A Dynamic Phonetic Analysis of /s/ and /θ/ in ʔayʔaǰuθəm (Mainland Comox Salish)*

Gloria Madeleine Mellesmoen
University of British Columbia

Abstract: This paper is an acoustic analysis of /θ/ and /s/ in ʔayʔaǰuθəm (Mainland Comox Salish). Building off previous impressionistic descriptions of articulatory similarity and perceptual ambiguity between the two fricatives in Coast Salish (Blake 2000; Suttles 2004), the present paper investigates the degree of acoustic overlap between the fricatives. Productions of /θ/ and /s/ are compared across four speakers on two fricative-internal measures, duration and $PeakERB_N$ trajectories, and one fricative-external measure, F2 formant transitions. The results suggest that the two sounds are acoustically quite distinct, though there is considerable inter-speaker and intra-speaker variability for /θ/. The lack of overlap for three of the four speakers suggests that the source of the reported ambiguity may be L1 English speaker perception, rather than the realization of Mainland Comox fricatives. The high level of variation suggests that /θ/ may be a recent and unstable innovation, supporting the reconstruction of a Proto-Comox [s]-like form.

Keywords: Mainland Comox, Salish, $PeakERB_N$ trajectories, fricatives, theta

1 Introduction

One of the challenges in the documentation of Salish languages is the diminishing number of speakers. This is particularly true in phonetic analysis, which is considerably harder without access to at least one fluent speaker. Despite being endangered or extinct, some Salish languages are partially preserved in digital recordings. This underscores the importance of conducting acoustic analysis in languages with remaining speakers to understand what can be inferred through recordings and methodologies that can be used to expand upon previous impressionistic descriptions. This has implications for the documentation of endangered languages.

Most previous phonetic work on Salish languages has explored laryngeal phenomena and pharyngeal segments (i.e. Bessell 1993; Carlson, Eisling, & Harris 2004; Bird, Caldecott, Campbell, Gick, & Shaw 2008). Though some of the Coast Salish languages have innovated /θ/, a typologically rare segment (Maddieson 1984:45), the only study of Salish fricatives describes Montana Salish (Gordon, Barthmaier, & Sands 2002), an Interior language without /θ/. In addition to being typologically relevant, /θ/ is also interesting within Salish, as impressionistic descriptions suggest articulatory similarity and perceptual ambiguity between /θ/ and /s/. This is documented for Halkomelem (Suttles 2004), Northern Straits (Thompson, Thompson, & Efrat 1974), and Comox (Blake 2000). Motivated by a gap in documentation and reported ambiguity, this paper is an acoustic study of /θ/ and /s/ in ʔayʔaǰuθəm (the Mainland dialect of Comox). I focus on phonetic evidence for claims of similarity using fricative-internal and fricative-external

* This work would not be possible without the fantastic (and patient) ʔayʔaǰuθəm consultants I have the opportunity to work with (Elsie Paul, Freddie Louie, Karen Galligos, Phyllis Dominic, and Joanne Francis). I would like to acknowledge Douglas Pulleyblank, Molly Babel, and Henry Davis for their support and feedback. Also, thank you to Patrick Reidy and Molly Babel for sharing their scripts with me.

UBC Qualifying Papers 4 (2015-2017).
Emily Sadlier-Brown, Oksana Tkachman and Avery Ozburn (eds.) Vancouver: UBCWPL, 2019.

measurements. In addition to describing acoustic attributes of the fricatives, I consider potential synchronic (listener experience) and diachronic (development from Proto-Salish *c) sources of perceptual ambiguity[1].

2 Background

2.1 /θ/ in Mainland Comox and Related Languages

ʔayʔaǰuθəm is a Central Salish language spoken by the Sliammon, Homalco, and Klahoose in British Columbia. For clarity, I will use the term Mainland Comox to refer to ʔayʔaǰuθəm in this paper to clearly delineate it from the Island Comox dialect, which is no longer spoken[2]. Mainland Comox is still spoken by approximately 36 L1 speakers, as of 2014 (First Peoples' Cultural Council 2014). Previous descriptions of the phonemic inventory have included eight fricatives (/θ/, /s/, /ɬ/, /š/, /x^{w}/, /χ/, /χ^{w}/, and /h/), which are all voiceless (Blake 2000:15; Watanabe 2003:10).

/θ/ is relatively uncommon cross-linguistically (Maddieson, 1984:45). Galloway (1982) and Kuipers (2002) proposed that Proto-Salish (PS) *c became either /s/ or /θ/ in Coast Salish, while PS *s is realized as /s/ across all these languages. They show that PS *c became /θ/ and *s remained /s/ in Mainland Comox, Pentlatch, and Halkomelem, while PS *s and *c merged in the Island dialect of Comox and the Lummi, Songish, and Sooke dialects of Northern Straits. The situation is more complicated in Saanich, where PS *c split into /θ/ and /s/. Thompson et al. (1974:185-187) suggested that the irregular distribution of /s/ and /θ/ forms results from contact with Halkomelem and describe a subset of lexical items where /θ/ alternates with /s/, such as the word for mouth (θaθən ~ sasən) or sockeye salmon (θəqiʔ ~ səqiʔ)[3].

While the diachronic development results in a one-to-one mapping between PS *c and *s and Mainland Comox /θ/ and /s/, there is variation in synchronic data that parallels Saanich. A single speaker (FL) of Mainland Comox will variably produce something like [θayəɬ] or [sayəɬ] for "lake". However, unlike in Saanich, this does not seem to be restricted to a subset of lexical items. Blake (2000) stated that /θ/ may easily be misperceived as /s/ and speculated that [θ] may have a grooved tongue shape, like [s]. Articulatory similarity between /θ/ and /s/ is also reported in the Musqueam dialect of Halkomelem, as Suttles (2004:4) indicated that "some speakers … articulate /θ/ further back, reducing the difference" from /s/. While these descriptions suggest tongue position or shape result in perceptual ambiguity, the actual similarity between /θ/ and /s/ has yet to be confirmed or quantified in any Coast Salish language through acoustic analysis.

An acoustic examination of /θ/ and /s/ in Mainland Comox may also shed light on the diachronic development of /θ/. Thompson et al. (1974) suggested that /θ/ in Saanich developed in a two-stage process; PS *c first fronted to *t^{θ} before becoming a fricative. The fronting-first analysis presented by Thompson et al. (1974) for Saanich is attractive because it provides a parallel to a PS *c̓ → /$\dot{t}^{\theta}$/ change that occurs in most of the languages with /θ/. Both *c and *c̓ could have been targeted by the same fronting process and then the plain affricate later evolved into /θ/. It is not necessary to treat these changes in parallel though. Data from Pentlatch allows for an alternate interpretation of this development. Galloway (1982) reported that the reflexes of

[1] Relevant IPA-to-APA mappings include: t͡θ = t^{θ}, t͡θ' = $\dot{t}^{\theta}$, t͡s = c, t͡s' = c̓, t͡ʃ = č, j = y, and ʃ = š.
[2] Though Comox has been used to refer to both dialects, ʔayʔaǰuθəm is the name preferred by the speakers.
[3] It is unclear if this distribution reflects a change in progress in Saanich.

PS *c and *ċ in Pentlatch were /θ/ and /ċ/, respectively[4]. While fronting of PS *c and *ċ may have occurred simultaneously in some languages with /θ/, this was not necessarily the case in Pentlatch. PS *c became /θ/ independent of the PS *ċ → /t̓$^{\theta}$/ change found in other languages, including Mainland Comox. If the two changes can be treated as separate fronting processes in Pentlatch, it is also plausible to consider the fronting of PS *c and *ċ as separate processes in Mainland Comox as well.

The synchronic grammar of Mainland Comox makes it harder to argue that fronting occurred before spirantization because it has an ejective /t̓$^{\theta}$/ and plain /t^{θ}/[5]. Their synchronic existence suggests that they can co-exist, reducing the likelihood that *t^{θ} would need to undergo further change due to instability. In an overview of previous work on Comox, Harris (1981) found that the distribution of [θ] and [s] was hard to reconcile. There was no neat separation between a θ-dialect and s-dialect. As shown in Table 1, Boas (as cited in Harris 1981) reported [θ] in words where modern Mainland Comox consultants (and Harris' Island consultant) use [s] and [s] in words where Mainland Comox consultants use [θ][6]. Harris (1981:24) speculated that Boas transcribed forms incorrectly, arguing against bidirectional dialect borrowing[7]. However, in light of reported ambiguity, there is a third possibility: the dialects diverged just before (or early in) the development of /θ/, resulting in an inconsistent distribution of /θ/.

[4] A preliminary examination of Pentlatch data (from Boas 1890) suggests a more complicated situation. Boas uses ç for [θ], such as in ē'maç 'grandchild' (cognate with Mainland Comox ʔɛmaθ) and çoman 'eyebrow' (cognate with θomən). Consistent with Galloway (1982), there are many places where Boas transcribes ts' ([ċ]) where Mainland Comox has [t̓$^{\theta}$]. The Pentlatch word ts'āwetēḵō'ya 'ring of finger' is likely cognate with the Mainland Comox t̓$^{\theta}$agət̓ɛqʷoǰɩtən 'ring'. (Note that Pentlatch retains the PS glides, which are voiced obstruents in Mainland Comox.) However, there is at least one lexical item where ç corresponds to a Mainland Comox [t̓$^{\theta}$]: çā'çaqam and t̓$^{\theta}$at̓$^{\theta}$ǰɛʔmɛn 'shadow' (from Blake 2000:327). Future work should examine the distribution of ç and ts' in Pentlatch to get a better sense of the status of PS *ċ.

[5] Admittedly, the latter is marginal and only appears in the possessive paradigm (Blake 2000:325). However, Galloway (1982) reported /t^{θ}/ in the Pentlatch pronominal paradigm and in a demonstrative article in the Cowichan dialect of Halkomelem. Though one might expect these instances of [t^{θ}] to have spirantized if other instances of *t^{θ} did, it is possible that these instances of [t^{θ}] are a later innovation and thus not subject to the *c → *t^{θ} → [θ] process. This would fit with the suggestion in Thompson et al. (1974) that the plain affricate arose from a *tθ sequence in Saanich. Davis (1978) suggests that /t^{θ}/ in Mainland Comox comes from the combination of /č/ and /s/. It is not immediately clear why this combination would result in the more front /t^{θ}/, but if /θ/ developed from an intermediate [s]-like form, the fricative in the /č/ and /s/ combination may have already been further front than typical realizations of /s/.

[6] Interestingly, Harris (1981) reports [θ] for 'go' in Boas' transcription. In the Pentlatch materials (Boas 1890), there is a single page of Comox sentences where one of the words is 'hōstōmut', built on the root ho 'go', suggesting that an alternation between [h] and [θ] in this word is not just a modern idiosyncrasy.

[7] Even if Boas (1890) did transcribe some of these incorrectly, Harris (1981) also describes differences in the distributions reported by Sapir (1914), Gibbs (1877), and Barnett (1955).

Table 1 s/θ distribution in Boas and Harris, compared to modern Mainland Comox

English	Boas	Harris	Modern Mainland Comox
‘head (suffix)’	-o:s	-os	-os
‘head’	moʔoθ	moʔos	moʔos
‘go’	θo:	so	θo/ho
‘husband’	gʸa:qas	gʸa:qas	gaqəθ

If the spirantization of PS *c to s occurred first in Comox, it might result in a time between *c and /s/ where the sound was realized as a [s]-like form. Subsequent fronting of this ambiguous form to /θ/ would preserve contrast between PS *s and *c. A failure to front this [s]-like form could result in a merger between PS *s and *c, such as in the Island dialect. If this is correct, it suggests that the two dialects diverged at a point of instability where PS *c had already begun to spirantize, but each dialect reconciled the instability in a different way. If Mainland Comox /θ/ developed from an intermediate [s]-like form, we may expect greater variability in words with an underlying /θ/, rather than /s/, reflecting a period of uncertainty where its status was unclear. Further, if fronting occurred to prevent a merger between PS *s and an intermediate Proto-Comox [s]-like form[8], derived from *c, /θ/ and /s/ should differ most on acoustic measures correlated with front cavity size, which allow for inference about frontness of a constriction, reflecting that /θ/ may resemble a more fronted /s/.

2.2 Perception of /θ/ in English

The only phonetic description of fricatives in Salish has been in Montana Salish (Gordon et al. 2002), which lacks /θ/. Without previous work to guide the formation of testable hypotheses, it is relevant to consider similar fricatives in English. This is also appropriate given that previous descriptions of Salish fricatives are impressionistic, often filtered through an English-speaking linguist's perceptual system, and thus compared to English distributions of /s/ and /θ/. Comparing Mainland Comox fricatives to English ones also allows for the opportunity to explore issues that will be relevant for L2 learners, who will likely approach Mainland Comox fricatives with an English L1 perceptual system. This means that a brief summary of English fricatives is relevant to understanding the synchronic source of the proposed ambiguity.

/θ/ is perceptually unstable in English. Lambacher, Martens, Nelson, and Berman (2001) compared how English and Japanese speakers perceive English fricatives, finding that English speakers often misclassified /θ/ as /f/. However, they did not find that /θ/ and /s/ were perceptually ambiguous. Johnson (2012) remapped a confusion matrix from Lambacher et al. (2001), and showed that /s/ and /θ/ are perceptually distinct to English speakers on dimensions that are best attributed to spectral shape and frication noise, such that /s/ has more high frequency components and is louder than /θ/. Johnson (2012) also remapped a confusion matrix from Lambacher et al. (2001) that shows Japanese speaker perception of English fricatives, where /θ/ is

[8] A pattern of obstruent fronting from PS to Mainland Comox may suggest that this could be part of a larger push-chain shift. PS *k, *k̓, and *x have become /č/, /č̓/, and /š/, respectively (Kuipers 2002).

close to /s/. This suggests the same acoustic information is not necessarily used cross-linguistically to distinguish fricatives.

There is evidence that the spectral characteristics of fricatives in a speaker's L1 phonemic inventory play a role in the perception of L2 fricatives. Wagner, Ernestus, and Cutler (2006) argued that listeners are able to perceive acoustic differences in formant transitions but that the integration of this information into categorization depends on the speaker's L1. If frication alone can be used to identify the fricative, than formant transitions are less likely to be used in categorical perception. Li, Edwards, and Beckman (2009) found that the English sibilants (/s/ and /š/) are distinguished by frication alone, while Japanese sibilants are best distinguished when information about formants at the onset of a following vowel is available. Johnson (2012) further noted that the formant transitions out of /s/ and /θ/ are very similar in English, suggesting that spectral information is key to distinguishing the two. Wagner et al. (2006) suggested that formant transitions might be most beneficial for listeners who speak a language with fricatives that have similar spectral qualities. If /s/ and /θ/ have similar spectral characteristics in Mainland Comox, the acoustic cues from vowel transitions may be useful to distinguish the two. Further, recall that Blake (2000) speculated that the Mainland Comox /θ/ "may actually have a grooved articulation which makes it sound much closer to [s]" (Blake 2000: 23). If true, it entails a more narrow constriction, which would result in /θ/ having louder frication noise, similar to /s/. This suggests that formant transitions, external to the fricative, may be more important in perceiving Mainland Comox fricatives than their English counterparts[9]. However, English speakers may not make use of this information as frication alone can distinguish /s/ and /θ/ in their language.

Though frication is useful in discriminating English fricatives, there is evidence that formant transitions are also used to categorize non-sibilant fricatives. McGuire and Babel (2012) found productions of /θ/ vary in English in different environments, with formant transitions providing evidence that /u/ is associated with a less interdental, more dental, [θ]. Listeners in the audio and audio-visual conditions, who were able to attend to acoustic information, were better able to distinguish /θ/ from /f/ before /u/. This suggests that, when faced with the perceptual ambiguity between /θ/ and /f/, English speakers can use F2 formants at vowel onset for clues about the size of the back cavity, which is decreased before /u/. Blake (2000:21) made reference to a similar environment in Mainland Comox, suggesting that transition from an interdental [θ] to a back vowel, or from a back vowel to an interdental [θ], requires more articulatory effort than the transition from or to [s], which is further back. She argued that this motivates the production of a more dental (further back) realization of /θ/ adjacent to a back vowel, /ə, a, u/, suggesting a similar pattern to English. However, the perceptual confusion described in Babel and McGuire (2012) is between /θ/ and /f/, in which case backing /θ/ results in a larger front cavity, making it more distinct from /f/. In Mainland Comox, a backed /θ/ would likely end up closer in articulatory space to a [s], suggesting that the most perceptual and acoustic ambiguity should occur in this environment. Further, if English listeners place greater value on formant transitions in the presence of /u/, or a similar back vowel, this will be more misleading when perceiving Mainland Comox, supporting the hypothesis that ambiguity should be greatest in these positions. This

[9] Vowel-consonant interactions are quite common in Mainland Comox, and generally in Salish languages, suggesting that transitions between segments may carry substantial information about fricative and vowel identity.

predicts that formant transitions at the onset and offset of a vowel adjacent to /θ/ should be the least distinct from /s/ before a back vowel.

Considering the contextual effects of vowels on fricatives highlights a shortcoming of the traditional measures of fricatives, which take spectral moments from a section of the frication. Power spectra compare amplitude at various frequencies, without a temporal measure. An analysis must make decisions regarding window size, position, and number of measurements (and how they are combined). This is problematic for Mainland Comox, as there are no previous analyses to indicate what will be meaningful over the duration of the fricative. There are also conflicting reports about the duration needed for identification or categorization, even in English. Behrens and Blumstein (1988) suggest that spectral measurements are generally stable, regardless of where the measurement is taken. However, Iskarous, Shadle, and Proctor (2011) find that the position of articulators varies during the production of /s/ in American English, suggesting that spectral properties may change over the course of the fricative. Further, there are differences between the duration of frication needed for a listener to identify different fricatives. Jongman (1989) reports that only 50ms of frication is needed to identify /s/, while full frication is needed for [θ], suggesting that there may be spectral information not captured by static measurements.

Dynamic measurements over the duration of the fricative can address the shortcomings of taking spectral measurements from a single steady state. Reidy (2015, 2016) takes this approach, using a measure of peak frequency (PeakERB) over the course of a fricative. Specifically, the PeakERB_N corresponds to the centre frequency of whichever channel in the auditory model had the most excitation at a given point. This measure approximates psychoacoustic activation and allows for a dynamic analysis of frication over its duration. Reidy (2016) used these PeakERB_N trajectories, fitted with orthogonal polynomial growth-curve models, to compare sibilants in English and Japanese, finding language-internal and cross-linguistic differences in the slope and shape of the trajectory. He found that /s/ had a less stable trajectory in both languages than the other sibilant fricative (English /š/ and Japanese /ɕ/), likely corresponding to having a smaller front cavity. The slope of Japanese /s/ was steeper before a vowel than English /s/, corresponding to a greater degree of coarticulation with the following vowel in Japanese. As front cavity size and consonant-vowel interactions are relevant parameters for describing Mainland Comox fricatives, this type of analysis is ideal for answering the questions proposed in this paper.

Guided by impressionistic descriptions of Salish /θ/ and phonetic work on English fricatives, the present paper investigates the acoustic correlates of /θ/ and /s/ in Mainland Comox. The fricatives are compared on two fricative-internal measures, duration and PeakERB_N trajectories, and one fricative-external measure, F2 formant transitions. I predict that /s/ and /θ/ will overlap on fricative-internal measures reflecting the perceived ambiguity reported by English speakers, who rely on frication to distinguish their corresponding fricatives. Specifically, I expect /θ/ and /s/ to be associated with comparable PeakERB values, reflecting high frequencies. Similarity on this measure, which may be indicative of either a narrow airflow channel from a grooved tongue or a smaller front cavity, would differ considerably from English. Following from the hypothesis that /θ/ in Mainland Comox developed from a Proto-Comox [s]-like form, I also expect that the two fricatives will be distinguished primarily by measures related to frontness, such as formant transitions, which correlate with back cavity length, or the PeakERB values, which can be associated with front cavity size. Following Blake (2000), I predict that differences between the fricatives will be reduced in the environment of a back vowel, consistent with a more retracted variant of [θ]. Finally, I test whether the influence of a back vowel applies equally in a regressive or progressive direction.

3 Methodology

3.1 Participants

Data analyzed in this paper come from field recordings with one male (FL) and three female (KG, PD, and EP) Mainland Comox speakers. KG is in her sixties, PD in her late seventies, and EP and FL are in their early eighties. KG, FL, and EP were recorded in a quiet room at a 48kHz sampling rate using an Audio Technica Pro 70 Cardioid Lavalier microphone with a Zoom H6N recorder. PD was recorded in her home at the same sampling rate using a Blue Snowball microphone recording in Audacity 2.0.6.

Data from an additional consultant was set aside because there were too many factors that impeded comparison with the other speakers, including background noise while recording and missing teeth, which are important in the production of fricatives.

3.2 Stimuli and Procedure

Items were elicited in a translation task. Consultants were given a word in English and asked to produce the Mainland Comox equivalent and repeat it twice for a total of three repetitions. There were a total of 50 words containing /s/, /θ/, /ɬ/, or /š/. Only data from /s/ and /θ/ are analyzed in the present paper. There were two words for each of six target environments: word initial, word final, before a front vowel, after a front vowel, before a back vowel, and after a back vowel. However, there was an additional word in each of the /s/ and /θ/ categories and some of the words had two fricatives, such as *θay̓ɛɬ* 'lake'. Additionally, sometimes a speaker would offer extra repetitions. The total number of /s/ and /θ/ tokens for each speaker is given in Table 2.

Table 2 Token Count by Fricative and Speaker

EP		FL		KG		PD	
/s/	/θ/	/s/	/θ/	/s/	/θ/	/s/	/θ/
57	51	57	51	57	54	81	67

3.3 Stimuli and Procedure

Fricatives and vowels were hand-marked in Praat. Fricative onset was defined as the point where an increase in amplitude in the waveform corresponded with higher frequency energy in the spectrogram, as in Reidy (2016). Fricative offset was marked at vowel onset, using the onset of voicing or periodic waveforms as a cue. Formant measurements (F2) in Hz were taken at six points during the vowel (5%, 10%, 25%, 75%, 90%, and 95%), using a Praat script. Five formants were extracted for each frame, with maximum formants being at 5500Hz for female speakers and 5000Hz for the male speaker. The window length was 0.025s, with 0.0025s between the midpoints of each frame. Pre-emphasis was set at 50Hz, such that an inverted low-pass filter enhanced frequencies above 50Hz, resulting in a flatter spectrum for the formant analysis.

The PeakERB_N trajectories were calculated across 17 windows over the duration of the fricative, which ranged from 0.034s to 0.388s. Each window was 20ms in length, evenly distributed over the course of the fricative, with frication onset at the centre of the first window and frication offset at the centre of the last one. PeakERB measures were derived using a set of R scripts (as in Reidy 2016). The script calculated a psychoacoustic spectrum for each window using a filter bank that models the logarithmic nature of the auditory system (Reidy 2015). PeakERB refers to the peak psychoacoustic frequency, which is the centre frequency of whichever channel in the auditory model had the most energy.

4 Results

4.1 Fricative Duration

The duration of fricatives ranged from 0.034s to 0.388s. As the longest fricatives occurred in word-final position, this was used as a reference level in a simple regression with duration (in seconds) as the dependent variable to determine if word position predicts fricative length. Fricative identity and the interaction between word position and fricative were also included. /θ/ was set as the reference level. There were significant effects of fricative identity and word-position, but the interaction was not significant. This is shown in Table 3.

Table 3 Effect of Fricative Identity and Position on Duration (s)

	Estimate	Std. Error	*t*-value	*p*-value
Intercept	0.230068	0.006979	32.966	2e−16 ***
Consonant - /s/	0.023055	0.0008678	2.657	0.00823 **
Context – Word-Initial	−0.102808	0.0008572	−11.994	2e−16 ***
/s/:Word-Initial	0.012295	0.011445	1.074	0.28338

Assessing significance at $p < 0.05$, the duration of /s/ was significantly longer than that of /θ/. Additionally, a fricative in a word-initial position is significantly shorter than one in a word-final position. The lack of a significant interaction between the fricative identity and word position terms suggests that the positional effect is stable across the fricatives, such that a word-initial fricative is generally shorter than a word-final one, regardless of whether it is /s/ or /θ/.

Figure 1 compares the relative durations of /s/ and /θ/, across all environments, by speaker. The regression in Table 3 suggested that fricatives were shorter in a word-initial position and Figure 1 reflects this. The regression also indicated that /θ/ is generally shorter than /s/. This is strongly reflected in the patterns for EP and KG, who have a substantially longer duration for realizations of /s/ than /θ/. The picture is less clear for FL and PD. For these speakers, /s/ appears to be slightly longer in the word-initial position. In the word-final position, this is reversed, as the interquartile region extends slightly higher for /θ/, though there is more variation in the production of /s/. The interquartile ranges also overlap quite a bit for fricatives in the word-final position for PD and FL.

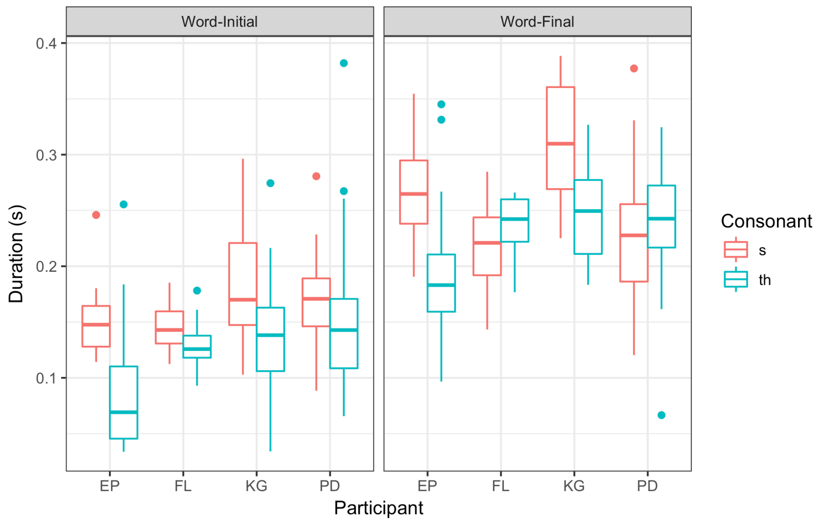

Figure 1 Fricative durations by speaker and word-position. Duration, in seconds, is on the y-axis and speaker is on the x-axis. Word-initial fricatives are in the left panel and word-final ones are on the right. The colours correspond to fricative identity: red is /s/ and blue is /θ/. This figure shows that /s/ is generally longer than /θ/, but that both fricatives are longer word-finally.

Taken as a whole, duration appears to be a good predictor of fricative identity for EP and KG. For FL and PD, /s/ and /θ/ are relatively well distinguished in a word-initial position by duration, but this does not extend to the word-final position. This suggests that these speakers may have more ambiguous fricatives than the other two. One of the research questions at the outset of this paper was whether the conditioning effect of a back vowel, which has been suggested to contribute to greater ambiguity, was regressive or progressive. As the word final position is composed of vowel-fricative sequences, to the exclusion of fricative-vowel ones, the duration results provide a preliminary clue that this effect, if supported by the following PeakERB_N trajectories and formant transition results, might be progressive.

4.2 PeakERB_N Trajectories

PeakERB_N trajectories for both fricatives in all environments, by speaker, are shown in Figure 2. The PeakERB value can be affected by several variables, including tongue position and shape. It is the peak frequency of whichever channel was most excited in the auditory model. The trajectories indicate how this varies over time, which allows for inference about the position and movement of the articulators over the duration of the fricative.

The 95% confidence intervals suggest greater variability for /θ/ than /s/, consistent with the prediction that /θ/ would have greater synchronic variation if it came from an intermediate [s]-like form. Across all speakers, /s/ is associated with higher PeakERB values, which fall somewhere between 25 and 30. /θ/ is associated with lower PeakERB values, relative to /s/, for each speaker.

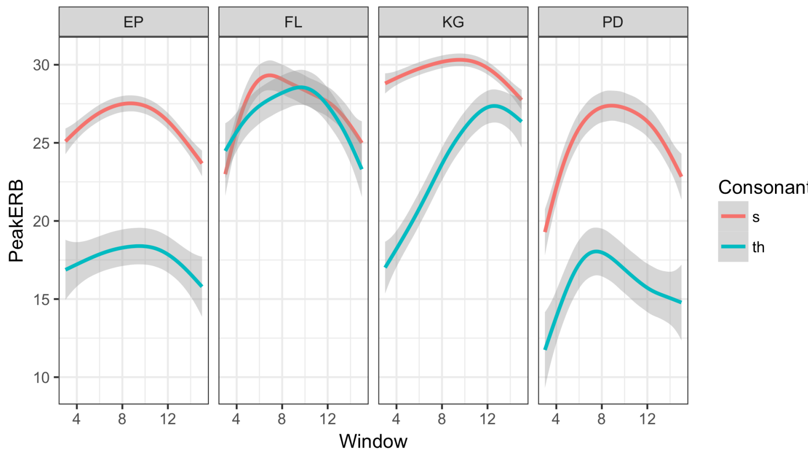

Figure 2 PeakERB$_N$ trajectories across all environments are plotted for each speaker. Window, as a measure of duration, is on the x-axis and PeakERB values are on the y-axis. Each panel corresponds to a different speaker and the colours denote fricative identity (red = /s/ and blue = /θ/). 95% confidence intervals are shaded in grey. Only one speaker, FL, shows overlap in fricative trajectories.

Though /s/ is associated with comparable PeakERB values for all speakers, the values for /θ/ show considerable inter-speaker variation. EP and PD have lower values for /θ/ than FL. Further, the PeakERB$_N$ trajectory of /θ/ for KG begins low, rivalling EP and PD, and ends up high, like FL. KG's /θ/ trajectory raises dramatically over the duration of the fricative, suggesting a substantial change in articulator position, such that /θ/ and /s/ start off distinct and end up quite close together. Otherwise, the general shapes of the PeakERB$_N$ trajectories are similar for /θ/ and /s/ within the productions of each speaker, reflecting the fact that the peak frequency rises and falls at similar point in fricative duration. The maximal point for /s/ in FL's productions is slightly earlier than for /θ/, though the confidence intervals show substantial overlap throughout the course of the fricative.

Given the limited data, it was not possible to examine the effect of both preceding and following vowel in the same model. Therefore, two models were fit for the PeakERB$_N$ trajectories of /s/ and /θ/ across all four speakers. The first model was the VF (Vowel-Fricative) model, which examined the effect of a preceding vowel (front or back) and the second one was the FV (Fricative-Vowel) model, which examined the effect of a following vowel (front or back). The first and last two windows were excluded to account for any errors in measurement at the boundaries. The fixed effects were time (linear, quadratic, and cubic), fricative identity, and whether underlying vowel was designated as front or back. The random effects were participant and the interaction between participant and consonant.

The results of the VF model are given in Table 4**,** where *t*-values greater than 2 or less than −2 are bolded. Fricative identity is significant, which means that /θ/ is associated with lower PeakERB values than /s/. This can be observed in the examination of PeakERB$_N$ trajectories across conditions in Figure 2. While vowel place, as a main effect, is not significant, the interaction between fricative identity and vowel place is significant in the VF model. This suggests that /θ/ has lower PeakERB values following a front vowel. This is reflected in Figure 3, which shows PeakERB$_N$ trajectories of the fricatives for each speaker, by vowel place.

Table 4 Vowel-Fricative (VF) Model

	Estimate	Standard Error	*t*-value
Intercept	**24.269**	**1.561**	**15.671**
Linear	−1.855	3.510	−0.528
Quadratic	**−12.495**	**2.491**	**−5.015**
Cubic	3.174	4.278	0.742
Consonant - [θ]	**−3.700**	**1.450**	**−2.551**
Vowel - Front	0.210	0.595	0.353
Linear:[θ]	−0.229	4.386	−0.052
Quadratic:[θ]	−0.336	2.930	−0.115
Cubic:[θ]	−5.103	4.605	−1.108
Linear:Front	−7.829	4.916	−1.592
Quadratic:Front	1.256	3.287	0.382
Cubic:Front	−4.548	4.349	−1.046
[θ]:Front	**−2.024**	**0.900**	**−2.249**
Linear:[θ]:Front	13.218	7.431	1.779
Quadratic:[θ]:Front	-0.810	4.968	−0.163
Cubic:[θ]:Front	11.377	6.576	1.730

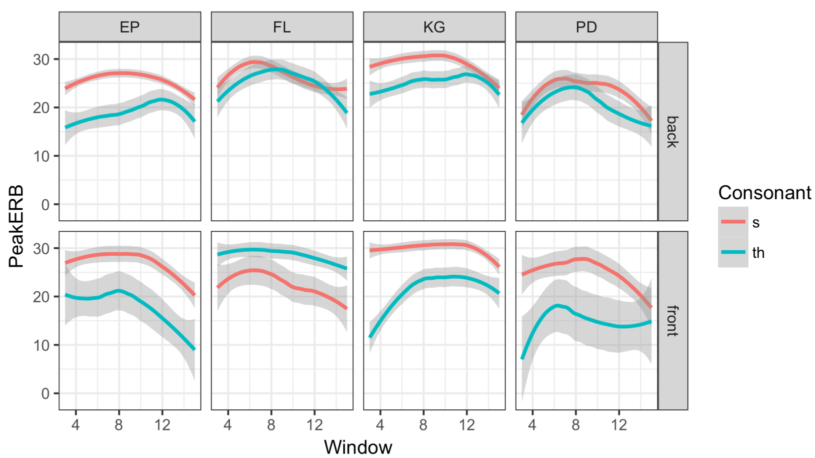

Figure 3 $PeakERB_N$ trajectories are plotted for each speaker by preceding vowel (corresponding to the VF, vowel-fricative model). Window, as a measure of duration, is on the x-axis and PeakERB values are on the y-axis. Each column corresponds to a different speaker and the rows specify whether the preceding vowel is back (top) or front (bottom). The colours denote fricative identity (red = /s/ and blue = /θ/). 95% confidence intervals are shaded in grey. The distance between $PeakERB_N$ trajectories is smaller in the back vowel condition, though this varies between speakers.

When a front vowel comes before the fricative, /s/ and /θ/ are distinct for all speakers. This is even true for FL, who showed substantial overlap in Figure 2. His trajectory of /θ/ is flatter and associated with higher PeakERB values than /s/ when following a front vowel. For PD and FL, there is overlap between the confidence intervals in the back vowel context across the fricative. For KG and EP, the trajectories get closer over the duration of the fricative. This results in overlap for KG in the latter half of the vowel. Thus, individual patterns are consistent with the model and the expected effect of a back vowel is observed in this progressive direction. However, even if the difference between /θ/ and /s/ is neutralized in this environment for FL and PD, and in the latter half for KG, the $PeakERB_N$ trajectories remain distinct for EP. Unlike the other speakers, the /θ/ trajectory for FL is higher than /s/ in the front vowel environment, partially due to a change in the height of /s/. The only significant effect of time in the VF model is quadratic time, which is negative and suggests that the trajectory of both fricatives is a concave downward curve. This is shown in both Figure 2 and Figure 3, where PeakERB values rise toward a maximal point and then fall. The steepness and maximal point varies by speaker and condition.

The results of the FV model are given in Table 5. Like in the VF model, the effect of fricative identity is significant, such that /θ/ is associated with lower PeakERB values than /s/. Vowel place, as a main effect, is similarly not significant. Unlike the VF model, the interaction between fricative identity and vowel place was not significant. The interpretation of this is that the place of a vowel following a fricative does not predict PeakERB values, meaning that the expected effect of a back vowel does not apply regressively. $PeakERB_N$ trajectories of /s/ and /θ/ for the FV condition are plotted in Figure 4 by speaker and vowel place. As suggested by the statistics, there is little difference between the two conditions. /s/ and /θ/ do not overlap in either condition, with the exception of FL's fricatives. For FL, the confidence intervals overlap at the beginning of the fricative and around window 12 in both conditions. For KG, /θ/ rises dramatically over the duration of the fricative in both conditions, resulting in very minimal overlap with the confidence interval for /s/ when a back vowel follows, but the two do not quite overlap before a front vowel. Overall, the position and shape of /s/ and /θ/ do not appear to be substantially affected by the following vowel.

Table 5 Fricative-Vowel (FV) Model

	Estimate	Standard Error	*t*-value
Intercept	**27.326**	**2.334**	**11.708**
Linear Time	**10.520**	**4.827**	**2.180**
Quadratic Time	**−9.700**	**2.649**	**−3.662**
Cubic Time	4.227	3.668	1.153
Consonant - /θ/	**−8.130**	**2.133**	**−3.810**
Vowel - Front	0.500	0.618	0.810
Linear:/θ/	−1.809	6.382	-0.283
Quadratic:/θ/	1.512	3.144	0.481
Cubic:/θ/	−5.401	4.052	−1.333
Linear:Front	−6.638	5.105	−1.300
Quadratic:Front	**7.290**	**3.413**	**2.136**
Cubic:Front	−7.031	4.515	−1.557
/θ/:Front	0.181	0.770	0.235
Linear:/θ/:Front	1.290	6.355	0.203
Quadratic:/θ/:Front	−4.745	4.248	−1.117
Cubic:/θ/:Front	7.655	5.618	1.362

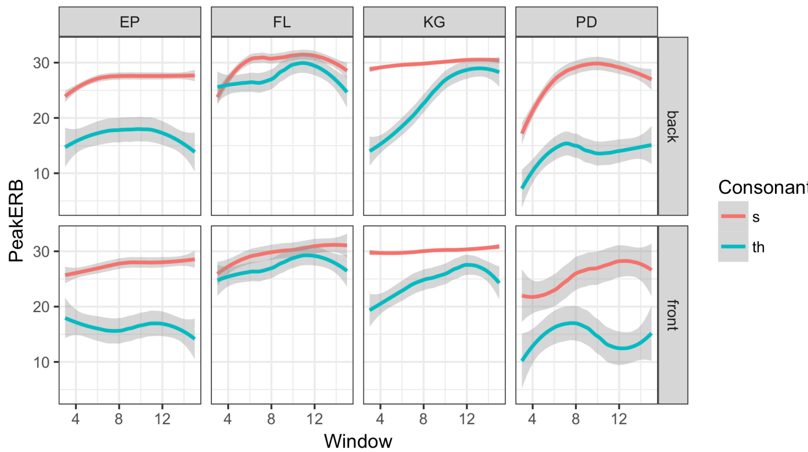

Figure 4 $PeakERB_N$ trajectories are plotted for each speaker by following vowel (corresponding to the FV, fricative-vowel model). Window, as a measure of duration, is on the x-axis and PeakERB values are on the y-axis. Each column corresponds to a different speaker and the rows specify whether the preceding vowel is back (top) or front (bottom). The colours denote fricative identity (red = /s/ and blue = /θ/). 95% confidence intervals are shaded in grey. Unlike in the VF data shown in Figure 3, the distance between $PeakERB_N$ trajectories does not seem to vary systematically between the vowel place conditions.

Quadratic time is significant in the FV model. This suggests a downward concave shape, matching plotted trajectories. KG and EP are an exception, with relatively flat /s/ trajectories. Linear time is also significant, with a positive coefficient, indicating that PeakERB values rise during the fricative. While this is true of all trajectories plotted in Figure 4, the trend is seen for both /θ/ and /s/. The interaction of quadratic time and vowel place suggest both fricatives have a less concave shape when before a front vowel. This is somewhat reflected in Figure 4. The first half of the /θ/ trajectory for EP and the second for PD are convex. KG's /s/ trajectory is very slightly convex. While most trajectories do not look convex, they are less concave and less steep than in the front vowel condition. This results in more stable PeakERB values, suggesting less movement of the articulators during production. Given that the interaction between quadratic time, fricative, and vowel position is not significant, this suggests that this affects both fricatives.

4.3 Vowel Formants at Fricative Onset and Offset

F2 trajectories for the high vowels, /i/ and /u/, following /θ/ and /s/ are given in Figure 5. 95% confidence intervals show overlap for all speakers at 5% of vowel duration. For these places of articulation, F2 transitions are associated with the size of the back cavity. For speakers aside from EP, the confidence intervals are wider for /u/ than /i/, suggesting more variability in this condition. After /s/, EP's /u/ had little variability. Further, while her productions of /i/ overlap at 5%, there is no /u/ overlap before each fricative. For PD, the confidence intervals for /i/ before /s/ and /θ/ barely overlap at 5%, while they overlap quite substantially for /u/. The largely overlapping F2 values at 5% suggest that the size of the back cavity does not substantially differ between the two fricatives. The possible exceptions to this are PD's fricatives before /i/ and EP's before /u/. The higher F2 for /s/ suggests that the back cavity is larger than for /θ/ at vowel onset. If there was a regressive effect of vowel on the fricative, minimizing distance between /θ/ and /s/, the F2 trajectories should be further apart before a front vowel. This can only be found marginally for PD. The large amount of variation for /θ/ aligns with the PeakERB$_N$ trajectory results.

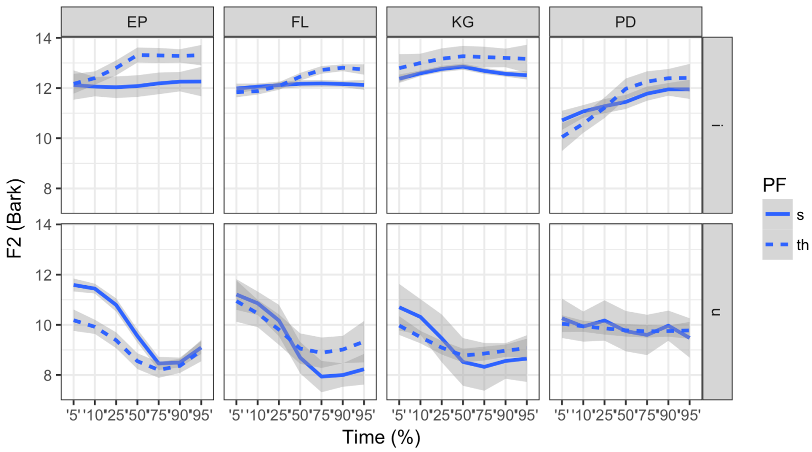

Figure 5 F2 trajectories are plotted for /i/ and /u/ following /s/ or /θ/, by speaker. This is the FV (fricative-vowel) condition and values at 5% correspond to transitions. Percentage of vowel duration is on the x-axis and F2 (Bark normalized) on the y-axis. Columns correspond to speakers and rows to vowel. Linetypes denote fricative identity (solid = /s/ and dashed = /θ/). 95% confidence intervals are shaded in grey.

Figure 6 shows F2 at the offset of /i/ and /u/, before /s/ or /θ/. Though all the trajectories suggest that the F2 of /i/ rises before /θ/, approaching that of /s/, the confidence intervals only overlap for KG. The F2 of /u/ before /θ/ is distinct from /u/ before /s/ for KG and PD. For EP, only the edges of the /u/ intervals overlap. FL is the only one with considerable /u/ overlap. In general, wider intervals for /u/ show more variability before /θ/ that is not found for /i/. F2 values at 95% allow for the inference of the back cavity size of the fricative. Only KG had overlap for /i/, suggesting that the back cavity size is different for /s/ and /θ/ following /i/ for most speakers and that it is larger for /s/. Some overlap is seen for EP and FL for /u/, suggesting a similar back cavity size for both fricatives in this environment.

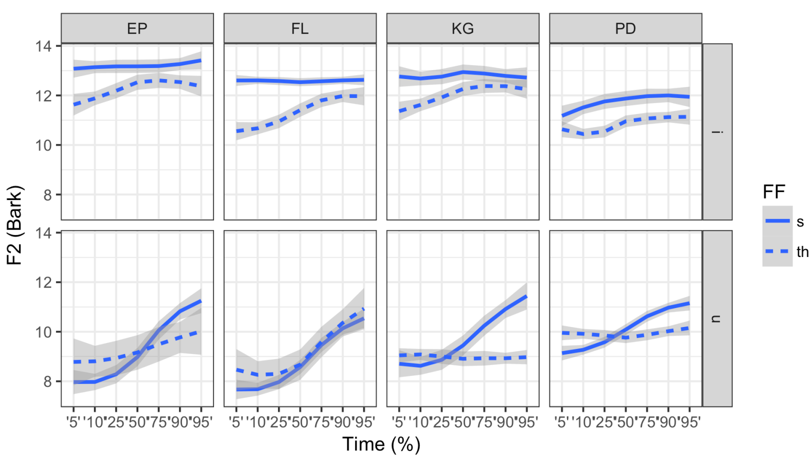

Figure 6 F2 trajectories are plotted for /i/ and /u/ before /s/ or /θ/, by speaker. This is the VF (vowel-fricative) condition and values at 95% correspond to the transition. Percentage of vowel duration is on the x-axis and F2 (Bark normalized) on the y-axis. Columns correspond to speakers and rows to vowels. Line types denote fricative identity (solid = /s/ and dashed = /θ/). 95% confidence intervals are shaded in grey.

5 Discussion

The fricative-internal measures, $PeakERB_N$ trajectories and duration, were expected to overlap for /s/ and /θ/, given the described ambiguity. I predicted /θ/ and /s/ would have high PeakERB values, reflecting high frequencies associated with a narrow airflow channel from a grooved tongue and a small front cavity. Though the fricative-internal measures were quite similar for FL, this was not found for the other speakers. The results show that /s/ and /θ/ are quite distinct. /s/ is longer in both a word-initial and word-final position and reaches higher peak frequencies than /θ/. This is not consistent with the predicted acoustic overlap. However, there are individual exceptions to these generalizations. FL had higher PeakERB values for /θ/ than /s/ following a front vowel, largely due to a change in the height of /s/. Further, FL and PD had a slightly longer /θ/ word-finally. An impressionistic examination of the $PeakERB_N$ trajectories shows that /s/ and /θ/ share the most similarity at offset for KG. This suggests drastic movement in articulators during the realization of /θ/, which would likely be missed by a static measurement of spectral moments. This provides evidence that dynamic measurements, such as $PeakERB_N$ trajectories, may be crucial for building a cross-linguistic understanding of fricative production.

For most of the speakers, the three acoustic measurements considered in this paper differentiate /s/ from /θ/. This was surprising given the reports of ambiguity in the literature. However, this provides an interesting clue about the perception of Mainland Comox, as filtered through an English L1 system. English expectations regarding the fricatives may interfere with the perception of them in Mainland Comox. This follows from Best's (1994) Perceptual Assimilation Model where unfamiliar sounds are mapped to corresponding phonemic categories in a listener's native language. Some nonnative sounds are deemed to be too different from L1 sounds and are perceived as non-speech sounds (nonassimilable - NA type). In this case, discrimination is based on how distinct they are as non-speech sounds, rather than how they relate to L1 phonemes. Both /s/ and /θ/ are present in English providing potential categories for listeners to map the corresponding Mainland Comox fricatives to (two category - TC type), which would aid perception. However, the reported ambiguity suggests that the English speakers may be mapping both sounds to a single English phoneme in perception, rather than two distinct ones. This fits with Best's (1994) category goodness (CG) type of perceptual assimilation where two unfamiliar sounds are perceived as a single L1 phoneme, but one of the sounds matches the English expectation and the other one is treated as deviating from the norm. Listeners are capable of discriminating between sounds of this CG type, but not with perfect accuracy. This matches the described ambiguity in Mainland Comox between /s/ and /θ/, where /θ/ is sometimes perceived as /s/ but /s/ is always perceived as /s/. This suggests that both may be mapped to the English /s/, but that realizations of /θ/ are more discrepant from the expected form. This allows for discrimination between /θ/ and /s/ in Mainland Comox by L1 English speakers in many, but not all, contexts. Jongman, Wayland, and Wong (2000) report mean duration values of 163ms and 178ms for /θ/ and /s/ in English, respectively. Across all environments, the Mainland Comox values are 150ms for /θ/ and 198ms for /s/. In this case, the two may be more easily discriminated because a 150ms /s/ may be more discrepant from what one expects of the English /s/ category. But, the mean duration of /θ/ is 230ms and /s/ is 253ms in a word-final position. These sibilants are longer than non-sibilants in English, so they may be more ambiguous in this context because neither is more prototypical on this measure. Therefore, the perceived fricative ambiguity in Mainland Comox may be a carry-over effect of linguists' L1 categories.

The present study also examined the effect of environment on the fricatives. It was expected, following Blake (2000), that /θ/ would be closer to /s/ when adjacent to a back vowel. The literature did not specify whether the strength of this effect applied equally in both directions. The present study found a progressive effect, such that vowel place predicted PeakERB values for a following fricative. While effects of consonant and time were expected to be comparable in both models, treating the data as VF (vowel-fricative) and FV (fricative-vowel) introduced word position as a confounding factor. Word-initial fricatives are not included in the VF model and word-final ones are similarly excluded in the FV one. Therefore, the results must be interpreted with the caveat that effects of word position and adjacent vowels cannot be completely disentangled at this time. This is particularly true given the duration results, which were longer in a word-final position. However, impressionistically, word-final /θ/ is easier to identify in post-/i/ contexts, like in *gaqɛθ* 'husband', than post-/a/ contexts, like in *ʔɛmmaθ* 'grandchild'.

Despite the significant progressive effect of a vowel on /θ/, a following or preceding back vowel had little effect on /s/. The effect of a back vowel on /θ/ also varied by speaker. FL showed overlap between PeakERB_N trajectories for /s/ and /θ/, regardless of environment, but slightly less when a front vowel came before the fricative. For KG and PD, the PeakERB_N trajectories for /s/ and /θ/ were closest before a preceding back vowel. EP had very little overlap in any condition, though the PeakERB values for /θ/ came closest to /s/ when a back vowel came before. These results suggest the identity of a preceding vowel may affect the realization of /θ/, but the following vowel does not. This is further supported by the vowel trajectories. At 5%, the F2 of both vowels after /s/ and /θ/ (FV condition) were similar for every speaker except EP, who had distinct F2 values for /u/. Conversely, there was less overlap at 95% for /i/ and /u/ before a fricative (VF condition) for all speakers, except FL[10]. Therefore, there is evidence that a back vowel affects /θ/ for some speakers, but that this effect is asymmetrical, only applying to a following fricative.

The interpretation of these results is limited by an inability to simultaneously control for vowels on either side of the fricative, as the stimuli list was not designed to account for vowels on either side of the fricative, meaning that it is possible that there are differences between /uθu/ and /iθu/ sequences. The choice of stimuli also warrants some discussion, as there is a cost associated with using lexical items. Using CV, VC, and VCV sequences or pseudowords would allow for a more controlled experiment and a cleaner, more balanced, data set. While this may be ideal in a lab setting, it is less feasible for fieldwork. It is also, in some respects, a more economical use of resources when working with an endangered language to elicit real language data. The data collected for this paper can also be used to answer other phonetic questions in future or made available in a teaching and learning context. Further, asking for random combinations of sounds does not guarantee a Mainland Comox pronunciation, as the unfamiliar sequences could be produced with English phonological and phonetic patterns, even if put in a carrier phrase. This is particularly an issue for the present study, which evaluates fricatives that have counterparts in

---

[10] It is worth noting that PD and KG, who had evidence of an effect of a preceding back vowel on PeakERB_N trajectories also had further apart F2 values in the /u/ condition going into the fricative. Therefore, while PD and KG display the most evidence of an allophonic difference in PeakERB_N trajectories, triggered by a preceding back vowel, F2 at vowel offset may still provide information useful in discrimination, even if the frication itself is more ambiguous.

English. As a final concern, most elders do not read or write in their language, meaning that orthography could not be used to elicit the stimuli. Therefore, though the use of more controlled stimuli was considered in the design of this experiment, using lexical items was a better choice.

Following from the hypothesis that /θ/ in Mainland Comox developed from an intermediate Proto-Comox [s]-like form, it was hypothesized that they would overlap the least on acoustic measures related to the frontness of the constriction. Peak frequencies allow for inference about the size of the front cavity. Higher values are associated with a smaller front cavity, influenced by the position of the constriction and channel size. However, lower values can also be associated with having a less clear filter. F2 transitions allow for the inference about the size of the back cavity at vowel transitions. In general, /s/ had higher PeakERB and F2 values (at 5% for FV and 95% for VF condition). This suggests that there is a smaller front cavity during /s/ and a larger back cavity at vowel transitions. Though size of the back cavity can only be inferred at transitions, PeakERB_N trajectories were steadier for /s/, meaning that the size of the back cavity likely remained stable during the fricative. A relatively front constriction produced with a grooved tongue would create a smaller front cavity and larger back cavity, which is unsurprising for /s/ and consistent with the results. /θ/ can be interpreted in relation to this, with the caveat that the acoustic measurements do not allow for explicit description of tongue position or shape.

/θ/ generally had lower PeakERB values, which can be associated with a larger front cavity or a less clear filter. As there is no reason to suspect that the point of constriction for /θ/ would be further back than /s/, indications of a larger front cavity for /θ/ should not necessarily be interpreted as a reflection of how front the constriction is. However, the PeakERB_N trajectories suggest that the articulators are more dynamic throughout /θ/ and that /θ/ often ends up most similar to /s/ in the latter half of the fricative. For KG, the measurements for /θ/ approach those of /s/ throughout the course of the fricative. This means that /θ/ ends up with higher PeakERB values, suggesting a reduction in front cavity size, or the creation of a more clear filter, over the duration of the fricative. This can be taken to mean that the fricatives are considerably different at initiation, but /θ/ becomes more /s/-like over time[11]. A reduction of front cavity for /θ/ can possibly be attributed to a combination of narrowing and retracting of the constriction or to raising the jaw, which would reduce the size of the sub-lingual area. The change of /θ/ over time is also reflected in the F2 transitions, as shown in Table 6. In the FV condition, the F2 values were similar at the fricative-vowel boundary, allowing for the inference that /s/ and /θ/ have a similar sized back cavity at offset. The opposite was found in the VF condition, where /s/ had higher F2 values than /θ/ with little overlap at fricative onset, indicating a larger back cavity for /s/. Tying this to the PeakERB_N trajectories, /θ/ had lower PeakERB values at onset, which rose through fricative duration, suggesting a reduction in front cavity size or movement toward a clearer filter. This may be indicative of retraction and change in tongue shape, resulting in a smaller channel size. Recall that the previous literature suggested that /θ/ in Coast Salish languages may be articulated with a grooved tongue (Blake 2000) or further back than one would expect for an interdental (Suttles 2004). The present study suggests that this may be both true and

[11] A follow-up analysis could examine if longer fricatives are more ambiguous when the articulators have more time to move from a /θ/ initiation to a /s/-like state. This raises questions about the role of duration, because word-final fricatives are longer. Given the analysis in this section, I expect word-final fricatives to be more ambiguous. Impressionistically, I do find that word-final /θ/ is harder to transcribe correctly.

false in Mainland Comox, depending where in the fricative the measurement is taken. However, other acoustic measures, such as variance or kurtosis, may provide clarification.

Table 6 Summary of F2 Results

	/u/		/i/	
	Fricative Onset	Fricative Offset	Fricative Onset	Fricative Offset
EP	/s/ > /θ/ (slight)	/s/ > /θ/	/s/ > /θ/	/s/ = /θ/
FL	/s/ = /θ/	/s/ = /θ/	/s/ > /θ/	/s/ = /θ/
KG	/s/ > /θ/	/s/ = /θ/	/s/ > /θ/ (slight)	/s/ = /θ/
PD	/s/ > /θ/	/s/ = /θ/	/s/ > /θ/	/s/ = /θ/
Pattern	/s/ > /θ/	/s/ = /θ/	/s/ > /θ/	/s/ = /θ/

The patterns observed in this study suggest that the position and shape of the tongue during articulation varies between speakers. The progression of diachronic changes proposed in this paper, where PS *c underwent lenition to a Proto-Comox [s]-like form before fronting to /θ/ in Mainland Comox leads to the prediction that there should be more variability in realizations of /θ/ than /s/, reflecting a period of uncertainty in its historical development. This was anticipated to occur within speakers, where /θ/ should vary more than /s/. This was borne out in the data as the confidence intervals showed greater variability in productions of /θ/. However, this pattern is also paralleled in comparison between speakers. /s/ is relatively stable across different contexts and does not show as much variation between speakers. In contrast, /θ/ is realized and affected by context differently for each speaker. This suggests that the ambiguity is unidirectional. Further, the synchronic instability of /θ/ across speakers on measures correlated with front/back cavity size may indicate that fronting is a more recent innovation[12].

Gick, Stavness, Chiu, and Fels (2011) found that speech production favours quantal regions, which are stable states that tolerate variability in muscle activation while requiring little active control. In the present data, the PeakERB_N trajectories of /s/ were more stable than /θ/ over the duration of the fricative, indicating less movement of the articulators. The Mainland Comox /s/ seems to be a relatively stable sound, which provides motivation for why an intermediate [s]-like sound from Proto-Salish *c might undergo fronting, rather than the PS *s, to resolve an unstable system. However, the prevalence of mergers between PS *c and *s across Coast Salish languages suggests that this contrast may have fewer minimal pairs. As functional load has been shown to be one of the factors that mediate whether a merger occurs (Wedel, Kaplan, & Jackson 2013), the motivation to retain a distinction between the two may be less strong. According to the minimum

[12] Suttles (2004) made a similar suggestion for Musqueam, theorizing that /θ/ has only recently reached its present form. If Nooksack was also undergoing a similar change, this might account for the idiolect variation where one speaker realized /s/ and /c/ closer to [θ] and [θs], respectively (Galloway 1982). In fact, the Nooksack [θs] might be roughly equivalent to the intermediate s-like form (from *c) proposed for Proto-Comox.

intervention principle (Todorov & Jordan, 2003), it is only necessary to correct behavior that interferes with task performance, which is communication in this case. If the difference between /s/ and /θ/ is less crucial to meaning, more variation will be tolerated in the system because it is less important to correct it. This kind of variation is found in individual speaker patterns; EP maintains a distinction between /s/ and /θ/ on almost every measure, while FL does not, and the other two speakers fall in the middle. However, all four are fluent speakers and able to communicate with each other in the language. This is consistent with Harris' (1981) descriptions of varying distributions of [s] and [θ] across different accounts of the Mainland and Island dialects: there is (and was) variation within the system.

If this study had focused on speech from one speaker, the conclusions would be different. For example, FL shows a pattern that resembles the Island Comox one (Harris 1981), suggesting that /θ/ and /s/ may be close to merged. In contrast, EP shows little acoustic evidence of them being similar. PD and KG showed patterns suggesting a conditioned allophone of /θ/ in the environment of a back vowel. This underlies two important conclusions in working with endangered languages. First, one should be mindful about generalizations based on a single speaker. These accounts should instead be taken as a description of what the grammar *can* look like for L1 speakers, demonstrating the variation tolerated in the system. Second, it is important to do as much phonetic documentation of as many speakers as possible while they still remain, so that we can better understand the extent and limitations of the variation in the language. However, this study also allows for a more hopeful perspective on the documentation of Salish languages as it suggests that there is valuable phonetic information that remains accessible from recordings, even in the absence of speakers. Though the methodology used in this paper benefits from access to multiple speakers and a more controlled list of stimuli, it can also be applied to existing field recordings and can allow for inference about articulation that can be used in comparative study or in the context of language revitalization.

6 Conclusion

This paper set out to discover the acoustic source of ambiguity between /s/ and /θ/ in Mainland Comox, though the two sounds were more distinct than expected. /s/ and /θ/ were distinguished by PeakERB$_N$ trajectories and formant transitions for three of the four speakers studied. Therefore, it is still unclear where the actual source of ambiguity is, though it is possible that this is largely rooted in L1 experience, assuming that speakers map unfamiliar sounds to L1 categories whenever possible, as proposed in Best's (1994) Perceptual Assimilation Model. Developing a further understanding of this will be beneficial for creating teaching materials that are tailored to the learners, who are generally L1 English speakers. Despite the acoustic differences between the two fricatives, there is a high level of inter-speaker variation, suggesting that /θ/ may be a recent and unstable innovation. The synchronic patterns described in this paper also provide preliminary evidence supporting the reconstruction of a Proto-Comox [s]-like form, which can be examined and tested through future comparative and phonetic work.

References

Barnett, H. (1955). The Coast Salish of British Columbia. University of Oregon Monographs. Studies in Anthropology IV. (Eugene; University of Oregon).

Behrens, S., & Blumstein, S. (1988). Acoustic characteristics of English voiceless fricatives – A descriptive analysis. *Journal of Phonetics, 16*(3), 295-298

Bessell, N. J. (1993). *Towards a phonetic and phonological typology of post-velar articulation* (Doctoral dissertation, University of British Columbia).

Best, C. T. (1994). The emergence of native-language phonological influences in infants: A perceptual assimilation model. *The development of speech perception: The transition from speech sounds to spoken words, 167*(224), 233-277.

Bird, S., Caldecott, M., Campbell, F., Gick, B., & Shaw, P. A. (2008). Oral–laryngeal timing in glottalised resonants. *Journal of Phonetics, 36*(3), 492-507.

Blake, S. J. (2000). *On the distribution and representation of schwa in Sliammon (Salish): descriptive and theoretical perspectives* (Doctoral dissertation, University of British Columbia).

Boas, F. (1890). *Pentlatch materials (Mss.497.4.B63c).* American Council of Learned Societies Committee on Native American Languages, American Philosophical Society, Philidelphia, PA.

Carlson, B. F., Esling, J. H., & Harris, J. G. (2004). A laryngoscopic phonetic study of Nlaka'pamux (Thompson) Salish glottal stop, glottalized resonants, and pharyngeals. *Studies in Salish linguistics in honor of M. Dale Kinkade, occasional papers in linguistics*, (17), 58-71.

Davis, J. (1978). Pronomial Paradigms in Sliammon. *International Conference on Salish and Neighbouring Languages 13*, 208-36

First Peoples' Cultural Council. (2014). Report on the Status of B.C. First Nations Languages. Retrieved from http://www.fpcc.ca/files/PDF/Language/FPCC -LanguageReport-141016-WEB.pdf

Galloway, B. D. (1988). Some Proto-Central Salish sound correspondences. In *In honor of Mary Haas, from the Haas Festival Conference on Native American Linguistics* (pp. 293-343).

Gibbs, G. (1877). Vocabulary of the Ko-mookhs. *Contributions to North American Ethnology, Vol. 1.* (Washington: Department of the Interior) Pp. 269-283.

Gick, B., Stavness, I., Chiu, C., & Fels, S. (2011). Categorical variation in lip posture is determined by quantal biomechanical-articulatory relations. *Canadian Acoustics, 39*(3), 178-179.

Gordon, M., Barthmaier, P., & Sands, K. (2002). A cross-linguistic acoustic study of voiceless fricatives. *Journal of the International Phonetic Association, 32*(2), 141-174.

Harris, H. R. (1981). A grammatical sketch of Comox (Doctoral dissertation, University of Kansas).

Johnson, K. (2012). *Acoustic and Auditory Phonetics.* John Wiley & Sons.

Jongman, A. (1989). Duration of frication noise required for identification of English fricatives. *The Journal of the Acoustical Society of America, 85*(4), 1718-1725.

Jongman, A., Wayland, R., & Wong, S. (2000). Acoustic characteristics of English fricatives. *The Journal of the Acoustical Society of America, 108*(3), 1252-1263.

Kuipers, A. H. (2002). *Salish etymological dictionary (No. 16)*. Linguistics Laboratory University of Montana.

Iskarous, K., Shadle, C. H., & Proctor, M. I. (2011). Articulatory–acoustic kinematics: The production of American English /s/. *The Journal of the Acoustical Society of America, 129*(2), 944-954.

Lambacher, S., Martens, W., Nelson, B., & Berman, J. (2001). Identification of English voiceless fricatives by Japanese listeners: The influence of vowel context on sensitivity and response bias. Acoustical Science and Technology, 22(5), 334-343.

Li, F., Edwards, J., & Beckman, M. E. (2009). Contrast and covert contrast: The phonetic development of voiceless sibilant fricatives in English and Japanese toddlers. *Journal of Phonetics, 37*(1), 111-124.

Maddieson, I. (1984). 1984. *Patterns of sounds*. Cambridge: Cambridge University Press.

McGuire, G., & Babel, M. (2012). A cross-modal account for synchronic and diachronic patterns of /f/ and /θ/ in English. *Laboratory Phonology, 3*(2), 251-272.

Reidy, P. F. (2015). *The spectral dynamics of voiceless sibilant fricatives in English and Japanese.* (Doctoral dissertation, Ohio State University).

Reidy, P. F. (2016). Spectral dynamics of sibilant fricatives are contrastive and language specific. *The Journal of the Acoustical Society of America, 140*(4), 2518-2529.

Sapir, E. (1914). Indian Tribes of the Coast. In A. Shortt and A. G. Doughty, eds, *Canada and Its Provinces, 21*: 315-346. (Toronto)

Suttles, W. P. (2004). *Musqueam reference grammar (Vol. 2)*. UBC Press.

Todorov, E., & Jordan, M. I. (2003). A minimal intervention principle for coordinated movement. In *Advances in neural information processing systems* (pp. 27-34).

Thompson, L. C., Thompson, M. T., Efrat, B. S. (1974). Some phonological developments in Straits Salish. *International Journal of American Linguistics, 40*(3): 182-196.

Wagner, A., Ernestus, M., & Cutler, A. (2006). Formant transitions in fricative identification: The role of native fricative inventory. *The Journal of the Acoustical Society of America, 120*(4), 2267-2277.

Watanabe, H. (2003). *A Morphological Description of Sliammon, Mainland Comox Salish: With a Sketch of Syntax.* Endangered Languages of the Pacific Rim, Faculty of Informatics, Osaka Gakuin University.

Wedel, A., Kaplan, A., & Jackson, S. (2013). High functional load inhibits phonological contrast loss: A corpus study. *Cognition, 128*(2), 179-186.