MAPPING PHONETIC VARIATION TO PHONOLOGICAL UNITS: FEATURE SHARING IN COMOX-SLIAMMON (SALISH) VOWELS

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ABSTRACT

The way that sounds interact with one another is important for understanding how gradient phonetic variation maps to discrete phonological units, especially in cases where there is a significant overlap in phonetic variation across different sound categories, such as with vowels in Comox-Sliammon, an underrepresented Salish language spoken in Canada. We consider vowels in Comox-Sliammon in context (phonological environment as defined by the identity of adjacent consonants) using predicted vowel trajectories from Generalized Additive Mixed Models. Vowels are better dispersed (and differentiated) by derived feature specification (where features are shared from adjacent consonants) than by underlying feature specifications (where vowel identity alone is considered). Consequently, we gain a fuller understanding of the phonetic-phonological mapping of sound systems by building an understanding of the phonological grammar (context) into our phonetic analysis (trajectories). This ultimately allows us to posit and test data-driven hypotheses about the phonological units for users of the language.

Keywords: fieldwork, Salish, phonetic variation, phonological mapping, features

1. INTRODUCTION

Sounds are produced in context, and adjacent (and non-adjacent) sounds can influence each other [1], creating phonetic variation. Phonetic variation must be mapped back to phonological units to create meaning out of the phonetic variation.

When there is a clearer one-to-one mapping between an underlying phoneme and the phonetic realization, sounds are more evenly dispersed in acoustic space and form relatively discrete categories. In this case, phonetic variation can be differentiated by phonemic units with little information about phonological environment (i.e., context). However, when there is substantial overlap in the phonetic realizations or a less clear mapping between a sound and acoustic space, it may not be possible to see discrete categories without considering the environment.

If a phoneme corresponds to a broad distribution in acoustic space and overlaps substantially with other phonemes, we predict that dispersion will be clearest between phonologically discrete allophones (i.e., context-dependent units). These context-dependent units are an intermediate unit between a phoneme and its phonetic implementation (see, for example, [2]). Assuming a modular feed-forward architecture of phonology (e.g, [3]), the intermediate allophone is derived by the grammar, which may change or alter the phonological properties of a sound (e.g., feature sharing). Where the application of the grammar results in more substantial changes to a sound resulting in more phonetic variation (i.e., broader distribution in acoustic space), the phonetic implementation may result in variation that shows little differentiation between phoneme categories, but maintains clearer distinctions between allophones.

In languages with one-to-many mappings between phonemes and allophones, describing the acoustic variation by phonemic units is less informative, which suggests that it would be difficult for language users to differentiate the phonemic units. Here, we test whether considering the phonological grammar (which is language-specific knowledge available to a speaker) provides insight into acoustic overlap previously observed in the Comox-Sliammon vowel system [4]. We analyze F1 / F2 trajectories of Comox-Sliammon vowels to examine how well they are differentiated when classified by phoneme (underlying vowel) compared to allophone (derived vowel) to explore the mapping between phonetic variation and phonological units in an underrepresented language.

2. VOWELS IN COMOX-SLIAMMON

Comox-Sliammon, a Central Salish language spoken in Canada, has four vowels (/a/, /i/, /u/, and /ə/), which may be considered a minimal vowel system (see [5]). The vowel /u/ is differentiated by position as a back (and rounded) vowel, while /a/, /i/, and /ə/ overlap considerably in F1 and F2 acoustic space corresponding to front vowels [4].[1] Adjacent consonants strongly influence the realization of /a/, /i/, and /ə/, and the inclusion of information about vowel environment greatly enhances contrast (i.e., dispersion of vowels) in the system [6].

We test the hypothesis that the unit of contrast in the Comox-Sliammon vowel system is not the underlying phoneme, but instead a derived allophone with a combination of phonological features inherent to the underlying vowel and those received in context (i.e., features shared from an adjacent consonant). Crucially, we focus on context rules (features received from an adjacent segment which affect the segment throughout its duration), rather than phonetic rules (co-articulation realized at the transition between two segments) [7].

We assume that consonant place features may be shared with adjacent vowels, consistent with earlier analyses of Comox-Sliammon (e.g., [8]). We adopt a feature geometry that assumes a unified set of features for consonants and vowels (e.g., [9]). We use [LOW] as a stand-in for either a [radical] feature or a [low] feature under [dorsal], and [FRONT] as a stand-in for a [-back] or [high] feature.

Table 1 provides the inherent phonological features associated with each of the three front vowels in Comox-Sliammon, alongside the relevant consonants.[2] The vowel /ə/ is underspecified for place prior to the phonological derivation.

Underlying Features		
Feature	Vowel	Consonants
[LOW]	/a/	/q/, /qʷ/, /q'/, /qʷ'/, /χ/, /χʷ/
[FRONT]	/i/	/tʃ/, /tʃ'/, /dʒ/, /ʃ/, /j/, /ˀj/
none	/ə/	
Derived Features		
Vowel Feature(s)	Environments	
[LOW]	$\text{ə}C_{low}$, $aC_{elsewhere}$	
[FRONT]	$\text{ə}C_{front}$, $iC_{elsewhere}$	
[FRONT, LOW][3]	iC_{low}, aC_{front}	
none	$\text{ə}C_{elsewhere}$	

Table 1: Underlying (top) and derived (bottom) features for Comox-Sliammon vowels

We consider F1 / F2 over the duration of the vowel for each of the environments listed in Table 1 to test the following hypotheses (see [6, 10]):

1. **Underlying Phoneme Hypothesis:** Vowels are best differentiated by underlying feature specifications (i.e., vowel categories).
2. **Derived Allophone Hypothesis:** Vowels are best differentiated by derived feature specifications (i.e., vowels in context).

If the vowels are best categorized by phoneme categorization, we expect discrete F1 / F2 trajectories for each vowels. However, if the vowels are best categorized by allophones, we expect discrete F1 / F2 trajectories for each vowels *only* when plotted by allophone (not by phoneme).

3. METHODS

The data analyzed were produced by two speakers of Comox-Sliammon in their 80s: one male (labelled: f) and one female (labelled: e). The tokens were selected from a larger set of recordings produced for an e-dictionary [11]. The selected vowels all bear primary stress (as the first vowel in the word) and represent each of the target environments (see Table 1). The present analysis considers the front vowels, which show considerable overlap (/i/, /a/, and /ə/). As a vowel that is both back and round, /u/ overlaps less with the other vowels in F1 and F2 acoustic space.

Vowels were hand-aligned by two trained fieldwork linguists and then a praat script was used to extract 5 equidistant F1 and F2 measurements across the vowel (hereafter "vowel trajectories"). We use Generalized Additive Mixed Models (GAMMs) for an exploratory analysis of the F1 and F2 vowel trajectories by visualizing the predicted values for these trajectories. Separate models are run for each formant by speaker. GAMM models include non-normalized formant values (dependent variable) with parametric terms for vowel categories and derived features, smooth terms for trajectories by vowel categories and derived features, and random smooths for word. Table 2 shows token count across both speakers by vowel categories and derived features. While speaker e has more tokens (e=193; f=147), the number per vowel categories and context is similar in proportion.

	/i/	/a/	/ə/	**Feature Totals**
Front	74	0	45	119
Front.Low	37	45	0	82
Low	0	62	54	116
None	0	0	23	23
Vowel Totals	111	107	122	

Table 2: Total tokens counts by vowel category (columns) and derived features (rows)

This is an exploratory, not confirmatory, investigation, so statistical significance (e.g., p-values) is not discussed. Rather, we interpret differences in trajectories through visualizations, which is recommended for exploratory investigation (e.g., [12]).

4. RESULTS

We see a large degree of overlap (i.e., little differentiation) in model predicted F1 and F2 trajectories across all vowel categories, which does not support the first hypothesis (F1 and F2 are best explained with reference to the underlying features associated with the vowel phonemes). In the left panels in Figure 1, F1 and F2 predicted vowel trajectories are plotted by underlying phoneme. These clearly demonstrate that the vowels are overlapped across the majority of the trajectory.

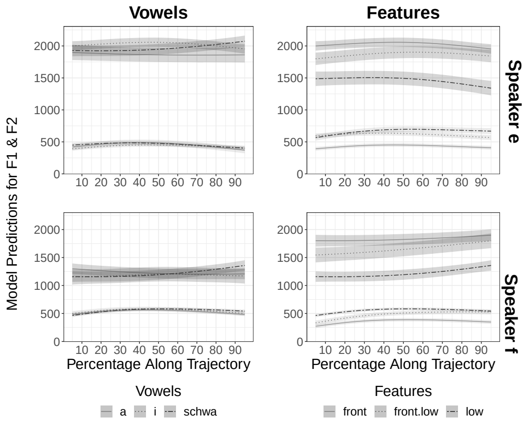

Figure 1: F1 and F2 model predicted trajectories with confidence intervals for each speaker (e - top row; f - bottom row) plotted by vowel category (left panels) and derived features (right panels)

The right panels in Figure 1 show the F1 and F2 predicted vowel trajectories plotted by categorically discrete allophones (i.e., derived features). For clarity, underspecified tokens (labelled: "none") are omitted in Figure 1. The panels on the right support hypothesis 2 (F1 and F2 are best explained with reference to derived feature specification). There is a clearer separation between the trajectories when plotted by derived feature specification than by underlying specification (phoneme).

The trajectories for derived feature groups occupy phonetic spaces consistent with the proposed features. The trajectories for the [FRONT] allophone have the highest predicted F2 (and lowest predicted F1), while the trajectories for the [LOW] allophone have the highest predicted F1 (and lowest predicted F2). Unsurprisingly, the trajectories for the [FRONT.LOW] allophone sits between the other two in both F1 and F2, moving in the expected direction (i.e., towards [FRONT] in the F2 space, and towards [LOW] in the F1 space).

While the overall findings hold for both speakers, we also find interspeaker differences. These differences are seen in Figure 2 where model predicted F1 (bottom row) and F2 (top row) trajectories are plotted by derived feature specifications in greater detail, including the underspecified ("none") tokens. We compare the trajectory shapes and amount of overlap across derived feature groups in this figure, but as values are not normalised, we do not compare the Hz values themselves across speakers.

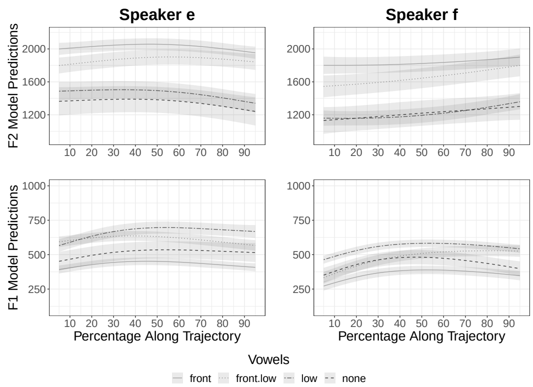

Figure 2: F1 (bottom row) and F2 (top row) model predicted trajectories with confidence intervals for each speaker (e - left panels; f - right panels) plotted by derived features

Generally, we see more movement over the trajectories for speaker f and more stable, flatter trajectories for speaker e. In the F1 space we see the [FRONT.LOW] trajectories are closer to the [LOW] trajectories and overlapping at points along the trajectory. However, there is more overlap at the beginning of the trajectory for speaker e, but more at the end for speaker f. For speaker f, the [FRONT.LOW] trajectory overlaps with the "none" trajectory, but not with the [FRONT] trajectory, and only the end of the [FRONT.LOW] trajectory overlaps with the [LOW] trajectory. Whereas, speaker e has more overlap between the [FRONT] and "none" trajectories, and between the [FRONT.LOW] and [LOW] trajectories. However, there is little overlap between the "none" and [FRONT.LOW] trajectories for speaker e.

Fewer interspeaker differences are observed for F2 trajectories. For both speakers, the [LOW] and "none" trajectories overlap (though speaker f's trajectories are more similar to each other) and most of the [FRONT] and [FRONT.LOW] trajectories overlap, except at the beginning.

While specific patterns are found, there is evidence of stronger effects at the edges (onset and offset) of the vowel. The onset and offset of trajectories are often different from each other and from the midpoints. This is likely, in part due to phonetic coarticulatory effects, which are expected. The effect of the adjacent consonants is not *just* coarticulation though, as each of the derived allophones differs at the midpoint as well, supporting their status as categorically discrete phonological units. The difference between the midpoint and rest of the trajectory is information that would not be captured by midpoint measurements, supporting the descriptive and analytical benefit of plotting formant trajectories.

5. DISCUSSION

The current analysis supports the derived allophone hypothesis: there is less acoustic overlap when vowels are plotted by derived feature specification (i.e., allophones) than underlying vowel feature specification (i.e., phonemes) for these speakers. While it is often suggested that phonetic variation maps directly onto phonemic categories, this data suggests that phonetic variation is actually mapped to subphonemic categories (i.e., allophones).

For Comox-Sliammon, vowels cannot be clearly distinguished in acoustic space by underlying phoneme. Considering an intermediate phonologically derived allophone allows for a clearer mapping between phonological units and phonetic realization. This demonstrates that understanding the grammar of a language is integral to understanding the phonetic variation. In order to produce accurate descriptions and analyses of an underdocumented language, it is crucial to consider the language-specific knowledge (such as the phonological grammar) that is available to speakers in production and perception.

We also find that the proposed derived allophones (based on phonological features) are supported by the phonetic realizations. The most front (i.e., highest F2) trajectories are the [FRONT] trajectories and the lowest (i.e., highest F1) trajectories are the [LOW] trajectories. The [FRONT.LOW] trajectories sit between these, but closer to the [FRONT] trajectories for F2 and [LOW] trajectories for F1. The positions of each trajectory is consistent with the expected relationship between formants and vowel height and backness.

Vowel trajectories also show the difference between the phonetic coarticulatory effects of adjacent consonants at the edges and the phonological effects of feature sharing, that are evident throughout the trajectory (including midpoint). The edges of the vowel trajectories often show stronger effects, such as lowering and fronting in the [FRONT.LOW] trajectories, which are likely due to phonetic coarticulation with the adjacent consonants. On the other hand, wholesale changes to the trajectory, such as the entire [LOW] trajectory being lower than the other trajectories, likely demonstrate phonological distinctions based on the allophone as a discrete phonological unit.

Although there are differences between speakers, such as speaker f having a greater degree of movement across the vowel trajectories, these differences do not affect the overall conclusions. Both speakers show significant overlap in the F1 and F2 trajectories for different vowel phonemes, as well as separation between the derived feature group trajectories. Additionally, the general patterns of the derived feature group trajectories, such as the [FRONT.LOW] trajectories being positioned between the [FRONT] and [LOW] trajectories, are consistent across speakers. Therefore, the main findings are still valid even when taking individual speaker differences into account.

We find that the derived allophone is a more useful phonological unit to explore phonetic variation in Comox-Sliammon. This has broader implications for language description and analysis, which feed into language revitalization efforts. It is not sufficient to teach the vowels of the language without discussion of the context and interactions between vowels and adjacent consonants. This highlights the importance of considering the grammar of a language when conducting phonetic analysis (especially with little previous work to guide an exploration when considering underrepresented languages).

The derived allophone hypothesis has implications beyond the description and analysis of Salish vowels. Precision is not lost when describing vowel systems by categorically discrete allophones, rather than phonemes; if labelling by phoneme is sufficient for a language, the number of vowels and labels can remain the same due to a 1-to-1 mapping between phoneme and derived allophone. The derived allophone allows for more precision when describing vowel systems that are less well-documented and where the phonological grammar creates substantial overlap between phonemic categories in acoustic space. The derived allophone approach integrates language-specific patterns in sub-phonemic organization, which is useful in the cross-linguistic description of vowel systems.

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[1] We consider /a/, /i/, and /ə/ to be front vowels in Comox-Sliammon given previous phonetic work [4], as well as phonological analysis [8].

[2] The relevant consonants given in Table 1 are only a subset of consonants in Comox-Sliammon; we only list the consonants that share the identified feature with the vowel.

[3] A further prediction is that it should be possible to have a /ə/ map to a [FRONT, LOW] allophone as well if between a [FRONT] and a [LOW] consonant (e.g., C_{front}əC_{low}). This is a question for future study.