Vowel Variation in Nłeʔkepmxcín: An Acoustic Study of Coarticulation*

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Abstract: Previous work on Nłeʔkepmxcín, a Northern Interior Salish language, has impressionistically described the vowel system as consisting of four primary vowels /i e ə u/ but with several allophonic realizations (Thompson & Thompson 1992). The current study aims to test the descriptions of vowel variation by choosing three consonantal environments (pre-velar, post-velar, labial) in both prevocalic and postvocalic positions with six vowel realizations which are represented by letters in orthography (i, e, a, ə, o, u). Results of the acoustic study suggest the strength of coarticulation varies by vowel. The front vowel /i/ among all vowels is the least resistant to coarticulatory effects as it significantly retracts following post-velar consonants. Additionally, these findings suggest there is great overlap in the vowel space in terms of the height dimension (F1) in general, and the coarticulation effects seem to be causing stronger retraction effects (F2) than raising effects (F1). Overall, the findings of this study align with previous research on other Northern Interior Salish languages in terms of the asymmetry in directionality of retraction effects (anticipatory > carryover), and therefore contribute to the acoustic study of vowel variation across Salish languages.

Keywords: Nłeʔkepmxcín, Salish, vowel variation, coarticulation, retraction

1 Introduction

Salish languages typically have a small vowel inventory (n ≈ 5). Despite the small vowel inventory, complications could persist in various aspects. In Salish languages, it is common for vowels to be produced with a great deal of variability which results in significant variation and overlap between different vowels (Mellesmoen & Huijsmans 2019; Kamigaki-Baron 2021). Previous description and phonetic works on Nłeʔkepmxcín thus far have been done either impressionistically through fieldwork (Thompson & Thompson 1992) or on higher prosodic structures (i.e., intonation and focus) (Koch 2007). This paper aims to provide a systematic description of vowel variation in Nłeʔkepmxcín. In doing so, the focus is on the coarticulatory effects of adjacent consonants since the variation documented seems to be related to the predictable consonant environments. In addition to providing acoustic evidence with regards to the study of vowels both within Salish languages and cross-linguistically, such work could have implications for the community as it helps

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with creating tools for teaching or guides for pronunciation when there is no easy access to audio materials.

Cross-linguistically, in acoustic studies, the first formant (F1) and the second formant (F2), as the correlates of dimensions of height (high/low) and position (back/front), respectively, are used as means of organizing the vowel systems (Becker-Kristal 2010; Ladefoged & Maddieson 1990). Vowel variation in Salish languages has been studied through different lenses, with a variety of acoustic measurements including F1 and F2. Bessell (1997) has studied the coarticulatory effects of consonants following and preceding vowels in St'át'imcets (Interior Salish) acoustically and found that vowels surrounded by phonologically retracted consonants (such as uvulars) in both directions are retracted. An ultrasound study conducted by Namdaran (2006) on non-low St'át'imcets vowels also supports this bidirectionality of retraction, although the retraction effect of uvulars on the preceding /i u/ vowels were larger than when they were followed by those vowels. Furthermore, Hudu's (2007) follow-up ultrasound study on low vowels in St'át'imcets shows that phonologically low vowels are susceptible to retraction as well, and similar to Namdaran's (2006) study, retraction in the leftward direction, that is when they are followed by retracted consonants, is more evident visually in the articulatory results of the ultrasound. Regarding other (Central) Salish languages, Nolan (2017) has studied the effect of stress and surrounding consonants on vowel variation in Lekwungen and discovered that uvular and glottal consonants have the most persistent effects on all vowels' F1 and F2. Mellesmoen and Cardoso (2021) analyzed vowel contrast in ʔayʔaǰuθəm (Comox-Sliammon) using multiple acoustic measures and Principal Component Analysis (PCA). They found that although duration, voice quality, F1, and F2 explain variance in the data, it seems that vowels overlap significantly in F1 and F2 space, but there is much less overlap for allophones taking into consideration phonological environment conditions. Bird and Leonard's (2009) study on SENĆOŦEN coarticulation gestural conflict of uvular consonants and the front vowel /i/ shows different individual strategies and variations in F1 and F2.

In the next subsection an overview of the vowel system based on the previous fieldwork in Nłeʔkepmxcín will be provided. In Section 2 theories of coarticulation relating to this study's framework will be considered and, finally, in Sections 3 and 4 the methodology and results will be discussed before the conclusion in Section 5.

1.1 Nłeʔkepmxcín vowel system

Nłeʔkepmxcín (exonym: Thompson River Salish) is a Northern Interior Salish language, spoken in south-central British Columbia along the Fraser, Thompson, Nicola and Coldwater rivers. According to FPCC's 2022 report[1] the community has 105 fluent speakers and 312 semi-speakers with overall 417 total speakers. Thompson & Thompson's grammar (1992:11) has described the Nłeʔkepmxcín vowel system as having 4 (primary) vowels /i, e, u, ə/ which are subject to various degrees of allophony due to "a complex interplay of free variation and conditioning in terms of surrounding consonants, syllable position and stress patterns". A summary of Thompson and Thompson's (1992:11-21) description of allophonic relationships between vowels and their retracted counterparts with regards to contexts of post-velar (q, q^w, χ, $χ^w$, ʕ, $ʕ^w$) and pre-velar (k, k^w, x, x^w, ɣ) are provided in the following points:

[1] First People's Cultural Council has 4 reports on the status of B.C.'s First Nations languages since 2010, the latest one being the 2022 version (which can be accessed from here: fpcc.ca/stories/status-of-languages).

- **high front vowels:** /i/ and /i̱/ (retracted)
    - /i/ → [e] before and after a post-velar in the same syllable (*sx̱íc* 'wood', *qʷincút* 'talk').
    - /i̱/ is very rare, usually appearing before "l, l̓" (*s̱íkm* 'making a piercing sharp whistle').
- **lower non-back vowels**: /e/ and /a/[2] (retracted)
    - Stressed /e/ lowers to [æ] following post-velars (*qéck* 'elder brother').
    - Unstressed /e/ except before "ʔ" turns into [ɛ] (*qemút* 'hat').
    - Stressed /e/ lowers following pre-velars in closed syllables when the coda is post-velar but not when the coda is any other obstruent in closed syllables and not when the following syllable starts with a pre-velar.
- **back rounded vowels:** /u/ and /o/ (retracted)[3]
    - [u] is heard before a rounded pre-velar (*cúkʷ* 'it is finished').
    - [o] is heard after post-velars and in open syllables followed by post-velars (*qʷúʔ* 'water', ʔú.qʷeʔ 'drink').
    - After unrounded back consonants /u/ is preceded by a brief [ə] onglide (*ʔesnk̓úxʷ* 'it is gouged out').
    - /o/ is common in retracting environments (*ʕʷóy̓t* 'sleep', *zóqʷ* 'dead').
- **lax vowels:** /ə/ and /ə̱/ (retracted)
    - /ə̱/ could sometimes be just a retracted version of a [ə] in retracted environments, however it also appears elsewhere (*sk̓ə̱łt* 'mud').
    - /ə/ is a lower high central vowel that has alternants that take the colorization of surrounding consonants.
    - A retracted and lowered version of /ə/ appears adjacent to post-velars; however, if the environment is a mix of post-velars and alveopalatals, it could be more central and higher (*qəscút* 'scratch oneself').

Regardless of the phonological analysis of vowels provided by Thompson and Thompson (1992), eight vowels are used in total in the orthography of the dictionary, which is also the basis of data collection in this paper.[4] Although it should be pointed out that "i̱" and "ə̱" occur rarely and

[2] Thompson and Thompson (1992) do not consider [a] to be one of the primary phonemes in the beginning of their chapter, but in the later sections, having reported the large variability between [e] and [a] at various levels such as the lexicon, individual, and dialect which according to them could be due to diachronic reasons, they state that it is necessary to recognize them as two distinct phonemes since there are words in which [e] is never substituted by [a] (1992:12). They also state that, among the retracted vowels, /a/ is the most common one.

[3] Thompson and Thompson (1992:18–19) mention some conditioning environments for /u/ and /o/ but also state there is some free variation heard among these two vowels, possibly due to historical reasons.

[4] For clarification, there are, in total, 28 vowel symbols used for all the realizations observed in the production of the vowels by Thompson and Thompson. Only eight of them are used in the orthography (See Figure 2 in Thompson & Thompson 1992:11).

therefore are merged with their undotted forms for now in the current work. The following table containing the vowels is adapted from descriptions in Thompson and Thompson (1992):

Table 1: Vowels used in the orthography of Nłeʔkepmxcín based on Thompson and Thompson (1992)

	Front	retracted	Central	retracted	Back
High	i	ị			u
Mid	e		ə	ə̣	o
Low		a			

Finally, it is worth noting that while the descriptions reported in the grammar are invaluable, issues regarding inconsistencies throughout the descriptions lead to the need for gathering data and further investigations of the interplay between phonetic variation and the phonemic status of the vowels.

2 Background

Before moving on to the background on coarticulatory effects, the goals of the current research which this study was motivated by will be set forth here.

2.1 Current research goals

The current study aims to provide an acoustic analysis of Nłeʔkepmxcín vowels which contributes to our understanding of the phonetic properties of Salish languages and specifically the Northern Interior subfamily (Nłeʔkepmxcín, St'át'imcets, and Secwepemctsín). The goals of the study therefore are threefold:

i. to collect data on context-dependent vowel variation in Nłeʔkepmxcín in terms of the coarticulatory effects to observe whether they align with the allophonic variation documented;

ii. to study the bidirectional effects of adjacent consonants on vowels in terms of retraction and raising/lowering;

iii. to compare the results of this study to previous acoustic studies on retraction in St'át'imcets as another Northern Interior Salish language.

2.2 Coarticulatory effects

Coarticulation as a phenomenon in speech production refers to co-production or overlap in articulatory gestures during speech which could lead to modifications of a given speech sound caused by another speech sound (henceforth "target" and "trigger", respectively) (Browman & Goldstein 1992). Naturally, coarticulation can be viewed from different aspects; temporal effects (i.e., the time that the motivation happens in and the relative duration into the target) and spatial effects (i.e., what areas in the articulation of the target are modified and to what extent). The spatio-temporal effects depend on several factors such as articulatory structures of the gestures, and the changes can be measured through different acoustic properties such as F2 or duration. Coarticulatory effects of the trigger on the following segments (rightwards) are referred to as "carryover" effects, which might be more variable compared to the "anticipatory" effects on the

preceding segments (leftwards) (Recasens 2018:2). The anticipatory effects mostly reflect speech planning (Whalen 1990). The difference in the effects between the two directions has been attributed to the motivation and the stage of the speech production process, among other factors. Recasens (2018) uses the terms coarticulatory "resistance" and "aggressiveness" to discuss degrees of coarticulation effects; the former is about the extent to which targets are susceptible to variation and the latter about the extent to which triggers are prone to cause change. In their model of coarticulation, Recasens et al. (1997) acknowledge the various levels of lingual coarticulatory resistance to coarticulatory effects depending on the degree of the primary lingual structure required during articulation. For example, in Vowel-to-Consonant effects, labial consonants are the least resistant to coarticulation from vowels since there is no gestural competition. In other words, the primary articulator in the production of labials is not involved in the production of vowels which use the tongue body. As for vowels, in Consonant-to-Vowel effects, schwa (/ə/) is the least resistant to coarticulation from adjacent consonants, and hence highly variable due to the "absence of any articulatory requirements upon the formation of a lingual constriction" (Recasens 1999:82). Investigations of Salish languages report that /ə/ exhibits the most variation depending on its environment (Central Salish: Mellesmoen & Huijsmans 2019, Interior Salish: Kamigaki-Baron 2021). Cross-linguistically, it is known that the front vowel /i/ is the most resistant to coarticulation effects from adjacent consonants, however, some studies have shown that when neighbored by a velarized consonant it undergoes dorsum lowering and retraction, that is the middle of the tongue is lowered and pulled back (Alfonso & Horiguchi 1987). The back vowel /a/ shows context-dependent variability such as raising effects when adjacent to velars (Recasens 1999:81–82) which is also reported in Salish languages (Bessell 1997, Shahin 2008).

From the spatial point of view, coarticulatory effects could arise due to conflicting demands on articulatory gestures. The conflict could be resolved by articulatory changes to the target sound. Gick and Wilson (2006) report on two other possible strategies: inserting a transitional element or fully deleting one of the sounds. Bird and Leonard (2009) have investigated these strategies in SENĆOŦEN in an acoustic study with two fluent speakers and found different strategies used by the speakers for the coarticulation of sequences of /qi/ and /iq/. Nevertheless, overall, three main strategies were implemented to resolve the conflict: vowel retraction, e.g., /qi/ to [qɪ]; transitional vowel, e.g., /qi/ to [qəi]; and transitional frication, e.g., /qi/ to [qxi].

From the temporal point of view, as has been mentioned before, depending on the manner and articulatory gesture of the adjacent triggers, there is variability in terms of how far and in which direction the effects can exhibit in the acoustic signal. Relevant factors could be the articulatory distance between the target and the trigger, or the involvement of the lingual articulator, which means the closer and more involved the gestures are, the larger the onset of the coarticulation consecutively. Relatively, carryover effects have higher saliency compared to anticipatory effects which may be associated with the pre-planned nature of anticipatory effects versus the structural properties of the coarticulator. Mellesmoen and Huijsmans (2019) have taken the first two formant measurements for the vowel trajectory at seven time points in ʔayʔaǰuθəm. In their study, an interesting finding when comparing palatal and uvular environments is that palatal consonants seem to have a greater influence on the position dimension (F2), while uvular consonants' influence is on the height dimension (F1).

3 Methodology

In this section, the methodology of the study including the information about the speakers and the procedure of data collection and analysis will be provided.

3.1 Consultants

This study features two fluent female speakers of Nłeʔkepmxcín. B. P. is a speaker of the Lytton dialect spoken in Lytton Valley; she was raised with monolingual Nłeʔkepmxcín-speaking parents. K. B. G. is a speaker of the Nicola Valley dialect and is a Kamloops Residential School survivor who is re-learning her language. All speech data, which consist of approximately 24 hours of recordings over various sessions, were recorded during fieldwork sessions with speakers from September 2022 to April 2023 remotely via the video conferencing software Zoom.

3.2 Materials and procedure

For this study, I compiled a word list (see Appendix) that met the required conditions in Table 2. The primary materials I consulted were the Thompson and Thompson (1996) dictionary, and FirstVoices.[5] In order to control for stress, I tried to limit my options to those that had the target vowel in a stressed syllable as much as possible. Each item or token in the list was first checked with speakers and recorded during elicitation sessions through a translation task which was either accompanied by pictures or narration of a hypothetical story. Due to limitations of time, the majority of the tokens were pronounced in isolation (or rarely in small phrases), that is, without a fixed carrier phrase. Consultants were asked to repeat them two to four times if possible; all repetitions with sufficient acoustic quality for analysis (that is without any extra background noise) were analyzed. Since the materials I consulted were based on previous documentation, the vowels considered in this study were six common vowels indicated by orthography: "i, e, a, ə, o, u". Based on the terminology and categorization from Thompson and Thompson (1992)'s description, the adjacent consonants were grouped into three conditions K, Q, and P (Table 2). The P condition only consists of the labial consonant /p/. It was chosen as the least resistant consonant to lingual coarticulation effects (where possible this condition provided a baseline control group).

Table 2: Adjacent consonant conditions

Description	Condition	Consonants
Pre-Velars	K	k, kʷ, x, xʷ, ɣ
Post-Velars	Q	q, qʷ, χ̣, χ̣ʷ, ʕ, ʕʷ
Labial	P	p

To recapitulate, carryover effects refer to the rightwards effects of pre-vocalic consonants (CV), and anticipatory effects refer to the leftwards effects of post-vocalic consonants (VC). Overall, 321 tokens (223 unique types) were considered in the analysis of the current study. Certain vowels were less common than others, and in fact some vowel and consonant sequences were difficult to find. For instance, the condition P with 'o' in the anticipatory direction seemed to be a rare sequence and remains without any representative token. The number of vowels in each condition is shown in the table below:

[5] firstvoices.com — An online resource initiated by the First Peoples' Cultural Council to share and promote Indigenous languages in B.C.

Table 3: Token frequencies by condition

Vowel	Total n	Carryover Effects			Anticipatory Effects		
		K	Q	P	K	Q	P
i	72	16	15	16	17	19	3
e	82	30	17	10	17	5	12
a	61	19	21	4	15	13	3
ə	44	15	16	2	8	7	3
u	37	13	11	3	13	4	3
o	25	6	2	3	2	12	-
	321	99	82	38	72	60	24

Speech data recorded through Zoom in a .m4a format had to be converted to .wav for importing into Praat (Boersma & Weenink 2022). After transcribing the elicitation sessions, the target tokens were annotated manually in the long audio recordings (e.g., at word and phoneme level) by the researcher. The vowel boundaries were marked on the phoneme interval layer, and afterwards midpoint F1 and F2 measurements were automatically extracted with a Praat script. Due to the small size of the dataset and the number of speakers, and also the unequal sample size from each speaker, the raw acoustic measurements of all speakers together were used in the statistical analysis. Pairwise t-tests were used to measure significance in differences between mean values of F1 and F2 using R studio (R Core Team 2023; Ahlman-Eltze & Patil 2021).

3.3 Research questions

Considering the goals of the current project and the background on coarticulatory effects in Salish languages, the specific research questions are outlined as follows:

- Q1: Are all vowels significantly retracted when they follow the post-velar (Q) and pre-velar (K) conditions compared to the labial (P) condition?
- Q2: Are all vowels significantly retracted when they precede the post-velar (Q) and pre-velar (K) conditions compared to the labial (P) condition?
- Q3: Are the front low vowel pairs represented with “e” and “a” in the orthography significantly different from each other (both in F1 and F2) when they are preceded or followed by the consonants in each condition?
- Q4: Are the back vowels pairs represented with “o” and “u” in the orthography significantly different from each other (both in F1 and F2) when they are preceded or followed by the consonants in each condition?

4 Results

4.1 Vowel space

At first, to observe the whole vowel space, we can look at the full vowel charts. The axes are reversed in vowel plots traditionally, so high F1 values correspond to a low tongue height, and high F2 values represent a front tongue position. Figures 1 and 2 show the full vowel chart including

all the six vowels in Nłeʔkepmxcín. The ellipses showing measurements of F1 and F2 are situated with 65% confidence. The points each represent a vowel token which are grouped by colors. The consonant conditions are grouped by shapes: dots (pre-velar K), triangles (labial P), and squares (post-velar Q). In these plots, at first glance, vowels show great variability and overlap in both carryover (see Figure 1) and anticipatory effects (see Figure 2) directions. The vowels "a, e, ə" seem to occupy the center of the vowel space showing more overlap than other vowels.

Figure 1: Full vowel plot of the carryover effects

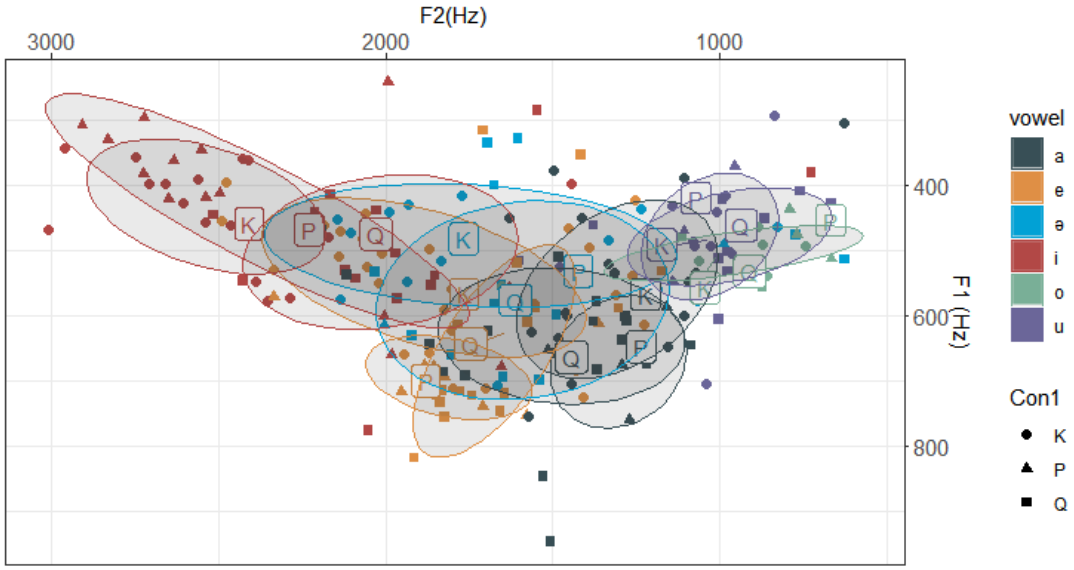
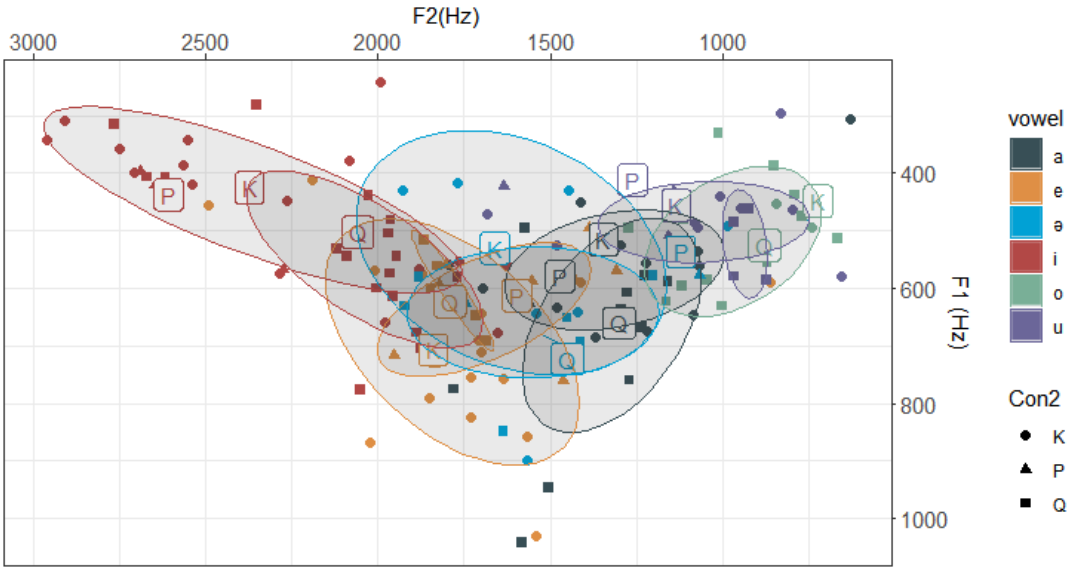


Figure 2: Full vowel plot of the anticipatory effects



In order to make the effect of the three conditions on each vowel more visible on the plots, Figures 3 for carryover and 4 for anticipatory effects show each vowel separately in a similar plot for the three conditions. Not all vowels have their F1 and F2 values moved in the same direction in the plot, so the effect of each consonant condition (colored) seems to vary in different vowels.

Figure 3: Vowel plots of the carryover effects

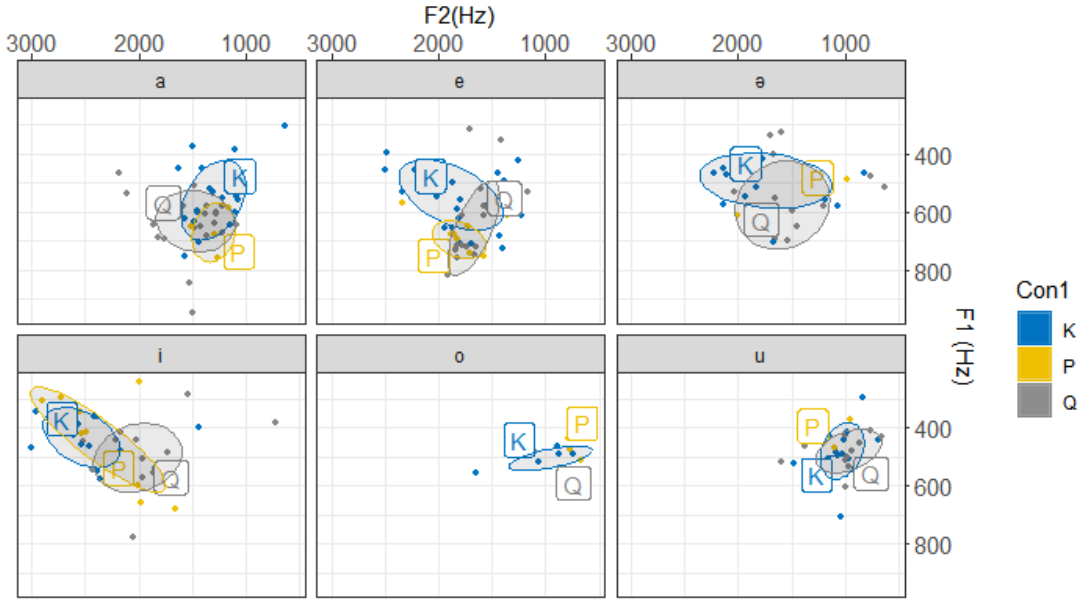
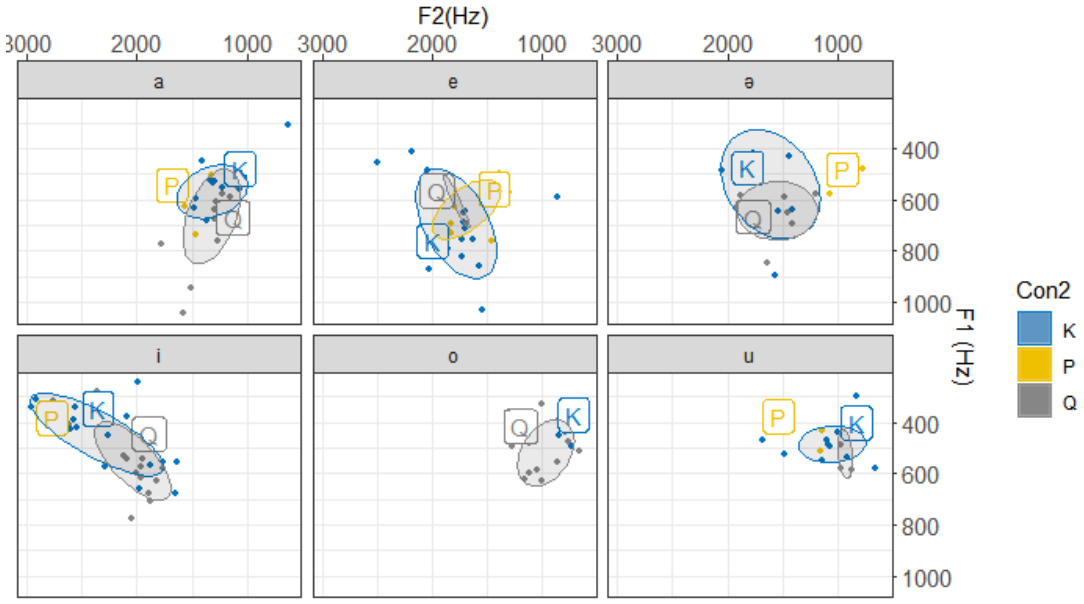


Figure 4: Vowel plots of the anticipatory effects

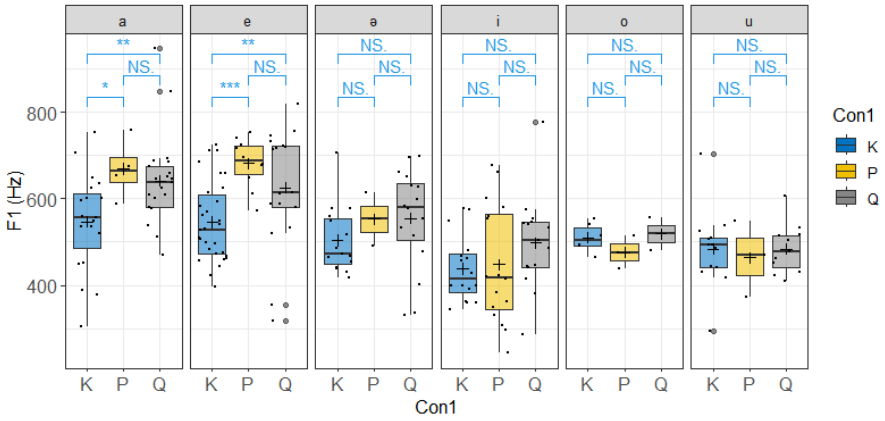


4.2 Coarticulatory effects of consonants on vowels

4.2.1 F1 (height)

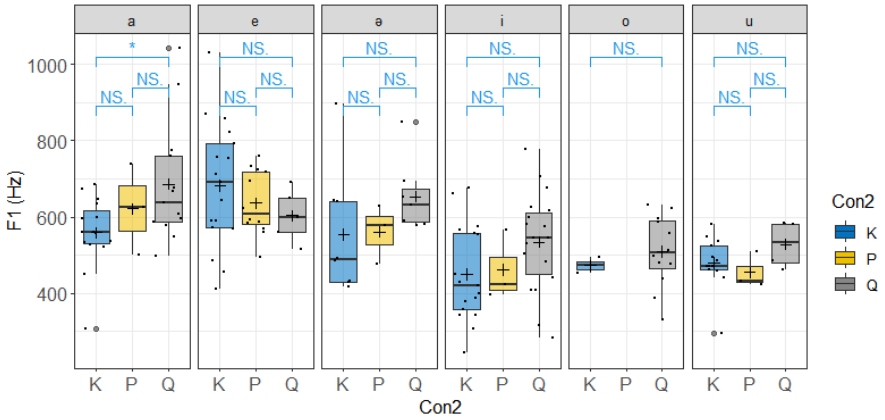
In order to obtain a closer look at the coarticulatory effects from preceding or following consonants on each of the vowels in terms of F1, we can plot the variation of vowels individually. Figures 5 for carryover and 6 for anticipatory effects show to what extent the mean F1 of a vowel at midpoint is significantly different across conditions. The significance level is annotated throughout the plots with: NS, *, **, ***; NS being no significant differences and *** the highest level of significance.

Figure 5: Carryover effects of consonants on F1



As can be seen in the plot above which includes the t-test results (Figure 5), the only vowels which show persistent coarticulatory effects of their preceding consonants are “a” and “e”; the rest of the vowels do not seem to show a significant difference when preceded by different consonant conditions. The vowel “a” has a significant difference of means between the Ka and Qa conditions, and between the Ka and Pa conditions. The vowels’ F1 value in the Ka condition seems to be lower than other “a”s. The same pattern can be observed in the vowel “e”, except with the difference that the vowel raising effect of K on “e” vs. P is stronger.

Figure 6: Anticipatory effects of consonants on F1

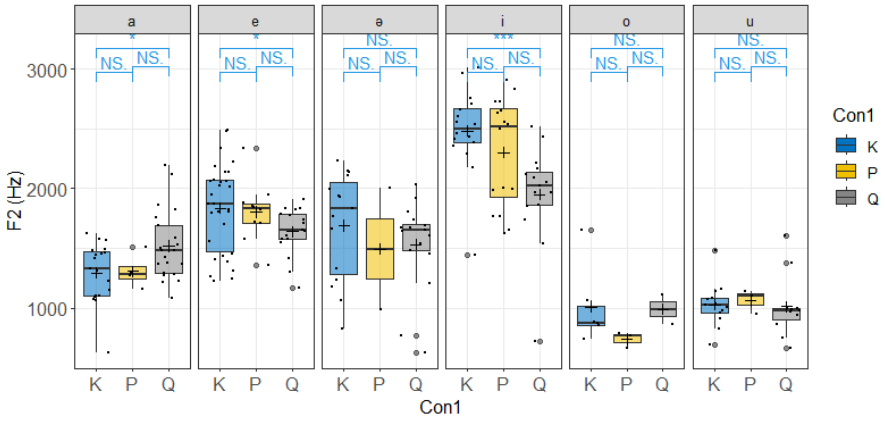


The anticipatory effects of the consonants which can been seen in the plot above (Figure 6) seem not to lead to persistent effects in any of the vowels except “a”. The Ka condition compared to the Qa condition seems to have a significant difference in the mean F1. This again results in a higher “a” in the K condition and lower “a” in the Q condition.

4.2.2 F2 (retraction)

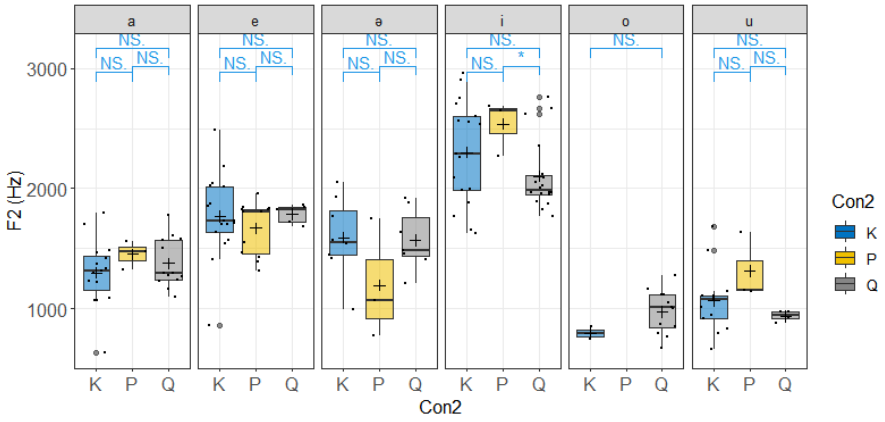
Moving on to F2, for obtaining a closer look at the coarticulatory effects from preceding or following consonants on each of the vowels, we can take a look at the plots of vowels individually. Figure 7 for carryover effects and 8 for anticipatory effects show to what extent the mean F2 of a vowel is significantly different across conditions.

Figure 7: Carryover effects of consonants on F2



As can be seen in the plot above (Figure 7), the t-test results reveal that the three vowels which show persistent coarticulatory effects of their preceding consonants are “a”, “e”, and “i”. The vowels “a” and “e” have a significant difference of means of F2 between the K and Q conditions. The vowel “i” also has a significant difference between F2 means of the Ki and Qi conditions, which compared to the other vowels this difference has a higher degree of significance (***).

Figure 8: Anticipatory effects of consonants on F2



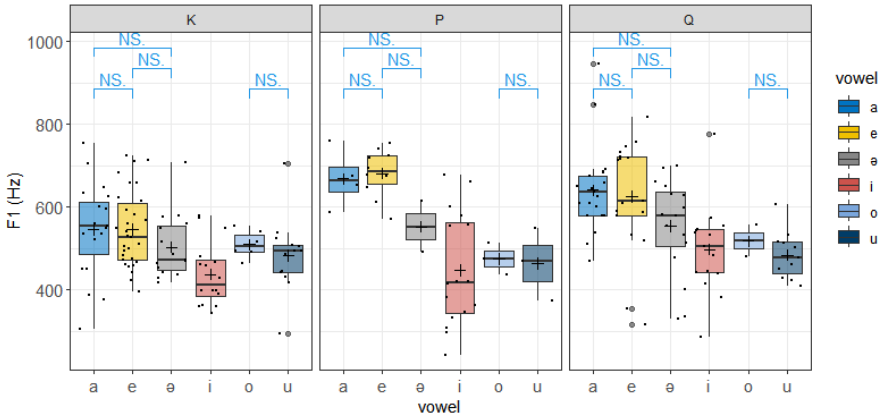
In the anticipatory effects of the consonants in the plot above (Figure 8), no significant difference between each conditions' effect on the F2 means of vowels seem to be reported by the t-test results, except in the vowel "i". Here the iQ condition shows a significant difference of means compared to the iP condition in terms of F2 or retraction, with iP being more retracted.

4.3 Vowel overlaps within conditions

4.3.1 F1 (height)

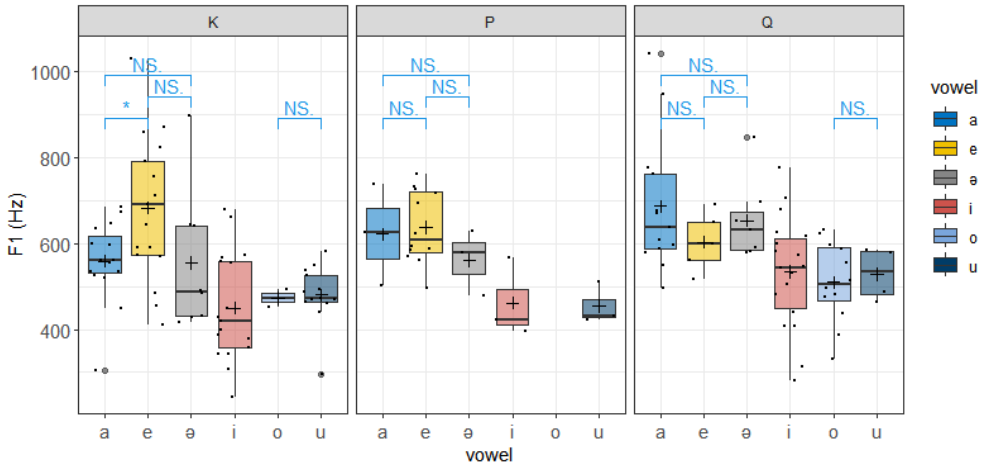
In order to look at the degree of overlap between the vowel categories in terms of F1, we can isolate the effect of the coarticulatory conditions. Figures 9 for carryover effects and 10 for anticipatory effects show to what extent the mean F1 of vowels at midpoint is significantly different within each condition. As these two plots show, vowel height measurements in these vowels (disregarding a few outliers) is situated in the center from 400–700 Hz. t-test comparisons are indicated in the plots only for the vowel pairs which are described in pairs previously, the back vowels "o" and "u", and the front low vowels "e" and "a" plus "ə", which seems to be located in the same area of the vowel plot.

Figure 9: Between-vowel variation of F1 across carryover effects



As can be seen in the plot (Figure 9) and as the t-test comparisons indicate, when keeping the carryover effects constant, there is no significant difference between the vowels "a", "e", "ə" and "o", "u" in terms of their F1. In addition, informally it could be observed that all vowel means in the KV condition are overall less variable in height and are confined to a smaller 400–550 Hz range approximately.

Figure 10: Between-vowel variation of F1 across anticipatory effects

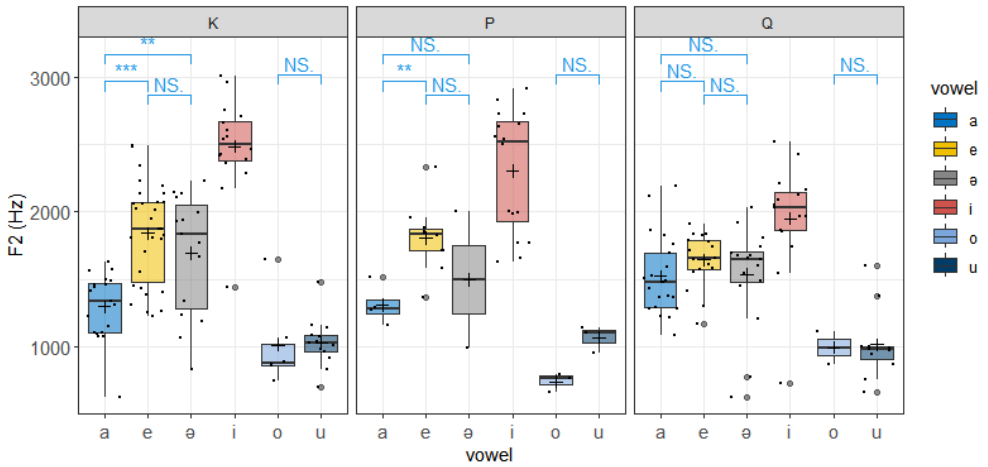


In the opposite direction (Figure 10), in particular in the VK condition, there seems to be more variance between vowels from the distribution of the box plots. Results of the t-tests show that in this condition there seems to be a difference in means of F1 statistically only between "a" and "e", although the degree of significance is low (*). However, the other two conditions VP and VQ seem to follow a similar pattern to the previous plot. In addition, informally it could be observed that compared to others in the VQ condition, the F1 means of all vowels are confined to a smaller 500 to 650 Hz range approximately and have more overlap.

4.3.2 F2 (retraction)

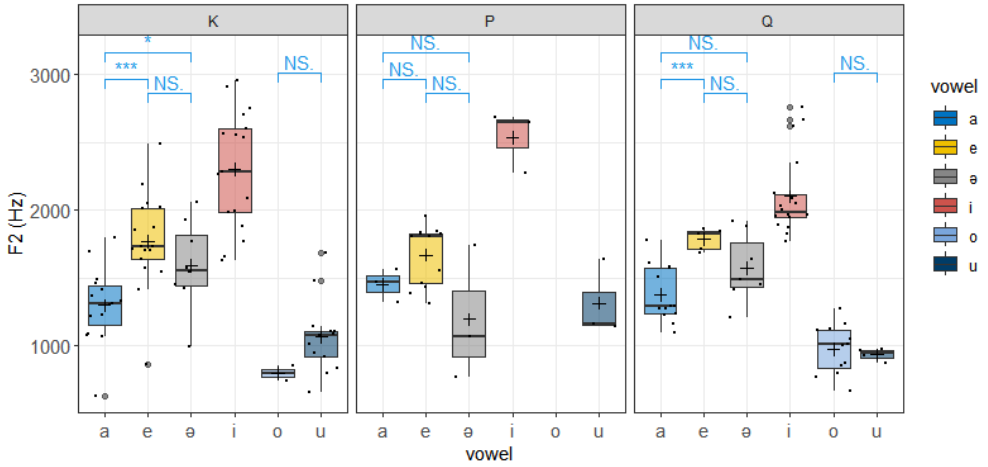
In order to look at the degree of overlap between the vowel categories in terms of F2, we can isolate the effect of the coarticulatory conditions. Figure 11 for carryover and 12 for anticipatory show to what extent the mean F2 of vowels is significantly different within each condition.

Figure 11: Between vowel variation of F2 across carryover effects



As can be seen in the plot (Figure 11), and as the t-test comparisons indicate, when keeping the carryover effects constant, in the conditions KV and PV there is a significant difference between the means of F2 between vowels “a” and “e”, and also between “a” and “ə” in the KV condition. In addition, informally it could be observed that all F2 means in the QV condition overall have less variation and are limited to a 1000–2000 Hz range approximately.

Figure 12: Between vowel variation of F2 across anticipatory effects



As can be seen in the t-test comparisons in the plot (Figure 12), when keeping the anticipatory effects constant in conditions VK and VQ there is a significant difference between the means of F2 between vowels “a” and “e”, and also between “a” and “ə” in the KV condition.

4.4 Discussion

The preliminary results obtained in this study regarding vowel variation in Nłeʔkepmxcín show that the coarticulation from consonants (triggers) to vowels (target) does not produce the same effect in all vowels. Starting with raising or change in F1, the back vowels “o” and “u” do not seem take any effect from the adjacent consonants and are resistant to them. However, in both directions the Q condition causes lowering of the “i” vowel. In the carryover direction, the K condition causes raising of “a” and “e”. Although, the low values (or raising effect) of K on “e” reverts to a high value (not raising or lowering effect) in the anticipatory direction.

With regard to retraction or change in F2, as might be expected, the back vowels which are already produced with a low F2 do not undergo any significant retraction effect from the consonants. The most front vowel, “i”, is strongly affected by the Q consonants. The retraction effect of K and Q consonants differs on “a” and “e”. In the anticipatory direction, the K and Q conditions behave differently for different vowels. For “i”, the K and Q conditions retract the vowel but for the other three non-back vowels “a”, “e”, and “ə” it seems like this effect is not consistent; in fact, it seems like the P condition in “ə” is more retracted than other conditions. It is worth noting that talking about the bi-directionality of effects and comparing anticipatory vs. carryover effects might not be quite meaningful here at this stage since the data points in these two groups are unbalanced. More importantly, for a one-to-one comparison, there might be other cofounding variables which were not fully accounted for; as an example, in anticipatory effects (i.e., CVK) or

the carryover effects (i.e., KVC), the effect of the other consonant C which is not controlled for might be a confounding variable.

Summarizing the results about the patterns in the overall vowel space, in terms of height, we could say that all the vowels seem to have a tendency to be in the mid position (F1 400–700 Hz) which leads to great overlap of vowel categories in that area of vowel space. We can see in the tongue-neutral coarticulatory position of the labial P, the relative height (F1) of the vowels in a continuum from high to low is: i > o, u > ə > e, a. In the Q condition compared to the K condition there seems to be an overall trend of pulling vowels into a lower tongue position or lowering effect.

According to the measurements of F2, the parameter related to the degree of the backness of the vowels, there seems to be less overlap. The vowel /i/, being located in a non-overlapping space, is the most front vowel (above 2000 Hz). Considering the tongue-neutral P condition, the relative backness of other vowels is u, o > ə, a > e.

The results from St'át'imcets point to a bidirectional effect of uvular consonants on the vowels "i" and "u" (Namdaran 2006) and anticipatory effects of the same consonants on the low vowel /a/ being stronger than the carryover effects (Hudu 2007). Bessell (1997) also looked at F1 as well as F2, and found lowering and backing effects following uvular consonants on "i, u, a, ə". This study shows a similar trend of lowering "i, ə" more than other vowels in both directions when adjacent to Q (the post-velar condition). In terms of the bidirectionality of the retraction effects, the current study confirms the previous studies in St'át'imcets in that there seems to be an asymmetry of magnitude of effects (anticipatory > carryover) specifically in the low vowel "a" which does not seem to show any retraction effects in the carryover condition.

5 Conclusion

The contribution of this paper for the acoustic study of vowel variation and retraction in Salish languages could be summarized in a number of ways. First, the present study provided basic acoustic descriptions of the vowel system of Nłeʔkepmxcín to evaluate impressionistic claims in previous fieldwork. In addition, the study focused on the coarticulatory effects of consonants on vowels grouped into 3*2 conditions (pre-velars, post-velars, labials)*(carryover, anticipatory), which makes it comparable with the findings on retraction across other Interior Salish languages. This was a first step to gather preliminary acoustic data on Nłeʔkepmxcín vowels. To conclude, the results seem to suggest that the strength of coarticulation varies by vowel and that there is significant overlap among most vowels compared in this study, in particular in the height dimension (F1).

One delimitation of the scope of the current study is that the phonetic properties of vowels were measured only at the midpoint. Adding more temporal variables, and including different time intervals during the production of the vowel, would enable discussing the phonological environment leading to more persistent coarticulation effects vs. purely phonetic coarticulation effects. Furthermore, as it is known from the literature, the role of stress, syllable, and higher prosodic structure is important for acoustic analysis; therefore, in order to have a more robust analysis such variables need to be taken into consideration in future studies. One of the shortcomings of the current study is that restrictions of time did not allow for having equal samples from all speakers. Since speakers are female and roughly the same height, all measurements were treated as part of one group together which obscures individual variations. Moreover, since there are not enough data points in each condition to have balanced representation of the different conditions, other statistical analyses would not be reliable at this stage as they might not meet the statistical assumptions required. Future directions for this research could consist of comparing

individual (or possibly inter-dialectal) variations, adding more consonantal environments and tokens as well as employing different statistical methods such as a Bayesian mixed effects model.

As this study aims to contribute to community-based research, an understanding of vowel variation and production of vowels could also have implications for classroom teaching and creating materials for learners. Studying the context-dependent variation in vowels and isolating the effects of consonants systematically could potentially be helpful for teachers to help learners make generalizations about vowel behaviors when they are faced with new lexical items. For instance, it is beneficial for beginner learners to be taught explicitly what coarticulation strategies are available when there are competing demands from different articulatory gestures to produce certain combinations of phonemes.

Finally, this work could also shed light on the typology of vowel inventories and the phonology of vowels by providing acoustic evidence which could be useful for conceptions of features such as height and local retraction of vowels.

References

Ahlmann-Eltze, Constantin & Indrajeet Patil. 2021. "ggsignif: R Package for Displaying Significance Brackets for 'ggplot2'." PsyArXiv. March 31.

Alfonso, Peter J. & Satoshi Horiguchi. 1987. Vowel-related lingual articulation in /əCVC/ syllables as a function of stop consonants. *Proceedings of the XIth International Congress of Phonetic Sciences* 2:41–44.

Becker-Kristal, Roy. 2010. *Acoustic typology of vowel inventories and Dispersion Theory: Insights from a large cross-linguistic corpus.* Ph.D. Dissertation, University of California, Los Angeles, CA.

Bessell, Nicola J. 1997. St'át'imcets vowels and consonants, a phonetic study. *Papers for ICSNL 32.*

Bird, Sonya & Leonard, Janet. 2009. Universality of articulatory conflict resolution: Evidence from Salish languages. *Northwest Journal of Linguistics* 3(2):1–29.

Boersma, Paul & David Weenink. 2022. Praat: Doing phonetics by computer (6.2.23). URL: http://www.praat.org/.

Browman, Catherine P. & Louis Goldstein. 1992. Articulatory phonology: An overview. *Phonetica* 49:155–180.

FPCC. 2022. *Report on the status of B.C. First Nations languages.* URL: http://www.fpcc.ca

Gick, Brian, & Ian Wilson. 2006. Excrescent schwa and vowel laxing: Cross-linguistic responses to conflicting articulatory targets. In Lous Goldstein, D.H. Whalen, and Catherine T. Best (eds.), *Laboratory phonology VIII*. Berlin, Germany: Mouton de Gruyter, 635–659.

Hudu, Fusheini. 2007. The low vowel and retraction in St'át'imcets. *Papers for ICSNL* 42:164–175.

Kamigaki-Baron, Michelle. 2021. Acoustic description of Secwepemctsín vowels. *Papers for ICSNL* 56:134–153.

Koch, Karsten. 2007. *Intonation and focus in Nłeʔkepmxcín.* Ph.D. Dissertation, University of British Columbia, Vancouver, BC.

Ladefoged, Peter & Ian Maddieson. 1990. Vowels of the world's languages. *Journal of Phonetics* 18(2):93–122.

Mellesmoen, Gloria & Amanda Cardoso. 2021. Investigating phonemic inventories without minimal pairs: Defining contrast in the vowel inventory of Comox-Sliammon (ʔayʔaǰuθəm). Paper read at *12th International Conference of Nordic and General Linguistics* (*ICNGL*), Oslo, Norway, 16 June.

Mellesmoen, Gloria. & Huijsmans, Marianne. 2019. The relationship between pronunciation and orthography: Using acoustic analysis as a practical illustration of Comox-Sliammon vowel quality. In Sasha Calhoun, Paola Escudero, Marija Tabain and Paul Warren (eds.), *Proceedings of the 19th International Congress of Phonetic Sciences*. Melbourne, Australia: ICPhS, 979–983.

Namdaran, Nahal. 2006. *Retraction in St'át'imcets: An ultrasonic investigation.* MA Thesis, University of British Columbia, Vancouver, BC.

Nolan, Tess. 2017. *A phonetic investigation of vowel variation in Lekwungen.* MA Thesis, University of Victoria, Victoria, BC.

R Core Team 2023. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. R-project.org.

Recasens, Daniel. 1999. *Lingual coarticulation*. In William J. Hardcastle & Nigel Hewlett (eds.), *Coarticulation: Theory, data and techniques*. Cambridge, UK: Cambridge University Press, 80–104.

Recasens, Daniel. 2018. Coarticulation. In *Oxford Research Encyclopedia of Linguistics*.

Recasens, Daniel, Maria Dolores Pallarès, & Jordi Fontdevila. 1997. A model of lingual coarticulation based on articulatory constraints. *Journal of the Acoustical Society of America* 102:544–561.

Shahin, Kimary. 2008. "Acoustic Testing for Phonologization". *Canadian Acoustics* 36(4):48-49.

Thompson, Laurence C. & M. Terry Thompson.1992. *The Thompson Language.* Missoula, MT: University of Montana Occasional Papers in Linguistics.

Thompson, Laurence C. & M. Terry Thompson. 1996. *Thompson River Salish dictionary: nłeʔkepmxcín.* Missoula, MT: University of Montana Occasional Papers in Linguistics.

Whalen, Douglas. H. 1990. Coarticulation is largely planned. *Journal of Phonetics* 18:3–35.

Appendix

Table A1: Selected Wordlist

Lexical Item	Translation
cáqcəqt	‘spruce hen’
c̓əc̓óq̓ʷ	‘writing’
cék	‘finished’
cəqcéq	‘tamed’
cəqém	‘recline your back’
c̓eskíkiʔ	‘chickadee’
cáχ̣	‘dripping’
c̓ikwik	‘dregs at the bottom’
c̓íp̓	‘pinched’
cíqʷ	‘red’
c̓lóx	‘warm’
c̓mék	‘hole in shoe’
cm̓éxt	‘delicious’
cúkʷsne xʔe	‘I finished with that’
cʔək	‘domesticated’
ɣəkmíns	‘flooded’
kazeʔúɬ	‘liar’
kázeʔ	‘tell a lie’
ḱəlḱíles	‘cut into many pieces’
ḱəl̓mín	‘scissors’
kəɬstés	‘remove the cover’
kást	‘bad’
ḱəχ̣ʷ	‘dimples’
ḱíḱeʔt	‘near’
kentemús	‘helper’
kentéyt	‘helper’
kʷəsó	‘domesticated pig’
kʷáʔ	‘acting crazy’
kʷəl	‘green’
kʷlíqəq	‘robin’
kʷúkʷpiʔ	‘chief’
kʷúp	‘push something’
kxʷékst	‘bruised on your hand’
ƛ̓ek̓t	‘flood’
ƛ̓éxix	‘joking around’
ɬípsəm	‘blinking’
ƛ̓íqt	‘sky’
lisék	‘sack of grains’
líχ̣kst	‘finger’
ɬképs	‘pot’
ƛ̓lʔék	‘arrive’
ɬmák	‘hole in socket’
ɬp̓éẃus	‘hang over a line’
miʔxétxʷ	‘you kick him’
múqʷe	‘blue heron’
ncíqm	‘to dig’
nemes qəɬmíns cníɬ	‘a very old woman’
niɣpíkn̓	‘lunch’
níkn̓ik̓ənux	‘cut a little bit’
níḱsip̓	‘cut wood’
nkəɬqín̓m	‘take the lid off’
nɬóqʷs	‘boiling liquid’
nƛ̓zéxetn	‘worn out’
npéps	‘a little pond’
np̓óles	‘making a hole’
nq̓aq̓ẏ́m̓en	‘a person who shoots a lot’
nsqáqχ̣eʔ	‘dog’
nsxʷákʷukʷ	‘the way I feel’
nsχ̣ʷóχ̣ʷst	‘something I want’
ntəkʷpán̓i	‘to become deaf’
nχ̣ət	‘hole’
nʔáq̓	‘rotten’
páqʷuʔkn	‘I am scared’
nsχ̣ʷóχ̣ʷst	‘something I want’
pén̓ete	‘fold something’
pépiyeʔ	‘alone by itself’
p̓áq̓ʷəɬ	‘platform for storing food’
pétkʷetn	‘needle’
pəxʷ	‘blow something with air’
píχ̣m̓	‘hunting’
piχ̣píχ̣m̓úɬ	‘hunter’

Lexical Item	Translation
piʔéɬ	‘a room’
piʔpstés	‘lose’
poʕʷcínm	‘knocking on the door’
ptekecéms	‘she overtakes me’
pxʷə́p	‘inflate’
q̓apúx	‘hazelnut’
qáznə	‘wave at someone’
qécks	‘older brother’
qəmqémt	‘lukewarm’
qemút	‘hat’
qəpqép wiy̓x	‘it got softer’
qəstés	‘scratch an itch’
qeʔméyc	‘nursing a baby’
qiqítn	‘summit of the mountain’
qláq̓	‘disagreement’
q̓ʷacés weʔa qʷu	‘it’s filled with water’
qʷáx̣	‘confused’
q̓ʷáxt	‘lost weight’
qʷéc	‘a warm place’
qʷəcqʷcíyx	‘to leave’
qʷecúym̓xʷ	‘warm climate’
qʷənqʷént	‘to be poor’
qʷʔéz	‘get bruised’
qʷincutúɬ	‘someone who speaks a lot’
qʷintwáxʷ	‘argument’
qʷíx̣ʷ	‘pitch wood’
q̓íy	‘he cooks’
qʷnóx̣ʷ	‘feeling poorly’
q̓ʷostna	‘take away water’
qʷúy’iʔ	‘cloudy’
kʷúxʷm	‘making a basket’
səxséx	‘misbehaving, up to no good’
séysik̓ʷ	‘broth’
séʔaq	‘fern’
sɣép	‘tree’
sík̓mintem	‘somebody got hit’
skə́kn̓	‘companion’

Lexical Item	Translation
sk̓ə́l	‘leather’
sk̓ə́ɬt	‘mud’
skiʔkíyeʔ	‘ancestor’
sk̓ʷúkʷmit	‘baby, child’
ʔeskʷəɬ	‘brown’
sk̓máx̣n	‘shoulders’
skʷózeʔ	‘son or child’
sɬaʔx̣áns	‘cucumber’
spéps	‘a little bunch of water’
spəták	‘potato’
spíləx̣m	‘news or information’
spúʔpúʔm	‘lungs’
sq̓aq̓epeʔ	‘sandy’
sq̓áwm	‘wolf’
sq̓ʷoq̓ʷyéps	‘strawberry’
sqʷoqʷyəc	‘rabbit’
stakʷolṣ	‘potato’
stékɬ	‘rain’
stpípq	‘weasel’
stpíq	‘white’
stx̣áɬp	‘diamond willow’
súp̓mn̓	‘breath’
swəl̓wl̓íqt	‘stinging nettle’
sx̣áyqs	‘coho salmon’
sx̣áy̓wih	‘husband’
sx̣íc̓kn̓	‘back (body part)’
sx̣íq	‘duck’
sxʷák̓ʷ	‘heart’
sxʷákʷukʷ	‘decide (fix your mind)’
sʕʷláps	‘big horn sheep’
təx̣péʔ	‘dogwood willow’
tóqʷt	‘fluffy’
txíʔxeʔt	‘thin or narrow’
sʕʷláps	‘big horn sheep’
wlóqʷ	‘opening in the woods’
x̣ák̓ʷt	‘crispy’
xázes	‘hanging or suspending’

Lexical Item	Translation
x̣əcə́m	‘bet or gamble’
xéɬt	‘refreshed’
x̣ətqə́m	‘making a hole’
xetxít	‘carve or notch’
x̣ətqx̣ətes	‘digging a hole’
xíẇ	‘brush hair’
x̣ítqəm	‘making a hole’
xíy	‘to land ashore’
xʷukʷxʷák kn	‘I’m lightweight’
xʷaʔlscút	‘having lots of possession’
ɬxʷáqsna	‘I hang something’
xʷélna	‘I lift it’
xʷíc̓ms	‘give away’
xʷoq̓ʷtés	‘take away’
xʷqʷáyx	‘losing weight’
xʷúc̓	‘vomiting’
xʷúp	‘push something’
xʷʔúx	‘stinky and rotten’
ýe uʔix	‘feel good’
yéx̣m	‘to widen space between two things’
yéx̣t	‘day before yesterday’
zéxtes ʔot	‘one side is longer than the other’

Lexical Item	Translation
zíkes	‘knocking over something’
ʔe skə̓ĺna píx̣mek ʔa ze	‘buckskin was hung on the branch’
ʔe spéym	‘flat place’
ʔe swlóqʷ	‘opening in the woods’
ʔe széxts	‘waiting to join to something’
ʔə̓lṣ̓íkʷ	‘turtle’
ʔéq̓mn	‘button’
ʔes páʕʷ	‘it’s frozen’
ʔes qʷuyqʷuy̓iʔ	‘sky is cloudy’
ʔes xʷóq̓ʷ	‘take away’
ʔescáq	‘set or positioned’
ʔescíqʷ	‘red’
ʔeskekn̓	‘companion’
ʔeskəɬxán	‘barefoot’
ʔeskʷúxʷ	‘something woven’
ʔespás	‘color fading away’
ʔesqʷoqʷyəc	‘rabbit’
ʔestóqʷt	‘it’s fluffy’
ʔesxʷʔúxʷ	‘smell’
ʔesʔúqʷeʔ	‘to be drunk’
ʔoqʷʔúqʷeʔ	‘to drink (PL)’