between additional prominence and vowel length was tested, but it did not improve model fit.

Table 70: Fixed effects summary of the model examining F0 and right-edge proximity among Alutiiq stressed vowels. Trimming removed 12 data points (1.09%).

Alutiiq F0 Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.9916	0.253281	15.78391	3.915016	0.001263
Right Edge Proximity (2nd syllable)	0.090321	0.327829	982.1031	0.275511	0.782981
Right Edge Proximity (3rd syllable)	0.384538	0.247328	960.6451	1.55477	0.12033
Right Edge Proximity (4th syllable)	0.958487	0.32189	1030.249	2.977688	0.002972
Right Edge Proximity (5th syllable)	1.398787	0.451811	1066.089	3.095955	0.002013
Vowel Length (Long)	1.072593	0.197924	1078.08	5.419208	7.38E-08
Syllable Closure (Open)	-0.26328	0.178767	568.4916	-1.47278	0.141364
Additional Prominence (Yes)	0.769123	0.281579	1077.984	2.731463	0.006408

To follow up on the observation that stressed vowels earlier in the word may be higher than those later in the word, the model was releveled around each position relative to the right edge. The significant results are given in Table 71, with each significant position relative to the releveled intercept listed under that intercept (for the full table, see Table 90 in Appendix B). Relevelling around penultimates showed that they were significantly lower in F0 than 4th-syllable and 5th-syllable vowels. 3rd-syllable were significantly lower than 5th-syllable as well. Overall, then, these results show that F0 tends to fall across stressed vowels in a word, with no particular peaks.

Table 71: *Fixed effects summary of the Alutiiq F0 model, releveled (significant differences only, see text).*

Relevelled Alutiiq F0 Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (2nd syllable)	1.120903	0.344976	46.45212	3.249222	0.002154
Right Edge Proximity (4th syllable)	0.818839	0.297307	1072.835	2.754189	0.005983
Right Edge Proximity (5th syllable)	1.340143	0.450133	1071.922	2.977214	0.002974
Intercept (3rd syllable)	1.367921	0.27889	20.83922	4.904876	7.66E-05
Right Edge Proximity (5th syllable)	1.093124	0.461718	1072.206	2.367514	0.018085

4.5.4. Summary of Results

The results for Alutiiq duration, intensity, and F0 among stressed vowels have not shown evidence that any particular syllabic position is more prominent than others. Rather, they show a general tendency for stressed vowels to lengthen towards the end of the word, with this effect being particularly noticeable on long vowels. Values for intensity and F0, meanwhile, seem to generally lower throughout the word. For short vowels only, antepenultimate stressed vowels are also higher in intensity than stressed vowels both earlier and later in the word.

These results do not provide evidence that stress in Alutiiq is culminative. For the purposes of comparative testing with the Yup'ik data, however, they should be followed up with hypothesis testing regarding rightmost stressed vowels. Furthermore, in order to definitively state that the observed patterns across Alutiiq stressed vowels are the result of general tendencies that affect all syllables, and not only stressed vowels, additional testing with a dataset that includes unstressed vowels is required. The following section presents this additional test, in parallel with the results given in section 4.5.

4.5.5. Follow-up: Testing the Rightmost Hypothesis in Alutiiq

Following the same methodology as in the parallel rightmost investigation in Yup'ik, this follow-up investigation was done on a dataset that included both the stressed vowels in the preceding Alutiiq analyses, as well as unstressed vowels. Each token in the Alutiiq dataset, whether stressed or unstressed, was assigned a rightmost label; because rightmost stressed vowels can occur in the penultimate and ultimate positions, for the sake of comparison both penultimate and ultimate unstressed vowels were considered rightmost. Table 72 shows the distribution of data (totalling 2,185 vowels):

Table 72: Distribution of rightmost and non-rightmost vowels by stress-length distinction in the Alutiiq dataset.

	Rightmost	Non-Rightmost
Stressed Long	187	96
Stressed Short	366	506
Unstressed Short	744	286

In this series of analyses, the first model tested the effects of the interaction between rightmost and stress-length category on Alutiiq vowel duration. This model is the same as the one presented in Section 4.5.1, with rightmost categorization replacing distance from the right edge. The model is summarized in Table 73. The interaction was significant, and so modelling was followed by pairwise testing (given in Table 74).

Table 73: Fixed effects summary of the model examining the interaction between stress-length and rightmost categories and its effect on duration of Alutiiq vowels. Trimming removed 44 data points (2.01%).

Alutiiq Rightmost Duration Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	81.5309	7.095712	3.243923	11.49016	0.000975
Rightmost (Not Rightmost)	-11.1305	2.167737	2131.005	-5.13462	3.08E-07
Stress-Length Category (Stressed Long)	37.63066	3.259775	2130.29	11.54395	<2E-16
Stress-Length Category (Unstressed Short)	-14.7923	1.759858	2129.185	-8.40542	8.00E-17
Rightmost (Not Rightmost) * Stress-Length Category (Stressed Long)	-14.4343	4.149908	2129.932	-3.47822	0.000515
Rightmost (Not Rightmost) * Stress-Length Category (Unstressed Short)	-6.43033	2.739987	2130.301	-2.34685	0.019024
IP Position (Final)	1.216025	1.992501	2131.538	0.610301	0.541728
Onset Present (No Onset)	-6.03965	2.151226	2129.911	-2.80754	0.005038
Syllable Closure (Open)	22.58253	1.535537	2131.142	14.7066	<2E-16

Table 74: Pairwise comparison results for rightmost and stress-length categories in terms of duration of Alutiiq vowels. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Stressed Long Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	-25.5648	3.691435	2129.425	-6.92544	5.73E-12
Stressed Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	-11.1305	2.1686	2131.017	-5.13258	3.12E-07
Unstressed Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	-17.5608	1.890698	2129.534	-9.28802	3.75E-20

The pairwise comparisons in Table 74 show that, within all three stress-length categories, non-rightmost vowels were significantly shorter than rightmost vowels. That this effect extends to unstressed vowels shows that this word-final lengthening is not limited to stressed vowels, and so it is not an indicator that rightmost stressed vowels in Alutiiq are significantly distinct by virtue of being primary stress. Rather, they are lengthened as a result of their word-final position, along with unstressed vowels. This is similar to the Yup'ik result for duration across stressed and unstressed syllables in Section 4.5, except here, the effect was consistent for all vowels, regardless of phonemic length.

The lower half of Table 73 shows that IP-final vowels were not generally different from non-final vowels (unlike in the model with more fine-grained position distinctions in Table 66). However, vowels in syllables without onsets were significantly shorter than those with onsets (again unlike in Table 66), and those in open syllables were significantly longer than those in closed syllables (this effect is the same in both models).

Turning then to intensity, the model described in Section 4.5.2 (see Table 68) was replicated with rightmost categorization replacing right-edge distance in the interaction with stress-length category. As with Alutiiq duration, the interaction was shown to have a significant effect on intensity (see Table 75), and so modelling was followed up with a pairwise comparisons (Table 76).

Table 75: Fixed effects summary of the model examining the interaction between stress-length and rightmost categories and its effect on intensity of Alutiiq vowels. Trimming removed 18 data points (0.82%).

Alutiiq Rightmost Intensity Model	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	72.71132	1.25356	35.09204	58.00386	<2E-16
Rightmost (Not Rightmost)	1.632082	0.301659	2150.808	5.41035	6.99E-08
Stress-Length Category (Stressed Long)	2.702238	0.469621	2149.821	5.754077	9.96E-09
Stress-Length Category (Unstressed Short)	-0.59832	0.25903	2149.447	-2.30985	0.020991
Rightmost (Not Rightmost) * Stress-Length Category (Stressed Long)	-1.46319	0.604965	2149.56	-2.41863	0.015662
Rightmost (Not Rightmost) * Stress-Length Category (Unstressed Short)	-0.44668	0.407865	2150.245	-1.09516	0.27357
Word Length (2 syllables)	-1.80388	1.07028	2148.212	-1.68543	0.092051
Word Length (3 syllables)	-2.85888	1.064274	2148.39	-2.68622	0.007282
Word Length (4 syllables)	-3.08157	1.066999	2148.59	-2.88807	0.003915
Word Length (5 syllables)	-3.73288	1.077039	2148.568	-3.46587	0.000539
Word Length (6 syllables)	-3.40237	1.114105	2148.447	-3.0539	0.002287
Word Length (7 syllables)	-4.5069	1.221912	2148.35	-3.6884	0.000231
Word Length (8 syllables)	-4.10544	1.672339	2148.369	-2.45491	0.014171
Onset Present (No Onset)	-2.52792	0.319861	2149.381	-7.90319	4.30E-15
Syllable Closure (Open)	0.315026	0.215035	2108.112	1.464998	0.143071
Additional Prominence (Yes)	1.382903	0.265831	2149.369	5.202191	2.16E-07

Table 76: Pairwise comparison results for rightmost and stress-length categories in terms of intensity of Alutiiq vowels. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Stressed Long Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	0.168895	0.535809	2149.13	0.315215	0.752629
Stressed Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	1.632082	0.301865	2150.805	5.406671	7.13E-08
Unstressed Short Vowel					
Contrast	Estimate	SE	df	t ratio	p value
Not Rightmost vs. Rightmost	1.185406	0.284034	2149.333	4.173469	3.12E-05

The pairwise comparisons show that within stressed long vowels, there was no significant distinction between rightmost and non-rightmost vowels. However, within stressed and unstressed short vowels, non-rightmost vowels were significantly louder than rightmost vowels. That this effect is limited to short vowels, and moreover, that it applies to both stressed and unstressed short vowels, implies that this rightmost reduction in intensity is not uniquely associated with stress.

The rest of Table 75 shows the same effects as Table 68 above, except that the effect of syllable closure was not significant in the present model.

The final investigation into the rightmost hypothesis for Alutiiq compared rightmost and non-rightmost vowels in terms of F0. As with the previous models, the F0 model given in Section 4.5.3 was reproduced, with right-edge distance replaced with rightmost categorization. This dataset was larger than the dataset for the model in that section because it included unstressed vowels. However, where the previous two rightmost tests (duration and intensity) were done on a dataset of 2,185 vowels, this model of F0 was run on a dataset of 2,027 vowels due to cases where F0 could not be measured. Unlike the Alutiiq duration and intensity rightmost models, however, the interaction between rightmost categorization and stress-length category did not have a significant effect on vowel F0 (recall that the best model of F0 in stressed Alutiiq vowels in Table 70 above did not include a significant interaction either). The model summary is presented in Table 77:

Table 77: Fixed effects summary of the model examining the interaction between stress-length and rightmost categories and its effect on the F0 of Alutiiq vowels. Trimming removed 30 data points (1.48%).

Alutiiq Rightmost F0 Model	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	0.95008	0.231076	15.04682	4.111546	0.000919
Rightmost (Not Rightmost)	0.731159	0.129339	1970.563	5.653054	1.81E-08
Stress-Length Category (Stressed Long)	0.979819	0.199626	1989.628	4.90827	9.94E-07
Stress-Length Category (Unstressed Short)	-0.13912	0.146711	1979.717	-0.94825	0.343119
Syllable Closure (Open)	-0.36406	0.141779	995.9084	-2.56778	0.01038
Additional Prominence (Yes)	0.840149	0.180576	1971.722	4.652599	3.50E-06

This model summary shows firstly that non-rightmost stressed short vowels were significantly higher in F0 than rightmost ones. Additionally, stressed long vowels had significantly higher F0 compared to stressed short ones, while F0 for unstressed vowels was not significantly different from that of stressed short vowels. In this way, these results parallel the Alutiiq rightmost intensity results, where rightmost short vowels are generally less prominent than non-rightmost short vowels, regardless of stress.

The only other fixed effects in Table 77 outside of stress-length were mostly the same as those in Table 70. The only difference was that the effect of syllable closure, which did not reach significance for the model of only stressed vowels, was significant in the present model: vowels in open syllables were significantly lower in F0 than vowels in closed syllables.

To summarize the Alutiiq rightmost hypothesis testing, none of the three models presented in this section (for duration, intensity, and F0) implied a relationship between rightmost categorization and any particular stress effect. There is not adequate evidence to support the hypothesis, adopted from Miyaoka's impressionistic descriptions of Yup'ik, that rightmost stressed vowels are primary in Alutiiq. Where rightmost vowels were significantly distinct from non-rightmost stressed vowels, they were less prominent: in this way, the Alutiiq results mirror the Yup'ik results. Of the three original Alutiiq models in Sections 4.5.1-4.5.3, only the duration figure appeared to have any kind of right-edge peak, in this case involving long vowels. However, the models given there and in Section 4.5.5 show clearly that there is no consistent measurable prominence peak among right-edge or rightmost stressed vowels in Alutiiq.

4.6. Discussion

As sister languages, Yup'ik and Alutiiq share some fundamental metrical features: both, for instance, create feet iteratively from left to right. Both have an underlying length contrast in their vowels, and both distinguish stressed long, stressed short, and unstressed short syllables. Furthermore, both languages use duration, intensity, and maximum F0 to differentiate stressed and unstressed syllables (see Alden & Arnhold submitted for Yup'ik, Alden & Arnhold n.d. for Alutiiq). Finally, both have been described as non-culminative at the word level, making no primary-secondary stress distinctions within prosodic words.

This aim of this chapter was to examine stressed vowels within words to determine if and how each language satisfies culminativity: namely, whether there are hierarchical distinctions among stressed vowels within the word domain. As this series of analyses has shown, neither Yup'ik nor Alutiiq appear to demonstrate notably distinct behaviors on rightmost stressed vowels. Regarding our hypotheses, there is not adequate evidence to endorse H_{Culm} as formulated in (27) in either language, nor any of the sub-hypotheses in (28). In this section, we will discuss what it means for Yup'ik and Alutiiq to not be culminative, given the nature of their stress rules and metrical parameters.

The results given in section 4 show that in Yup'ik, there is no single stress position in which vowels consistently surface differently than any other position elsewhere in the word. Further examination revealed that the rightmost stress category, in which stressed vowels are the closest to the right edge of their respective prosodic word, only interacts with the stress-length category (stressed long, stressed short, unstressed short) in terms of duration. For duration, then, it was shown that non-rightmost long and unstressed short vowels are significantly shorter than rightmost ones, suggesting general word-final lengthening, and non-rightmost stressed short vowels are significantly longer than rightmost ones. This is not a pattern of behavior that is reflected in the corresponding intensity and F0 models. Instead, for both intensity and F0, the interaction between stress-length and rightmost categories was not significant, and non-rightmost vowels were significantly more prominent than rightmost ones, i.e. rightmost vowels were lower in F0 and intensity. Ultimately, these results fail to corroborate the findings in Gabas (1996), namely the result that Yup'ik stressed vowels exhibit the highest pitch on the rightmost stressed syllable, as originally posited by Miyaoka (1971).

There are no claims regarding the distribution of primary stress in the Alutiiq literature. In examining the effects of right-edge distance and rightmost categorization in section 5, this study of Alutiiq stressed vowels was intended to allow for direct comparison between Yup'ik and Alutiiq. The two languages were similar, insofar as neither featured prominence effects that were associated with any given position relative to the right edge—or, whenever a certain acoustic correlate did increase towards the right edge, it affected stressed and unstressed syllables alike (for instance, word-final lengthening). In terms of Alutiiq intensity, there was a general trend for intensity to become lower across a word. The only notable effect of rightmost position on intensity was a reduction in prominence. There was no indication that any given Alutiiq stress position is louder than any other. Lastly, there was no measurable relationship between F0 and syllable position beyond a general trend for F0 to become lower across a word. While rightmost stressed vowels are significantly different than others, there is no indication that this is related to a distinguishing stress effect. Like with intensity, these syllables are lower in F0 than other stressed vowels, and there was no position that was privileged above the ultimate position in any way that was not otherwise explainable by word-finality effects. This word-final reduction in F0 may instead be a result of word-final phonology, such as the HL boundary tone in Yup'ik (cf. Woodbury, 1984), also working in Alutiiq.

The natural extension of the conclusion that Yup'ik and Alutiiq are not culminative at the word level is to question why it matters that stress be culminative, or what this conclusion changes about the contemporary conception of the metrics of the two languages. In metrical theory, stressed vowels are generated by parameters: in these languages, parameters define binary iambic feet iteratively from left-to-right, with some respect to syllable weight in Yup'ik (see Alden & Arnhold submitted, 2022 for a discussion of Yup'ik syllable weight) and binary-ternary footing in Alutiiq (see Hewitt, 1994; Hewitt & Ann, 1991; Leer, 1985b, 1985c; Martínez-Paricio & Kager, 2016; Rice, 1988; among others). Authors such as Hayes (1995) propose that Yup'ik and Alutiiq[25] feature cyclical footing wherein the first cycle of stress derivation foots heavy syllables first, and that in the absence of heavy syllables, the first cycle foots iambically from left to right. Culminativity in metrical theory is therefore not a consequence of rule ordering but is rather a universal of stress systems that is subject to parametric variation that determining its domains and expression (Hayes 1995:25). The same is true of stress and culminativity in an Optimality Theory framework, although OT works under constraints rather than parameters (Bakovic, 1996; Houghton, 2006, for OT in Yup'ik, Alutiiq).

The notion of culminativity as parametric has since been developed by authors such as Hyman (2006, 2009) and Bogomolets (2020). Bogomolets in particular proposes that, in the context of highly synthetic languages, culminativity can be seen as a macroparameter containing within it a language-specific set of microparameters. This allows for morphosyntactic boundaries to behave as micro-domains within the polysynthetic word, such that stress may be culminative within the root or stem, the affixal domain, or some other language-specific structure. Bogomolets' proposed paradigm of microparameters for stress in highly synthetic languages is presented in (29).

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[25] Hayes refers to Alutiiq as *Pacific Yup'ik*.

(29) Culminativity parameters (adapted from Bogomolets, 2020:194-196)

i. (*Macro)* Is stress culminative in *some* domain in the language? Y/N, if Y:
  a. (*Micro)* Is stress culminative in roots? Y/N
  b. (*Micro)* Is stress culminative in stems? Y/N
  c. (*Micro)* Is stress culminative in the morphological word? Y/N
ii. (*Macro)* Are two adjacent units bearing stress (stress clash) banned in *some* domain? Y/N

In (29), the sample microparameters illustrate how this view of culminativity allows for both distributional parameters, exploring the domains of culminativity within morphologically complex words, and for constraining parameters, which can limit the expression of stress, for instance, in clash environments. In general, this proposition refines the widely accepted maxim that *one stress = one prosodic word* (Hayes, 1995a; van der Hulst, 1999), which is problematic for synthetic languages where the domain of culminativity may be smaller than both the prosodic and morphosyntactic words. For example, in highly synthetic Dene languages, stress patterns demarcate individual morphemes, or salient morphosyntactic spans within complex word structures (see McDonough, 1999, 2000; Rice, 2005, 2019).

Thus, metrical theory allows for languages to satisfy culminativity at prosodic domains below the word level—namely, that the stressed-unstressed distinction within, say, an iamb satisfies culminativity at the foot level, even if culminativity is otherwise unfulfilled at the word level (Hayes, 1995:25; Bogomolets, 2020). In this view, culminativity becomes less about privileging a single stress as primary and more about defining syllabic relationships in terms of binaries (e.g. heads and dependents) within language-specific domains. For a language that satisfies word-level culminativity, then, there is a distinction in the word domain between primary and secondary stress. For a language that satisfies only foot-level culminativity (Dixon, 1977 for Yidin; Voegelin, 1935 for Tübatulabal), the binary distinction is between foot heads and non-heads, but at the word level, there may not be a primary-secondary distinction. This is not fundamentally opposed to van der Hulst's (2023) claim that words in all languages have a word domain head: he specifically states that such heads do not necessarily have to be correlated with any acoustic expression if the head's relationship to the rest of the word is cognitive and governs mental representations of word-internal structure (573). Therefore, it may well be that, per van der

Hulst’s assertion, in Yup’ik and Alutiiq the word domain head is cognitively present, but not prosodically marked.

The function of culminativity in this view, then, can be described as the tendency of a language to create ordered binary structures, with the parameters of individual languages determining the domain and expression of this binary distinction. This definition aligns much more closely to Bogomolets’ (2020) proposition that culminativity is a macroparameter composed of microparameters. In Yup’ik, for instance, which seems to form longer words composed of more morphemes overall than Alutiiq, the microparameter of culminativity may be fulfilled not at the word level, but instead at the morphemic level. In this case, stress level distinctions may instead be made within spans of morphemes, or otherwise within morphemes themselves. Follow-up research on a more targeted dataset composed of Yup’ik words containing morphemes of various syllable numbers, or words of various morphemic compositions, could shed light on whether this is the case. The results here have shown that even stressed vowels on the morphosyntactic head are not marked with a primary distinction: if they were, the results of the studies here would show a peak in acoustic values on stressed vowels early in the word, usually the first stress, since roots are always word-initial in Yupik languages (see Jacobson, 1984 for a discussion on the relationship between roots and stress in Yup’ik). However, there does not appear to be any relationship between duration, intensity, and F0 on the one hand and privileging of the word root on the other hand in either Yup’ik or Alutiiq.

In Alutiiq, meanwhile, regardless of the absence of a classical primary-secondary stress distinction, there is nevertheless a binary distinction between two stress levels, both within the domain of the foot and across foot types (see Alden & Arnhold, n.d., for a discussion of stress levels in Alutiiq). In short, Alutiiq may not need to distinguish primary and secondary *stressed syllables* at the word level because it defines several other levels of prosodic binaries: between foot heads and non-heads; between minimal (binary) and maximal (ternary) foot heads; and between stressed vowels targeted for accent and upstep (Alden & Arnhold, n.d.). Take, for instance, a word composed of two heavy feet (the smallest possible set of sequential stressed syllables in Alutiiq), as in (30), or two binary iambs, as in (31). In Alutiiq, H accents, which are expressed via longer duration, higher intensity, and higher F0, dock to stressed vowels. Where two H accents occur in sequence, the second one is upstepped, expressed as an increase in duration (see Alden & Arnhold 2023 for a discussion of the metrics and acoustics of accent and upstep in Alutiiq).

(30)	kuuggiaq ‘coffee’	
Syllable	ˈkuː	ˈɣiaq
Accent	H	¡H

(31)	mayurciquq ‘he will climb’			
Syllable	ma	ˈjuχ	tʃi	ˈquq
Accent		H		¡H

Examples (30) and (31) show that while both words contain two stressed syllables, the stressed vowels are differentiated from one another by accent. As a result, the binary distinction between stressed vowels within the words in (30) and (31) is not made by stress, but by metrically-conditioned accent. As Alutiiq is able to use accent to express metrical structure, the distinction does not need to be made by stress in order to exist. Hence, culminativity can be fulfilled by metrically-conditioned accent, rather than stress. If the function of culminativity is to organize prosodic structures, then clearly Alutiiq structures are very well organized.

One of the key features of Alutiiq metrics is that it generates ternary feet amid binary feet, and that these ternary feet are composed of a nested iamb and an adjunct. Alden & Arnhold (n.d.) show that there is a ternary distinction in the acoustics of Alutiiq vowels, a trichotomy composed of unstressed vowels, stressed vowels (minimal foot heads), and stressed ‘additionally prominent’ vowels (maximal foot heads; traditionally called ‘additionally lengthened’; see Leer 1985b, c; 1994 and Martinez-Paricio and Kager, 2017). In Sections 5.2, 5.3, and 5.5, the Alutiiq intensity, F0, and rightmost models all showed the effects of additional prominence, corroborating Alden & Arnhold (n.d.) in demonstrating that stressed vowels targeted for additional prominence are acoustically distinct from those that do not.

Example (32) shows a word that contains both a binary and a ternary foot. In ternary feet, H accents are assigned to the head and L accents to the adjunct (in this case, the syllable *qu*). The presence of an L accent interrupts a sequence of H accents and prevents the latter H, on the stress of the binary foot, from upstepping. Unlike in (30) and (31) above, the heads of the feet here are not distinguished by accent. Instead, the maximal head is given additional prominence, while the minimal head is not. Additional prominence is triggered by the nested foot structure (Martinez-Paricio & Kager, 2017), and so is metrical—and again, as with accent, a metrically-conditioned phenomenon has distinguished two foot heads within one word without varying their stress[26] (Alden & Arnhold, n.d.). In this way, the expression of maximal foot headedness amid sequences of minimal feet also fulfills culminativity. This is not a primary-secondary stress distinction, however, as maximal feet are not obligatory: many Alutiiq words are composed entirely of binary minimal feet, in which case, none qualify for additional prominence.

(32) atuquniki
‘if he uses them’ (Leer 1985a:113)

Syllable	a	ˈtu	qu	ni	ˈki
Footing	((a.	ˈtu).	qu)	(ni.	ˈki)
Accent		H	L		H
Additional Prominence		Yes			

These examples are intended to demonstrate that Alutiiq’s complex prosody allows it to outsource the expression of culminativity onto non-stress metrical phonology. In other words, culminativity can be seen not as a characteristic of stress specifically, but rather as a characteristic of metrical structures: so long as some metrical structure no smaller than the foot and no larger than the prosodic word distinguishes heads from non-heads, or otherwise differentiates binaries within some domain smaller than the prosodic word, culminativity is fulfilled. These metrical structures are usually expressed via stress on foot heads, and so too is culminativity expressed via stress. In a language like Alutiiq, however, which expresses metrical structure on vowels via stress, accent, and additional prominence, so long as binary distinctions are made within words by at least one of these options, culminativity is fulfilled.

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[26] This conclusion is reminiscent of Leer’s (1985c, 1994) Pitch Groups: a layer in the prosodic hierarchy above the foot and below the word, composed of a sequence of two binary iambs. Foot heads within these Pitch Groups are distinguished by additional prominence (referred to there as lengthening). Here we do not propose that culminativity is achieved by a level in the prosodic hierarchy; rather, that metrical phonology will conspire to create binary contrasts within Alutiiq words where stress alone does not, or cannot, distinguish the contrast.

4.7. Conclusion

This study has examined the behavior of stressed vowels within words in two sister languages, Central Alaskan Yup'ik and Chugach Alutiiq. These languages have been previously described as non-culminative: although both have metrical stress systems, various authors have claimed that stressed vowels are not ordered relative to one another, such that there is no primary-secondary distinction among stressed vowels (Jacobson, 1984, 1985; Leer, 1985a, 1985b, 1985c, 1994; Woodbury, 1987, 1995; among others).

The Yup'ik study reported in Section 4 does not provide corroborating evidence for Miyaoka's (1971, 1985, 2012) assertion that the rightmost stress of a Yup'ik word is primary. Rightmost stressed vowels (the majority of which are on penultimate and ultimate syllables) were not consistently more prominent by any acoustic measure than stressed vowels elsewhere in the word. The Alutiiq study in Section 5 revealed a similar pattern among rightmost stressed vowels as in Yup'ik: namely, while no position was more prominent than others, ultimate stressed vowels and rightmost syllables, including unstressed ones, were found to be significantly longer in duration, but lower in intensity and F0 than vowels elsewhere in the word, in line with cross-linguistically common tendencies of prosodic finality marking.

Yup'ik and Alutiiq may still express culminativity at a domain smaller than the prosodic word. In both languages, their complex word-internal morphology may define a culminativity domain smaller than the word—for instance, at the morpheme level, or across spans of morphemes, as in Dene languages. This is a promising area for future research, involving more targeted datasets that include a controlled variety of morphological constructions. In the case of Alutiiq, culminativity may further be fulfilled thanks to its non-stress metrical prosody. If we take culminativity to be a principle of metrical systems rather than a principle of stress, then non-stress expressions of metrical structure can differentiate stress binaries instead of stress. This may be happening in Alutiiq, with accent and additional prominence differentiating foot heads within words where stress alone cannot.

In the analysis of Yup'ik and Alutiiq stressed vowels, this study has revealed the different ways in which stressed vowels are expressed across words in the two languages, while discussing their apparent lack of word-level culminativity and nuances in the motivators of culminativity. The finding that neither language is culminative at the word-level affirms that Yup'ik and Alutiiq do not behave according to classical principles of stress languages in general and invites further research into head marking and hierarchy in polysynthetic languages overall.

5. General Discussion and Conclusion

This dissertation has examined the acoustic expression of stress and other metrical phenomena, as well as relevant syllable-altering phonology, in Central Alaskan Yup'ik and Chugach Alutiiq. While documentation efforts in the late 20th century have provided thorough descriptions the stress patterns of each language (Jacobson, 1984, 1985a, 1985b, 1990; Jacobson & Jacobson, 1995; Krauss, 1985; Leer, 1985b, 1985a, 1985c, 1994; Miyaoka, 1970, 1985; Reed et al., 1977; Rice, 1988; Woodbury, 1985, 1987, 1995; among others), there has to-date been only one acoustic study of Yup'ik stress (Gabas, 1996), and none of Alutiiq. Both languages are described as having interesting and elegant prosodic systems, and the acoustic examinations of their metrical phonology presented in Chapters 2-4 has both substantiated and refined extant descriptions. Furthermore, this dissertation has sought to discuss the nuances of the metrical behavior of each language in terms of metrical stress theory, touching on the relationship between stress and syllable weight, complex metrical footing, and culminativity.

This chapter aims to concisely answer the three research questions presented in Chapter 1, based on the acoustic analyses which were presented in Chapters 2-4. This chapter first presents a summary of the study chapters, followed by a recap of the research questions and a discussion of the results with respect to the questions. This is followed with a discussion of the dissertation contributions in the broader context of language documentation. The final section concludes with an outline of possible future research directions based off of the research in this dissertation.

5.1. Summary of dissertation chapters

The Yup'ik study presented in Chapter 2 investigated the acoustic differences between long and short vowels, as well as between stressed and unstressed vowels. These two characteristics have a close relationship with weight, wherein syllables with long nuclei are always heavy, stressed syllables with short nuclei are also heavy, and unstressed syllables with short nuclei are light. The main portion of Chapter 2 examined whether duration, intensity, or F0 were correlates of vowel length, and the effect of stress on these correlates. It also examined F0 fall across a vowel, although it found that it was more correlated with duration than length or stress, and so was not considered an important acoustical correlate for the purposes of the study. The critical results were that duration, intensity, and F0 were all correlates of stress, while only duration and intensity were correlates of phonemic vowel length.

Interestingly, whereas previous literature states that the distinction between long vowels and stressed short vowels is neutralized via iambic lengthening (Hayes, 1995), the results showed that while short vowels are made more prominent when they are stressed, the distinction between them and long vowels persists. In other words, there is a stress-length trichotomy in Yup'ik, composed of the least prominent unstressed short vowels, more prominent stressed short vowels, and most prominent long vowels. These distinctions are further modulated by syllable closure and boundary effects. However, no matter the interfering phonology, the ternary distinction is maintained. Ultimately, this means that the relationship between syllable weight and moraic constituency is unclear. Long vowels and stressed short vowels are both seemingly bimoraic—long vowels by virtue of their phonemic length and stressed short vowels by way of iambic lengthening—but are produced distinctively. The most likely analyses proposed in Chapter 2 are that Yup'ik stress is in the midst of an incomplete length neutralization process, or that Yup'ik distinguishes between bimoraic stressed short vowels and trimoraic long vowels.

In addition to the main analyses concerning stress and syllable weight, Chapter 2 also provided a preliminary examination of gemination as a weight-influencing phenomenon. Yup'ik features gemination in V.CVV environments, although it is contested in the literature whether this gemination is limited to occurring within binary feet (Hayes, 1995) or can occur across foot boundaries (Halle, 1990; Jacobson, 1985a; Jacobson & Jacobson, 1995; Mithun, 1996; Reed et al., 1977; Woodbury, 1987). The gemination study presented in Chapter 2 found that onsets targeted for gemination are longer than those that are not, regardless of their position relative to foot boundaries. The results further implied that geminates within feet are longer than those across feet, although both are longer than non-geminates. This was interpreted as sufficient evidence to conclude that gemination can reach across foot boundaries. This result allowed for a more accurate prediction of syllable weight and stress assignment in the Yup'ik dataset (Alden & Arnhold, 2022; see also Appendix A).

The Alutiiq study, presented in Chapter 3, addresses the same central questions as the Yup'ik study regarding the acoustic correlates of stress and phonemic length. This allows for convenient comparison of the two languages, while also exploring the ways in which their metrical behaviors differ. According to prior descriptions, Alutiiq shares the fundamentals of its metrical system with Yup’ik, insofar as long vowels are obligatorily stressed and short vowels are made heavy in order to bear stress. Furthermore, length distinctions are regularly threatened by neutralization in the form of compression, which targets both underlyingly long vowels and vowels lengthened via stress in closed or word-final syllables. Moreover, Alutiiq features additional metrically bound prosody described in the literature as additional lengthening, tone, and onset fortition (Leer, 1985a, 1985b, 1985c, 1994).

In terms of the basic acoustics of stress and length, the study in Chapter 3 showed that duration, intensity, and maximum F0 are all used to distinguish both stressed vowels from non-stressed vowels, and long vowels from short vowels. Like with Yup’ik, then, there is a distinction between stressed short and long vowels, resulting in a stress-length trichotomy. Further examination of neutralizing phonology showed that Alutiiq seeks to maintain this trichotomy wherever possible. Compressed vowels were shorter than non-compressed vowels, but among the vowels targeted for compression, long vowels were still significantly longer than stressed short vowels. Based on this result, the conclusion is that compression is not a complete neutralization process, but rather incomplete neutralization.

Looking into additional lengthening revealed that two head types, minimal binary heads and maximal internally-layered ternary heads, are acoustically distinguished via intensity and F0. However, duration is not significantly different between the two. For this reason, the term ‘additional lengthening’ is misleading; rather, *additional prominence* is a more descriptive alternative. It is important to note here that although the existence of a difference between maximal and minimal foot heads means that there are two stress levels in Alutiiq, this is not evidence for culminativity (see Chapter 4 for a discussion of Alutiiq culminativity).

Rather than finding evidence of four salient tone categories (L, H, !H, and toneless) as described in the literature, F0 (as well as duration and intensity) was found to distinguish a general high accent from a general non-high accent. Within the high accents, which attach to stressed syllables, H is attested in the literature to be upstepped (!H) when Hs are in sequence. However, while the results in Chapter 3 indicate that H and !H are distinguished via duration, such that !H is longer than H, this should not be called upstep, as F0 is not involved. Within non-high accents, meanwhile, Ls, which attach to maximal foot adjuncts, were longer and marginally louder than unaccented syllables. We interpret this to mean that metrical accent co-occurs with stress as a means of expressing metrical structure, but does not behave as canonical tone. Rather, it is more similar to Beckman's (1986) *stress accent*, as Alutiiq accent appears to both be distributed metrically, like stress, and draws on the same acoustic correlates as stress.

Finally, regarding onset fortition, a brief examination of onset duration revealed that foot-initial onsets are significantly longer than non-initial onsets. This was the only investigation in Chapter 3 that dealt with consonants, rather than vowels. It demonstrated that foot-initial onsets are capable of expressing metrical structure via foot boundary marking, although a more targeted study would likely reveal more nuanced information about how onsets are affected by foot position.

The last content chapter of this dissertation, Chapter 4, *Is stress in Chugach Alutiiq and Central Alaskan Yup'ik actually non-culminative?*, sought to address questions regarding culminativity in the two languages. Using the same datasets as the previous two chapters, in this series of studies, stressed vowels were compared to one another based on their proximity to the right edge of the word in order to determine whether any given stress position was more prominent (by any of the evaluated acoustic measures) than any other. Moreover, a hypothesis from Miyaoka (1970, 1985, 2012) stating that the rightmost stress in a Yup'ik word is primary was tested. The results showed that no given stress position is demonstrably more prominent than any other in either Yup'ik or Alutiiq. While the culminativity studies did not provide adequate evidence to support Miyaoka's claims, they do affirm other literature that describe these languages as having non-culminative stress. We conclude, however, that stress may yet be culminative, with additional complexity to its manifestation from language-specific parameters, non-stress metrical prosody, and the intricate morphosyntax of polysynthetic languages.

5.2. Discussion of research questions and implications for phonological theory

The dissertation set out to examine the following research questions, given in Chapter 1 as (6), (7), and (8), repeated here for convenience:

(33) Yup'ik research questions

a. For the purposes of describing syllable weight, what is the relationship between gemination and foot boundaries?

b. In acoustic terms, how do speakers differentiate a stressed vowel from an unstressed vowel?

c. How are long vowels distinguished from short vowels? Is this distinction maintained when short vowels are stressed?

(34) Alutiiq research questions

a. In acoustic terms, how do speakers differentiate a stressed vowel from an unstressed vowel?

b. How are long vowels distinguished from short vowels? Is this distinction maintained when short vowels are stressed?

c. How do other metrically-bound phonological phenomena, including length neutralization (compression), additional lengthening, tone, and onset fortition, affect the segments of the syllables they target? Does their acoustic expression align with descriptions of their functions and behaviors (e.g. compression neutralizing length distinctions, additional lengthening implying a duration effect, and tone implying an F0 effect)?

(35) Culminativity research questions

a. Is any given stress in the Yup'ik or Alutiiq word produced distinctly from other stresses within the domain of the prosodic word?

b. If so, what are the acoustic correlates that encode this distinction?

c. If not, what are the implications of non-culminativity in the context of polysynthetic words and metrical stress theory?

Chapter 2 dealt with the research questions in (33). Regarding (33a), it was shown that gemination is not beholden to foot boundaries, and that consonants targeted for gemination that cross foot boundaries are longer than consonants not targeted for gemination. For (33b), the acoustic study of Yup'ik stress showed that speakers differentiate stressed vowels from unstressed vowels via higher duration, intensity, and F0. Lastly, for (33c), long vowels are distinguished from short vowels via duration and intensity; moreover, the length distinction is preserved when short vowels are stressed.

Chapter 3 addressed the questions in (34). For (34a), stressed vowels have higher duration, intensity, and F0 than unstressed vowels. Regarding (34b), long vowels also have higher duration, intensity, and F0 than short vowels, and the length distinction is preserved when short vowels are stressed. For (34c), the results in Chapter 3 showed that, while compression does shorten the vowels it targets, it does not completely neutralize length distinctions. Additional lengthening did have an effect that distinguished maximal foot heads from minimal ones, but it only involved intensity and F0 and not duration. Of the four tones described in Alutiiq literature, F0 only distinguished two general categories of high and low tones; within each category, there were additional duration and intensity distinctions between neutral and low accented vowels and high and upstepped accented vowels. Lastly, foot-initial onsets were shown to be longer than non-initial onsets, confirming prior descriptions of onset fortition.

Chapter 4 addressed the questions in (35). Regarding (35a) and (35b), the overall result was that no particular stress was shown to be more prominent than any other within the prosodic word domain. (35c) is a theoretical discussion informed by the previous empirical research questions. In Chapter 4, we discuss the possibility of parameters of culminativity that define domains below the word level in polysynthetic languages, as well as a conception of culminativity that divorces it from head marking and considers the role that non-stress metrical prosody plays in organizing prosodic structures.

In broad strokes, the patterns that emerged in Yup'ik and Alutiiq outlined two languages caught between the desire to preserve phonemic length distinctions amid complex weight systems and wanting to neutralize length differences in favor of a syllable weight distinction. In each language, vowel length and stress draw on the same acoustic correlates in order to compromise between these two opposing tendencies. The compromise—a ternary stress-length distinction—is then put to the test against co-occurring prosody, such as Alutiiq accent and additional prominence, and competing prosody, such as compression. As a result, despite the superficial similarity of the Yup'ik and Alutiiq metrical systems, each language has its own unique patterns of rhythmic expression that lends both character and structure to language performance.

The most striking and fundamental of these patterns is the way in which both languages have to compromise between neutralizing and maintaining the phonemic length distinction in vowels while juggling stress, weight, and, for Alutiiq especially, other interfering metrical phonology. Regarding this prosodic compromise, the core finding of Chapters 2 and 3 is that both

Yup’ik and Alutiiq deal with their competing priorities by producing a trichotomy of stress and length, distinguishing unstressed short, stressed short, and long vowels. The preservation of this trichotomy is of the highest priority, as it is preserved no matter the interfering circumstance, whether it be neutralization of prominence or the addition of more prominence. Moreover, this trichotomy may or may not be analogous to syllable weight. If it is analogous, then long vowels must be at least trimoraic in order to justify their length relative to bimoraic stressed short vowels, and if it is not analogous, then when stress adds a mora to a short vowel, the length neutralization between that short vowel and a long vowel is incomplete.

The culminativity studies in Chapter 4 revealed another important similarity between Yup’ik and Alutiiq metrical prosody: neither stress system is demonstrably culminative at the word level. That is to say, within a prosodic word, there is no acoustical differentiation of primary and secondary stresses. This is interesting from both a phonological and a typological angle, as it is generally accepted as a principle of stress systems that such distinctions be made (e.g. Liberman & Prince, 1977; Hyman, 2014). Often, culminativity serves as the prosodic expression of head marking, where the head of the prosodic word is given primary stress (Beckman, 1986; Blevins et al., 1992; Gordon, 2016; Hayes, 1995; L. Hyman, 1977; Hyman, 2014; Liberman & Prince, 1977). Clearly this is not the case in Yup’ik and Alutiiq, where there is no primary stress. However, we maintain that both languages are most likely still culminative, although the ways in which they express culminativity and the function culminativity serves in their metrical prosody differs.

We propose that Yup’ik and Alutiiq maintain the principle of culminativity, not because the head of the prosodic word needs to be marked with primary stress, but because the complexity and length of multimorphemic words requires organizational prosody in order to parse. In other words, levels of stress are not distinguished at the word level because they are distinguished at a domain below the word level: here, we maintain that, per Bogomolets (2020), the parameters of culminativity define a domain smaller than the word. At minimum, this follows Hayes’ (1995) analysis that allows for culminativity to be minimally fulfilled by binary foot structures, such that the heads of some prosodic unit are distinguished from non-heads of that unit. In this case, culminativity is fulfilled by stressed-unstressed distinctions within the foot (or internally-layered binary foot-adjunct distinctions, in the case of the Alutiiq maximal foot). This proposal for the function of culminativity as organizational, rather than head-marking, is not necessarily at odds with established phonological understandings of obligatory head marking as a universal rule. Van der Hulst (2023), for instance, proposes that heads do not have to be expressed acoustically, so long as the head's relationship to the rest of the word is represented in mental schema of word-internal structure. In Yup'ik and Alutiiq, then, the head may be morphosyntactic rather than prosodic. This could be confirmed with perceptual research into head marking and the relationship between polysynthetic morphosyntax and prosody.

It is important to point out here that, while we propose that culminativity is organizational and beholden to domains smaller than the word in Yup'ik and Alutiiq, it may further be the case that the uniquely complex prosody of Alutiiq allows for some of the burden of that organization to be outsourced from stress to other metrical phonology. It is well established in Chapter 3 that Alutiiq acoustically marks metrical constituency of its vowels with non-stress prosody (i.e. additional prominence and accent) in addition to stress. This suggests that culminativity may not be a principle of stress alone, but rather a feature of metrical systems. Furthermore, in the conceptualization of culminativity as parametric, one of the parameters may be the specification of which metrically bound phonological process is at play in expressing binary contrasts.

5.3. Phonological and phonetic research in the documentation context

Up until now, this discussion has focused on the research presented in this dissertation in the context of phonological theory. More broadly, this research also demonstrates the use of archival recordings for phonetic and phonological acoustical research on underdocumented languages. The clarity and consistency of the results across the content chapters shows that archived analog recordings, when recorded in high quality and maintained and digitized properly, can be used as data for acoustic research.

There are several notable considerations when using archival data. Firstly, one is limited by the data that has been archived and its discoverability: locating recordings of adequate quality is not always easy, and ideal recordings may not exist. Where there are recordings, there may not transcriptions available. For this project, there was no annotation available for the recordings, so the accompanying texts had to be found separately and connected to the recordings in the archive in order for phonetic annotation to take place. Moreover, the studies here were performed on data collected from a small pool of speakers, as only that pools' recordings were available through the Alaska Native Language Archive. Secondly, as Babinski et al. (2022) discuss, there is sometimes little consistency in transcription, file naming, data description, and general notation across collections. This can make proper attribution particularly challenging, especially if critical information, such as speaker identity, is unavailable. In this project, the only audio materials used were connected to published materials, such as narratives and textbooks. This ensured both the quality and consistency of the recordings and the availability of attribution details, but in general, such materials may not be available for any given underdocumented language.

Lastly, in using archival recordings, one's methods are limited by the contents of those recordings. Working with archival recordings differs from controlled phonetic studies with curated, balanced datasets. On the one hand, archival recordings only contain what they contain, and nothing more. For instance, across all of the studies in this dissertation, there is a dearth of long words (more than nine syllables in Yup'ik, or eight in Alutiiq). In a field setting, this could be rectified by eliciting longer words, but here, whatever words were not on the extant recordings were not available at all. While this does open to door to future research directions (see the discussion in the following section), it can be frustrating to have to compromise on one's analytical methods because of perceived data limitations. On the other hand, one advantage of working with archival recordings is that the researcher was not involved in the creation of the recordings, so there is minimal researcher bias in the recordings themselves. The recordings also represent the language as it is. Imbalance in the dataset due to the limitations of archival recordings may cause the lack of long words or unequal numbers of stressed long, stressed short, and unstressed vowels. However, it is also possible that, as archival recordings produced independently of a linguistic study, they represent samples of natural language, and the number of long words present and the disparity between the numbers of each vowel category are noteworthy features of the language.

The methodological challenges of using archival materials are well worth overcoming. The practice of using archival materials for linguistic research keeps those materials in circulation and prolongs the legacies of the language holders who created them. Furthermore, the process of searching through archives to find data can be very informative regarding the state of documentation and what sorts of materials exist or, arguably more importantly, what materials do not exist yet. As was the case here, the rise in digitization practices may make recordings for underdocumented languages more accessible for researchers all over the world. Lastly, the availability of archival materials increases the reproducibility of scientific research, as the same materials are available for everyone. For these reasons, this project has demonstrated both that archival materials can and should be used for linguistic research, and that linguists and community researchers involved in language documentation should continue to grow archival collections (Babinski et al., 2022; Himmelmann, 1998; McDonnell et al., 2018; Whalen & McDonough, 2019).

5.4. Conclusion and future directions

All in all, this dissertation has established the fundamental acoustic properties of Yup'ik and Alutiiq metrical prosody. It represents the first comprehensive acoustic analysis of stress and associated prosody in the two languages, including non-stress metrical phonology and length neutralization, as well as cursory investigations of claims surrounding onset length in cases of gemination and fortification. The results of the studies done as part of this doctoral project serve to support, corroborate, and provide new nuance to extant impressionistic descriptions, while considering the ramifications of the demonstrated metrical performance in the context of metrical stress theory. However, this is by no means a complete description of Yup'ik or Alutiiq prosody, and the results have also opened up opportunities for future research in the field of applied phonology in the Yupik languages.

One of the most immediate areas for follow-up research concerns the preliminary results presented in Chapters 2 and 3: namely, more controlled investigations of onsets. The Yup'ik gemination results imply that foot boundaries affect geminates, insofar as geminates within feet are longer than those that cross foot boundaries. Alutiiq onsets are also affected by foot constituency, as onset fortition was shown to affect foot-initial consonants. At this time, however, the relationship between onset fortition and gemination is not entirely clear, nor did the preliminary studies here investigate acoustical characteristics of onsets beyond duration. A more controlled study might examine voice onset time or spectral tilt, and might control for place and manner of articulation more thoroughly than was necessary for the scope of this dissertation.

Importantly, the results of these studies also allow for stress and other metrical phonology to be controlled for in examinations of intonation, phrase marking, and other areas of prosodic research. The results may also inform theoretical research on non-stress metrical prosody, including not only accent and additional prominence on Alutiiq vowels, but also foot demarcation via onset fortition. Such research may examine the relationship between metrical structures and principles classically associated with stress, such as culminativity. In that regard, one of the most promising areas for follow up research involves the morphosyntax-phonology interface in the context of polysynthetic languages in order to better understand how stress and other metrical cues are affected by word-internal morphology. Research that examines prosodic performance within word-internal syntactic domains would also shed light on the culminativity parameters at work in Yup'ik and Alutiiq—for instance, determining if there is a primary-secondary distinction within word stems or some other syntactically-defined span of syllables.

Finally, this research was limited to language production, insofar as it was a series of studies of acoustic correlates of metrical phenomena. One particularly valuable area of follow-up research would be to examine the perception of stress and metrical prosody. While all language research in the Alaska Native context is constrained by the effort to recover from historical and ongoing language suppression in the region, we are hopeful that efforts over the past several decades to reinvigorate Yup'ik and Alutiiq will allow for a sustainable speaker population that makes such perceptual research possible.

The most fundamental conclusion, behind all of the statistics and theory given in this dissertation, is that Yup'ik and Alutiiq are languages with indisputably complex metrical prosody. Indeed, many of the findings across the three content chapters show that the systems are in fact more intricate that the already-impressive impressionistic descriptions imply. The mechanisms and theoretical implications of this prosody should make study of these languages and contributing to their conservation a high priority for linguists. There is no question that, should either language go dormant, a valuable window into how humans are able to perform rhythm in language will close. It is fortunate, then, that more community members and researchers are engaged and committed to the cultural and linguistic reclamation than ever before.

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Appendix A: User's Guide to Central Alaskan Yup'ik Stress Derivation

1. Introduction

This guide synthesizes the stress pattern of Central Alaskan Yup'ik (henceforth: Yup'ik) into steps for deriving footing and stress. Its goal is to demonstrate how the basic patterns of Yup'ik metrics, as adjusted from the description provided in Hayes (1995b), can be ordered to derive the stress of any given Yup'ik word.

This model was developed for, and validated by, the acoustic analysis of six recordings of spoken Yup'ik, four recordings of supplementary educational materials for a Yup'ik language textbook (Reed, 1977) and recordings of Paschal Afcan's *Napam Cuyaa* (Afcan & Hofseth, 1972) and Annie Blue's *Cikmiumalria Tan'gaurluq Yaqulegpiik-llu*, in the book *Cungauyaraam Qulirai: Annie Blue's Stories* (Blue, 2007). All recordings are available in the Alaska Native Language Archive (ANLA identifiers: ANLC3111a, ANLC3111b, ANLC3112a, ANLC3113a, CY(SCH)967A1972g, and CY970B2007) (Alaskan Native Language Archive, n.d.). Acoustic analysis found consistent phonetic correlates of stress as marked following this User's Guide (Alden & Arnhold, submitted).

2. Metrical Model of Yup'ik Stress

In Hayes' (1995) metrical model, Yup'ik stress parameters include that all feet are binary, quantity sensitive, iambic, constructed left-to-right, and iterative, with the foot's head being obligatorily heavy. Yup'ik stress assignment is additionally complicated by presence of lexical stress, automatic gemination and the influence of morphological and prosodic boundaries, as well as irregular metrical behavior of closed syllables (see Halle, 1990; Jacobson, 1984, 1985, 1990; Jacobson & Jacobson, 1995; Leer, 1985a, b); Miyaoka, 1985, 2012; Reed, 1977; Woodbury, 1987, 1995; among others). We began from Hayes' description of the stress pattern and tested the cyclical derivation's output against the recordings. Where there was a misprediction or lack of a prediction for any given word, adjustments to the Hayes model were made. Mispredictions necessitated expanding the automatic gemination environment from (C)V.CVV sequences within a foot to all (C)V.CVV sequences, contra Hayes, but in line with the rest of the Yup'ik literature, as cited above, and observations from the recordings, as well as the explicit inclusion of lexical gemination and lexical stress in the present model. Other adjustments were necessary to expand the applicability of the model to the complete data set. Thus, although Hayes does not explicitly discuss CVVC syllables, the present model follows his assumption that codas always contribute a mora, applying it also to syllables with long nuclei; it also explicates the consequences of schwa deletion in closed syllables (see Alden & Arnhold, submitted, for a more detailed description of basic stress patterns in Yup'ik, Hayes' model and the adjustments resulting in the present model).

The resultant steps for accurately deriving the Yup'ik stress pattern, starting from the underlying form, are as follows:

0. Pre-Footing Lexical Phonology, in which lexical stress and lexical gemination are considered as part of the underlying form;
1. Foot Determination, in which the underlying form of a word (minus any clitics) is assigned iterative iambic feet from left to right;
2. Automatic Gemination, in which (C)V.CVV -> (C)VG.GVV;
3. Defooting in Double Clash, in which closed syllables lose a mora when between stressed syllables or between a stressed syllable and the right edge of a word;
4. Schwa Deletion, in which stressed schwas in open syllables are deleted and the onset of the syllable is reassigned as the coda of the preceding syllable[27];
5. Clitic Incorporation, in which clitics are added back into the derivation;
6. Iambic Lengthening, in which light, open syllables that are assigned stress are lengthened;
7. Phrase-Final Effects, wherein the final syllable of an IP is de-stressed.

This guide makes use of a metrical interpretation of the stress pattern of Yup'ik—that is, that prominent syllables are distributed by a foot level in the prosodic hierarchy. Furthermore, here Yup'ik footing is treated as cyclical: following each step in the derivation, the entire derivation begins again, cycling as many times as necessary to reach the right edge of the word. Processes 2-5 of the stress derivation trigger cyclic re-footing, i.e. returning to step 1.

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[27] Schwa deletion may optionally also apply in closed syllables, but in this case has no metrical consequences, as the coda of the syllable becomes syllabic and the onset is not reassigned.

3. Sample Derivations

In this section, the adjusted model will be demonstrated using the words *paqequraqekek*, *itrucaaqellria-gguq-am, tuqulluki*, and *maqaruaq*. These four examples were chosen because they trigger different processes in the derivation: *paqequraqekek* demonstrates schwa deletion; *itrucaaqellria-gguq-am* undergoes cliticization, automatic gemination, and defooting in clash; *tuqulluki* is a prototypical example for iambic lengthening; and *maqaruaq* demonstrates automatic gemination and superheavy footing.

Each Table 78-83 represents one cycle in the metrical derivation, where the input of each subsequent table is the output of the previous.

Table 78 begins the sample derivations with syllabification. The input for syllabification is the underlying form of each word. The Yup'ik spelling system reflects the phonemic form of each word, such that *paqequraqekek* is /paqəquχaqəkək/, *itrucaaqellria-gguq-am* is /itχuʧaːqəɫχiaxuqam/, *tuqulluki* is /tuquɫuki/, and *maqaruaq* is /maqaχuaq/ (note that while double vowel letters mark vowel length, double consonant letters indicate voicelessness). None of these examples feature lexical stress or lexical gemination, although if they did, these would be represented in the underlying form. Note that clitic boundaries are respected during syllabification.

Table 78: Examples of syllabification.

	paqequraqekek	itrucaaqellria-gguq-am	tuqulluki	maqaruaq
Underlying Form	/pa.qə.qu.χa.qə.kək/	/it.χu.ʧaː.qəɫ.χia.xuq.am/	/tu.qu.ɫu.ki/	/maqaχuaq/
Syllabic Form	CV.CV.CV.CV.CV.CVC	VC.CV.CVː.CVC.CVV.CVC.VC	CV.CV.CV.CV	CV.CV.CVVC
Closure (Open-Closed)	O.O.O.O.O.C	C.O.O.C.O.C.C	O.O.O.O	O.O.C
Length (Short V̆ - Long Vː)	V̆. V̆. V̆. V̆. V̆. V̆	V:. V̆.Vː.V̆.Vː.V̆.V̆	V̆.V̆.V̆.V̆	V̆.V̆.V:
Weight (Light-Heavy)	L-L-L-L-L-H	H-L-H-H-H-H-H	L-L-L-L	L-L-H

Table 79 demonstrates foot determination, following an adjusted version of Hayes' footing parameters in which CVVC syllables always constitute their own foot.

Table 79: Examples of foot determination.

	paqequraqekek	itrucaaqellria-gguq-am	tuqulluki	maqaruaq
Input (Syllabic Form)	CV.CV.CV.CV.CV.CVC	VC.CV.CVː.CVC.CVV.CVC.VC	CV.CV.CV.CV	CV.CV.CVVC
Clitic Removal	---	VC.CV.CVː.CVC.CVV	---	---
Initial Foot Determination	(CV.CV).(CV.CV).(CV.CVC)	(VC).(CV.CVː).(CVC).(CVV)	(CV.CV).(CV.CV)	(CV.CV).(CVVC)

Itrucaaqellria-gguq-am ends with two clitics, -*gguq*- and -*am*, which are temporarily set aside at this step in the derivation. When determining initial footing, it is assumed that codas do contribute to weight and that heavy syllables can only occupy the head of a foot. The result is a variety of foot shapes, including (CV.CV), (VC), (CV.CV:), (CVC), and (CVV).

Table 80 represents the next stage in the derivation, automatic gemination. Automatic gemination (also called pre-long strengthening) is the process by which an open syllable becomes closed (Jacobson, 1985, 1995; Miyaoka, 1971, 2012). Hayes (1995) correctly specifies the main trigger environment (environment 1 in Table 80) as a light-long (CV.CVV/CV:C) sequence; however, in the metrical analysis proposed in this study, this gemination can also be triggered by an unfooted open syllables preceding a long syllable (environment 2) or across foot boundaries (environment 3). These three environments, which together represent all (C)V.CVV environments, are each identified in their own row.

Table 80: Examples of automatic gemination (pre-long strengthening).

	paqequraqekek	itrucaaqellria-gguq-am	tuqulluki	maqaruaq
Input	(CV.CV).(CV.CV).(CV.CVC)	(VC).(CV.CVː).(CVC).(CVV)	(CV.CV).(CV.CV)	(CV.CV).(CVVC)
Environment 1	---	(VC).(**CV.CV**ː).(CVC).(CVV)	---	---
Environment 2	---	---	---	---
Environment 3	---	---	---	(CV.**CV).(CVV**C)
Gemination	---	(VC).(CV**G.G**Vː).(CVC).(CVV)	---	(CV.CV**G).(G**VVC)
Refooting	---	(VC).(CVG).(GVː).(CVC).(CVV)	---	---

In the example words, *itrucaaqellria-gguq-am* contains environment 1: in the second foot of the word, composed of the syllables *ru.caa* (CV.CV:), the Hayes condition is met and the long syllable geminates, resulting in a (CVG.GV:) foot. This violates the constraint that heavy syllables cannot occupy weak foot positions, and so cyclical footing applies and the sequence is divided into two feet instead, (CVG).(GV:). Automatic gemination also applies to *maqaruaq*, only this time, it occurs across the foot boundary (environment 3) and does not trigger refooting.

Adjusting syllable shape has consequences, one of those being the introduction of a CVC syllable in a double clash environment, i.e. between two stressed syllables or between a stressed syllable and the rightmost edge of the word. Table 81 shows how this is resolved: by de-footing the CVC syllable in clash.

Table 81: Examples of defooting in double clash.

	paqequraqekek	itrucaaqellria-gguq-am	tuqulluki	maqaruaq
Input	(CV.CV).(CV.CV).(CV.CVC)	(VC).(CVG).(GVː).(CVC).(CVV)	(CV.CV).(CV.CV)	(CV.CVG).(CVVC)
CVC Foot in Clash	---	(VC).**(CVG)**.(GVː).**(CVC)**.(CVV)	---	---
Defoot in Clash	---	(VC).CVG.(GVː).CVC.(CVV)	---	---

The result of automatic gemination on *itrucaaqellria-gguq-am* is several clash environments in which CVC syllables occur between other stressed syllables. These CVC syllables are then de-footed, resulting in the syllables *ru, qell,* and *gguq* becoming de-footed and defooted. The mechanism for achieving this, following Hayes, is that the coda loses its mora, which means the CVC syllable becomes light and cannot form a foot by itself anymore. In *maqaruaq*, which also featured gemination, the newly created closed syllable is not a CVC syllable, but a CVVC syllable. This means that even if its coda becomes non-moraic, the syllable still has a bimoraic vowel and remains heavy. Thus, it maintains its footing even between a stressed syllable and the right word edge.

Next in the derivation is schwa deletion. Table 82 demonstrates how schwas that are set to receive stress are instead obligatorily deleted in open syllables.

Table 82: Examples of schwa deletion.

	paqequraqekek	itrucaaqellria-gguq-am	tuqulluki	maqaruaq
Input	(CV.CV).(CV.CV).(CV.CVC)	(VC).CVG.(GVː).CVC.(CVV)	(CV.CV).(CV.CV)	(CV.CVG).(CVVC)
Schwa Deletion Environment	(CV.C**V**).(CV.CV).(CV.CVC)	---	---	---
Schwa Deletion	(CV.C).(CV.CV).(CV.CVC)	---	---	---
Refooting	(CVC).(CV.CV).(CV.CVC)	---	---	---

Paqequraqekek has, up until this point in the derivation, not met any of the criteria for any metrical processes beyond initial footing. The result of initial footing, however, is the second syllable *qe* becoming stressed. The nucleus of this syllable is a schwa. Therefore, schwa deletion is triggered, and the result is two neighboring stops, *pa.qe.qur* -> *paq.qur*. While this does result in a geminate stop, it is not necessarily an instance of gemination as a phonological process: rather, it is a result of the stressed schwa deleting and the circumstance of two identical stops coming together, rather than one stop extending leftwards. Another example illustrating the deletion of a stressed schwa in an open syllable is *atepik* /ɑ.tə.pɪk/ 'real name' (Hayes 1995:253). In this example, initial footing also makes the syllable *tə* the head of an iamb. Rather than stressing the schwa, it is deleted, resulting in [ˈɑt.pɪk].

At this point, clitics are re-introduced back into the derivation and footed accordingly. Table 83 shows the last three steps, cliticization, iambic lengthening, and phrase-final defooting. The final three steps of the derivation process can all be discussed together, as there is only one branch that leads to cyclical refooting.

Table 83: Examples of cliticization, iambic lengthening, and phrase-final defooting.

	paqequraqekek	itrucaaqellria-gguq-am	tuqulluki	maqaruaq
Input	(CVC).(CV.CV).(CV.CVC)	(VC).CVG.(GVː).CVC.(CVV)	(CV.CV).(CV.CV)	(CV.CVG).(CVVC)
Cliticization	---	(VC).CVG.(GVː).CVC.(CVV).CVC.CV	---	---
Refooting	---	(VC).CVG.(GVː).CVC.(CVV).(CVC).CV	---	---
Iambic Lengthening	(‘CVC).(CV.’CVˑ).(CV.ˈCVC)	---	(CV.’CVˑ).(CV.’CVˑ)	(CV.’CVG).(ˈCVVC)
Phrase-Final Defooting	(‘CVC).(CV.’CVˑ).(CV.CVC)	---	(CV.’CVˑ).(CV.CVˑ)	(CV.’CVG).(CVVC)
Output (Syllabic)	(‘CVC).(CV.’CVˑ).(CV.CVC)	(‘VC).CVG.(‘GVː).CVC.(‘CVV).(‘CVC).CV	(CV.’CVˑ).(CV.CVˑ)	(CV.’CVG).(CVVC)
Output (Phonetic)	[‘paq.qu.’χaˑ.qə.kək]	[‘it.χuʧ.’ʧaː.qəɬ.’χia.’xuq.am]	[tu.’quˑ.ɬu.kiˑ]	[ma.ˈqaχ.χuaq]

Following the schwa deletion in Table 82, the clitics set aside early in the derivation are re-introduced in Table 6. In *itrucaaqellria-gguq-am*, there are two clitics, and the first can be footed. It is a CVC syllable, but is not in double clash; therefore, the clitic *-gguq-* does receive stress. This does not cause any change to any of the feet to the left of the clitic. However, it is often the case, as it is in *itrucaaqellria-gguq-am*, that the new word-final syllable is not in a position to be footed, since the resultant foot would contain a heavy syllable not being the head, *(CVC.CV). In these instances, the last syllable simply is not footed and the derivation moves forward into iambic lengthening. Sometimes, however, a clitic will attach to a word that previously ended with a light syllable, as with the clitic *-mi* in *upnerkami* /up.nəχ.ka.mi/. In these cases, the syllable *ka* and clitic *-mi* form a foot of their own, with the clitic receiving stress, as shown in Table 84.

Table 84: Example of a footed clitic receiving stress.

Input	/up.nəχ.ka.mi/ VC.CVC.CV.CV
Clitic Removal	VC.CVC.CV
Footing	(VC).(CVC).CV
Cliticization	(VC).(CVC).CV.CV
Refooting	(VC).(CVC).(CV.CV)
Iambic Lengthening	(VC).(CVC).(CV.CVˑ)
Output	(ˈVC).(ˈCVC).(CV.ˈCVˑ) [ˈup.ˈnəχ.ka.ˈmi]

Table 84 demonstrates that a clitic can receive stress when it can form the head of a foot with a previously unfooted light syllable, although this stress would be deleted phrase-finally. Note that the output of Table 84 features a closed syllable with a stressed schwa, *ner* /nəχ/: the presence of this schwa is optional, and its deletion would not impact the metrical derivation of the word.

In addition to cliticization, Table 83 above also demonstrates iambic lengthening and phrase-final defooting. Iambic lengthening ensures that no light syllable bears stress: only heavy syllables may be stressed, and so any CV syllable that is derived to be stressed must be lengthened. For *paqequraqekek*, this affects the second foot (qu.χa). For *tuqulluki*, this affects both feet, such that the alternating stress rhythm (tu.ˈqu)(lu.ˈki) is achieved. Iambic lengthening is marked with the half-long diacritic in the output forms, so as to avoid implying equivalence with phonemically long vowels. Lastly, any stressed IP-final syllables are defooted. For the sake of example, we will assume the words in this section are spoken in isolation, and therefore constitute their own IPs: as a result, *paqequraqekek* loses its stress on *kek*, *tuqulluki* loses its stress on *ki* and *maqaruaq* loses its stress on *ruaq*. The end result of the full derivation is the surface forms [‘paq.qu.’χaˑ.qə.kək], [‘it.χuʧ.’ʧaː.qəɬ.’χia.’xuq.am], [tu.’quˑ.ɬu.ki], and [ma.ˈqaχ.χuaq].

Appendix B: Culminativity Tables

Table 85: Yup'ik duration pairwise comparison table. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowel

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-2.94753	6.163035	1222.747	-0.47826	0.996903
Right Edge Proximity (1) vs. Right Edge Proximity (3)	33.06189	8.100202	1223.646	4.081612	0.000677
Right Edge Proximity (1) vs. Right Edge Proximity (4)	46.221	11.11362	1221.318	4.15895	0.000489
Right Edge Proximity (1) vs. Right Edge Proximity (5)	27.84643	13.06364	1222.89	2.131599	0.271614
Right Edge Proximity (1) vs. Right Edge Proximity (6)	35.62914	20.41117	1223.058	1.745571	0.501756
Right Edge Proximity (2) vs. Right Edge Proximity (3)	36.00942	7.845033	1221.748	4.590091	7.15E-05
Right Edge Proximity (2) vs. Right Edge Proximity (4)	49.16854	11.06937	1221.183	4.441856	0.000141
Right Edge Proximity (2) vs. Right Edge Proximity (5)	30.79396	13.14112	1221.758	2.343328	0.177641
Right Edge Proximity (2) vs. Right Edge Proximity (6)	38.57667	20.35329	1222.325	1.895353	0.405434
Right Edge Proximity (3) vs. Right Edge Proximity (4)	13.15912	11.9164	1220.519	1.104286	0.879717
Right Edge Proximity (3) vs. Right Edge Proximity (5)	-5.21546	13.80293	1220.829	-0.37785	0.999001
Right Edge Proximity (3) vs. Right Edge Proximity (6)	2.567253	20.79358	1221.912	0.123464	0.999996
Right Edge Proximity (4) vs. Right Edge Proximity (5)	-18.3746	15.3904	1220.973	-1.1939	0.839907
Right Edge Proximity (4) vs. Right Edge Proximity (6)	-10.5919	21.84906	1222.017	-0.48477	0.996698
Right Edge Proximity (5) vs. Right Edge Proximity (6)	7.782712	22.79837	1221.12	0.341371	0.99939

Short Vowel

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-23.8008	5.094535	1223.888	-4.67183	4.87E-05
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-24.0733	5.948149	1222.151	-4.0472	0.000781
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-25.0732	6.694457	1222.499	-3.74537	0.00259
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-30.6011	8.340782	1222.753	-3.66885	0.003458
Right Edge Proximity (1) vs. Right Edge Proximity (6)	-13.7104	11.23472	1223.072	-1.22036	0.826986
Right Edge Proximity (2) vs. Right Edge Proximity (3)	-0.27256	5.544323	1223.523	-0.04916	1
Right Edge Proximity (2) vs. Right Edge Proximity (4)	-1.2724	6.513889	1223.168	-0.19534	0.999961
Right Edge Proximity (2) vs. Right Edge Proximity (5)	-6.80032	8.144929	1222.364	-0.83492	0.961004

Right Edge Proximity (2) vs. Right Edge Proximity (6)	10.09037	10.97569	1223.149	0.919338	0.941621
Right Edge Proximity (3) vs. Right Edge Proximity (4)	-0.99985	6.923379	1221.059	-0.14442	0.999991
Right Edge Proximity (3) vs. Right Edge Proximity (5)	-6.52777	8.538319	1221.358	-0.76453	0.973343
Right Edge Proximity (3) vs. Right Edge Proximity (6)	10.36292	11.25881	1221.104	0.920428	0.941336
Right Edge Proximity (4) vs. Right Edge Proximity (5)	-5.52792	8.6068	1221.535	-0.64227	0.987764
Right Edge Proximity (4) vs. Right Edge Proximity (6)	11.36277	11.2933	1221.833	1.006152	0.915986
Right Edge Proximity (5) vs. Right Edge Proximity (6)	16.89069	12.07889	1221.269	1.398365	0.728092

Table 86: Yup'ik intensity table with all results from releveling around distance from the right edge.

Relevelled Yup'ik Intensity Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (2nd syllable)	80.63969	4.565959	1.106069	17.66106	0.027196
Right Edge Proximity (1st syllable)	-1.86081	0.259817	1231.222	-7.16201	1.36E-12
Right Edge Proximity (3rd syllable)	1.092158	0.295571	1230.894	3.695078	0.000229
Right Edge Proximity (4th syllable)	1.467623	0.371303	1230.426	3.952627	8.17E-05
Right Edge Proximity (5th syllable)	0.823641	0.462303	1230.192	1.781606	0.07506
Right Edge Proximity (6th syllable)	0.583104	0.62627	1230.352	0.931075	0.351997
Intercept (3rd syllable)	81.73185	4.568756	1.108319	17.8893	0.026656
Right Edge Proximity (1 syllable away)	-2.95297	0.316847	1230.511	-9.31985	<2E-16
Right Edge Proximity (2nd syllable)	-1.09216	0.295571	1230.894	-3.69507	0.000229
Right Edge Proximity (4th syllable)	0.375466	0.381579	1229.929	0.983977	0.32532
Right Edge Proximity (5th syllable)	-0.26852	0.471494	1230.068	-0.5695	0.56912
Right Edge Proximity (6th syllable)	-0.50905	0.632917	1230.005	-0.8043	0.421381
Intercept (4th syllable)	82.10731	4.576671	1.116456	17.9404	0.026011
Right Edge Proximity (1st syllable)	-3.32844	0.381774	1230.096	-8.71833	1.00E-17
Right Edge Proximity (2nd syllable)	-1.46762	0.371303	1230.426	-3.95263	8.17E-05
Right Edge Proximity (3rd syllable)	-0.37547	0.381579	1229.929	-0.98398	0.32532
Right Edge Proximity (5th syllable)	-0.64398	0.478706	1230.085	-1.34526	0.17879

Right Edge Proximity (6th syllable)	-0.88452	0.636995	1230.114	-1.38858	0.165212
Intercept (5th syllable)	81.46333	4.584592	1.123768	17.76894	0.025793
Right Edge Proximity (1st syllable)	-2.68445	0.468691	1230.406	-5.72756	1.28E-08
Right Edge Proximity (2nd syllable)	-0.82364	0.462303	1230.192	-1.78161	0.07506
Right Edge Proximity (3rd syllable)	0.268517	0.471494	1230.069	0.569502	0.56912
Right Edge Proximity (4th syllable)	0.643982	0.478706	1230.085	1.345257	0.17879
Right Edge Proximity (6th syllable)	-0.24054	0.671971	1230.015	-0.35796	0.720437
Intercept (6th syllable)	81.22279	4.605389	1.144639	17.63647	0.02464
Right Edge Proximity (1st syllable)	-2.44392	0.643051	1230.417	-3.8005	0.000151
Right Edge Proximity (2nd syllable)	-0.5831	0.626269	1230.353	-0.93107	0.351999
Right Edge Proximity (3rd syllable)	0.509054	0.632917	1230.005	0.804298	0.42138
Right Edge Proximity (4th syllable)	0.884519	0.636995	1230.114	1.388582	0.165211
Right Edge Proximity (5th syllable)	0.240538	0.671971	1230.015	0.357959	0.720435

Table 87: Yup'ik F0 pairwise comparison table. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowels					
Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-2.6896	0.298557	1192.338	-9.00867	<.0001
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-2.35671	0.421358	1192.295	-5.59311	4.13E-07
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-2.0846	0.588287	1191.371	-3.5435	0.00548
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-2.86504	0.683719	1192.211	-4.19038	0.000428
Right Edge Proximity (1) vs. Right Edge Proximity (6)	-2.42432	1.066815	1192.35	-2.27249	0.206174
Right Edge Proximity (2) vs. Right Edge Proximity (3)	0.332894	0.414268	1191.595	0.803573	0.966901
Right Edge Proximity (2) vs. Right Edge Proximity (4)	0.605003	0.587598	1191.453	1.029621	0.908018
Right Edge Proximity (2) vs. Right Edge Proximity (5)	-0.17544	0.680748	1191.666	-0.25772	0.999846
Right Edge Proximity (2) vs. Right Edge Proximity (6)	0.265276	1.062312	1192.013	0.249716	0.999868
Right Edge Proximity (3) vs. Right Edge Proximity (4)	0.272109	0.636345	1191.181	0.427612	0.998185
Right Edge Proximity (3) vs. Right Edge Proximity (5)	-0.50834	0.72338	1191.295	-0.70273	0.981637

Right Edge Proximity (3) vs. Right Edge Proximity (6)	-0.06762	1.089112	1191.792	-0.06209	1
Right Edge Proximity (4) vs. Right Edge Proximity (5)	-0.78045	0.810237	1191.425	-0.96323	0.929403
Right Edge Proximity (4) vs. Right Edge Proximity (6)	-0.33973	1.147383	1191.833	-0.29609	0.999696
Right Edge Proximity (5) vs. Right Edge Proximity (6)	0.44072	1.193182	1191.372	0.369366	0.999105

Short Vowels

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-1.59926	0.275525	1193.242	-5.80442	1.24E-07
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-1.26336	0.319524	1193.245	-3.95389	0.001144
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-0.41149	0.367296	1191.778	-1.12033	0.873046
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-1.32183	0.442731	1192.925	-2.98563	0.034246
Right Edge Proximity (1) vs. Right Edge Proximity (6)	-0.79522	0.591449	1192.647	-1.34452	0.759985
Right Edge Proximity (2) vs. Right Edge Proximity (3)	0.335902	0.295719	1193.208	1.135882	0.866392
Right Edge Proximity (2) vs. Right Edge Proximity (4)	1.187769	0.353993	1192.354	3.355346	0.010576
Right Edge Proximity (2) vs. Right Edge Proximity (5)	0.277434	0.427186	1192.384	0.649444	0.987129
Right Edge Proximity (2) vs. Right Edge Proximity (6)	0.804047	0.575668	1192.642	1.39672	0.729088
Right Edge Proximity (3) vs. Right Edge Proximity (4)	0.851868	0.375333	1191.41	2.269634	0.207385
Right Edge Proximity (3) vs. Right Edge Proximity (5)	-0.05847	0.450354	1192.199	-0.12983	0.999995
Right Edge Proximity (3) vs. Right Edge Proximity (6)	0.468145	0.591011	1191.321	0.792109	0.968894
Right Edge Proximity (4) vs. Right Edge Proximity (5)	-0.91034	0.46147	1192.1	-1.97269	0.358705
Right Edge Proximity (4) vs. Right Edge Proximity (6)	-0.38372	0.596738	1191.673	-0.64303	0.987697
Right Edge Proximity (5) vs. Right Edge Proximity (6)	0.526613	0.631901	1191.928	0.833379	0.961307

Table 88: Alutiiq duration pairwise comparison table. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowel

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	26.56342	5.707393	1121.295	4.654213	3.58E-05
Right Edge Proximity (1) vs. Right Edge Proximity (3)	21.54043	6.202633	1120.605	3.472789	0.004849
Right Edge Proximity (1) vs. Right Edge Proximity (4)	20.03624	6.976182	1120.391	2.872093	0.033736
Right Edge Proximity (1) vs. Right Edge Proximity (5)	43.10261	8.780638	1119.841	4.908825	1.04E-05

Right Edge Proximity (2) vs. Right Edge Proximity (3)	-5.02298	4.921224	1119.652	-1.02068	0.845888
Right Edge Proximity (2) vs. Right Edge Proximity (4)	-6.52718	5.548523	1119.047	-1.17638	0.764952
Right Edge Proximity (2) vs. Right Edge Proximity (5)	16.53919	7.739724	1119.077	2.136923	0.205165
Right Edge Proximity (3) vs. Right Edge Proximity (4)	-1.50419	6.258142	1119.301	-0.24036	0.999263
Right Edge Proximity (3) vs. Right Edge Proximity (5)	21.56218	8.244234	1119.075	2.615425	0.068239
Right Edge Proximity (4) vs. Right Edge Proximity (5)	23.06637	8.601064	1119.022	2.681804	0.057298

Short Vowel

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	7.696602	3.815533	1114.542	2.017176	0.25832
Right Edge Proximity (1) vs. Right Edge Proximity (3)	11.75015	4.05397	1117.702	2.898432	0.031249
Right Edge Proximity (1) vs. Right Edge Proximity (4)	27.45842	4.511803	1119.546	6.08591	1.59E-08
Right Edge Proximity (1) vs. Right Edge Proximity (5)	25.67597	5.684568	1121.718	4.516784	6.80E-05
Right Edge Proximity (2) vs. Right Edge Proximity (3)	4.053552	3.125703	1119.046	1.296845	0.69324
Right Edge Proximity (2) vs. Right Edge Proximity (4)	19.76182	3.648956	1119.068	5.415747	7.43E-07
Right Edge Proximity (2) vs. Right Edge Proximity (5)	17.97936	5.092762	1119.07	3.530376	0.003944
Right Edge Proximity (3) vs. Right Edge Proximity (4)	15.70827	3.87317	1119.07	4.055662	0.000512
Right Edge Proximity (3) vs. Right Edge Proximity (5)	13.92581	5.262977	1119.079	2.645995	0.063003
Right Edge Proximity (4) vs. Right Edge Proximity (5)	-1.78246	5.517681	1119.016	-0.32304	0.997646

Table 89: Alutiiq intensity pairwise comparison table. Negative estimates correspond to smaller values for the left one of the two compared factor combinations.

Long Vowel

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-0.55406	7.26633	1118.698	-0.07625	0.999992
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-8.73258	8.593983	1118.373	-1.01613	0.848011
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-8.75136	9.642568	1118.523	-0.90758	0.894051
Right Edge Proximity (1) vs. Right Edge Proximity (5)	11.51088	11.21168	1118.04	1.026687	0.843063
Right Edge Proximity (2) vs. Right Edge Proximity (3)	-8.17851	6.58418	1117.125	-1.24215	0.726591
Right Edge Proximity (2) vs. Right Edge Proximity (4)	-8.1973	7.162007	1117.211	-1.14455	0.782713
Right Edge Proximity (2) vs. Right Edge Proximity (5)	12.06495	9.359209	1117.046	1.289099	0.698031

Right Edge Proximity (3) vs. Right Edge Proximity (4)	-0.01878	6.953573	1117.477	-0.0027	1
Right Edge Proximity (3) vs. Right Edge Proximity (5)	20.24346	9.088098	1117.171	2.22747	0.170276
Right Edge Proximity (4) vs. Right Edge Proximity (5)	20.26225	9.352948	1117.031	2.166402	0.193308

Short Vowel

Contrast	Estimate	SE	df	t ratio	p value
Right Edge Proximity (1) vs. Right Edge Proximity (2)	-11.4439	4.578849	1119.902	-2.4993	0.091473
Right Edge Proximity (1) vs. Right Edge Proximity (3)	-22.4614	6.490947	1118.936	-3.46042	0.005066
Right Edge Proximity (1) vs. Right Edge Proximity (4)	-4.25261	7.220079	1119.35	-0.589	0.976732
Right Edge Proximity (1) vs. Right Edge Proximity (5)	-2.58804	8.434377	1119.176	-0.30684	0.998074
Right Edge Proximity (2) vs. Right Edge Proximity (3)	-11.0175	5.417564	1117.31	-2.03366	0.250529
Right Edge Proximity (2) vs. Right Edge Proximity (4)	7.191322	5.558039	1117.335	1.29386	0.695089
Right Edge Proximity (2) vs. Right Edge Proximity (5)	8.855891	7.036293	1117.431	1.258602	0.716681
Right Edge Proximity (3) vs. Right Edge Proximity (4)	18.20882	4.719561	1117.74	3.85816	0.00114
Right Edge Proximity (3) vs. Right Edge Proximity (5)	19.87339	6.54281	1117.705	3.03744	0.020584
Right Edge Proximity (4) vs. Right Edge Proximity (5)	1.664568	6.326113	1117.062	0.263127	0.998947

Table 90: Alutiiq F0 table with all results from releveling around distance from the right edge.

Relevelled Alutiiq F0 Model Summary	Estimate	Std. Error	df	t value	Pr(>|t|)
Intercept (2nd syllable)	1.120903	0.344976	46.45212	3.249222	0.002154
Right Edge Proximity (1st syllable)	-0.18657	0.324612	981.3995	-0.57476	0.565588
Right Edge Proximity (3rd syllable)	0.247018	0.328405	1074.517	0.752177	0.452109
Right Edge Proximity (4th syllable)	0.818839	0.297307	1072.835	2.754189	0.005983
Right Edge Proximity (5th syllable)	1.340143	0.450133	1071.922	2.977214	0.002974
Intercept (3rd syllable)	1.367921	0.27889	20.83922	4.904876	7.66E-05
Right Edge Proximity (1st syllable)	-0.43359	0.247031	965.9683	-1.75521	0.07954
Right Edge Proximity (2nd syllable)	-0.24702	0.328405	1074.517	-0.75218	0.452109
Right Edge Proximity (4th syllable)	0.571821	0.333103	1075.316	1.716649	0.086331
Right Edge Proximity (5th syllable)	1.093124	0.461718	1072.206	2.367514	0.018085

Intercept (4th syllable)	1.939742	0.345875	47.95528	5.608218	9.91E-07
Right Edge Proximity (1st syllable)	-1.00541	0.320347	1026.003	-3.13851	0.001747
Right Edge Proximity (2nd syllable)	-0.81884	0.297307	1072.835	-2.75419	0.005983
Right Edge Proximity (3rd syllable)	-0.57182	0.333103	1075.316	-1.71665	0.086331
Right Edge Proximity (5th syllable)	0.521304	0.472813	1072.738	1.102557	0.270467
Intercept (5th syllable)	2.461046	0.470602	150.7992	5.229573	5.58E-07
Right Edge Proximity (1st syllable)	-1.52672	0.452958	1065.256	-3.37055	0.000777
Right Edge Proximity (2nd syllable)	-1.34014	0.450133	1071.922	-2.97721	0.002974
Right Edge Proximity (3rd syllable)	-1.09312	0.461718	1072.206	-2.36751	0.018085
Right Edge Proximity (4th syllable)	-0.5213	0.472813	1072.738	-1.10256	0.270467