Cool thing about ultrasound #17: now I can pronounce /hiqət/!*

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This paper reports on an ultrasound study of one fluent SENĆOŦEN speaker's pronunciation of /qi/ and /iq/ sequences. Results show that the speaker rolls his tongue forward (/qi/) or backwards (/iq/) along the palate during the /q/ closure, allowing him to pronounce these difficult sequences without compromising the uvular closure or the vowel target. From a purely linguistic perspective, these findings provide insight into the kinds of strategies speakers use to pronounce difficult sound sequences; from a language learning perspective, the study illustrates how effective ultrasound imaging can be as a way of teaching learners how to pronounce tricky sound sequences.

1 Introduction

The languages of the Pacific Northwest are well known for including sounds and sound sequences that are difficult to pronounce. This paper focuses on sequences involving the uvular consonant /q/ adjacent to the high front vowel /i/. Such sequences are difficult because the tongue must move very rapidly between two antagonistic positions: it must be retracted for /q/ but advanced and raised for /i/. What is interesting about these sequences is that there is no single 'right way' to pronounce them: the strategies used vary across languages, across speakers of a single language, and even across words pronounced by a single speaker. This paper reports on an ultrasound study of one speaker's pronunciation of SENĆOŦEN words with /iq/ and /qi/ sequences. Results show that he rolls his tongue backwards (/iq/) or forward (/qi/) along the palate during the /q/ closure, a strategy which allows him to pronounce the sequences without compromising the nature of the vowel or the uvular closure. From a purely linguistic perspective, this study sheds valuable light on the ways in which fluent speakers manipulate their articulators to pronounce difficult sequences. From a language learning perspective, the study also illustrates the usefulness of ultrasound imaging as a tool for teaching pronunciation.

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The remainder of the paper provides the details of the study outlined above: section 2 provides background literature on the articulation of difficult sound sequences and on the SENĆOŦEN language; section 3 lays out the methodology used in the current study; sections 4 presents the results and 5 discusses them, first from the perspective of language teaching and then from a purely linguistic (phonetic) perspective.

2 Background

2.1 Articulatory conflict

The term 'articulatory conflict' is used by phoneticians to refer to cases in which sequences of sounds require the tongue to be in two antagonistic positions (almost) simultaneously (Gick & Wilson 2006). The sequences /iq/ and /qi/ provide clear examples of articulatory conflict: the tongue must be advanced and raised for /i/ but retracted for /q/. Because of the speed with which speech is produced, when /i/ and /q/ are adjacent to one another, the tongue must move very rapidly between these two antagonistic positions, which is what causes the conflict.

In order to resolve articulatory conflicts, different strategies can be adopted (Gick & Wilson 2006). For /qi/ and /iq/ sequences, one or both of the segments can be compromised, a transitional element can be inserted between the two segments, or one of the segments can be deleted altogether. These possibilities are listed in (1), along with illustrative sound changes.

(1) Possible articulatory conflict resolution strategies (Gick & Wilson 2006)
   a. Segment compromise: /qi/ → [qɪ]
   b. Transitional element: /qi/ → [qᵊi]
   c. Segment deletion: /qi/ → [q]

Previous work on articulatory conflict, in particular on /qi/ and /iq/ sequences, has shown that the strategies used differ across languages. For example, whereas Nuu-chah-nulth speakers pronounce /qi/ as [qɪ] and /iq/ as [iᵊq], Tsilhqut'in speakers do the opposite: they pronounce /qi/ and [qᵊi] and /iq/ as [ɪq][1] (Gick & Wilson 2006). Strategies can also differ across speakers within a given language. For example, within SENĆOŦEN, Bird & Leonard (2009) found that of two fluent speakers, one was much more likely than the other to insert an epenthetic fricative between /i/ and /q/ in /iq/ sequences (/iq/ → [iˣq]).

The question that arises from this variation is: what factors influence speakers as they decide (consciously or subconsciously) how to pronounce speech strings? To answer this question, it is essential to gain a better

[1] This Tsilhqut'in pattern was initially reported in Cook (1993). It is somewhat controversial though (Linda Smith, p.c.). Further research is necessary to confirm the facts.

understanding of how speakers deal with sequences like /qi/ and /iq/ in a range of contexts and a range of languages. To this end, the current study was designed to record two fluent SENĆOŦEN speakers using lingual ultrasound (Stone 2005), to get a direct look at what their tongues were doing while pronouncing words with /qi/ and /iq/ sequences. Ultrasound imaging is becoming increasingly popular as a tool for studying the articulatory details of speech, in particular those involving the tongue[2]. By placing the transducer under the chin, it is possible to see the tongue moving in real time, as it travels from one speech target to the next. The basic set-up is relatively easy (at least for doing qualitative analysis) and is minimally invasive (Gick 2002). For the most part, participants are thoroughly entertained by watching the gymnastics performed by their tongues as they speak, and as a result usually enjoy the recording sessions.

2.2 SENĆOŦEN language and articulatory conflict

SENĆOŦEN is a dialect of North Straits Salish (Central Salish), traditionally spoken on the Saanich Peninsula just north of Victoria on Vancouver Island and in the surrounding Gulf and San Juan islands. Although there are currently fewer than 20 speakers, language revitalization efforts are in full swing, including a master-apprentice program, a language-nest program for pre-schoolers, regular language classes offered at the band schools, and various other language-related projects.

As is typical in languages of the Pacific Northwest, SENĆOŦEN has a very rich consonantal inventory, including uvular consonants – which are of particular interest here. Figure 1 provides the set of phonemic consonants, organized by place (columns) and manner (rows) of articulation. The uvular consonants are bolded.

p		t		tʃ	(k)	k^w	**q**	**q^w**	
p’	t'^{θ}	t’	tɬ’	tʃ’		k'^w	**q’**	**q'^w**	ʔ
	θ	s	ɬ	ʃ		x^w	**χ**	**$χ^w$**	h
m		n	l	y		w	**ɴ**		
m’		n’	l’	ỵ’		w’	**ɴ’**		

Figure 1. SENĆOŦEN consonant inventory (adapted from Montler, 1986:7).

Bird & Leonard (2009) conducted an acoustic study of the pronunciation of /qi/ and /iq/ by two fluent SENĆOŦEN speakers (the same speakers who participated in the current study). They found that, overall, /qi/

[2] See Moisik (2010) for linguistic applications of laryngeal ultrasound.

sequences tended to be pronounced with some degree of compromise on the vowel target (2a) whereas /iq/ sequences tended to be pronounced with a transitional fricative (2b).

(2) Overall tendencies in the pronunciation of /qi/ and /iq/ sequences (Bird & Leonard 2009)
   a. /qi/ → [qɪ], [qɛ] or [qe]
   b. /iq/ → [i^{x}q]

However, a lot of variation existed in how these sequences were pronounced, both within and across speakers. In general, of two speakers recorded, Speaker 1 had relatively varied strategies, including several cases that were coded auditorily as "no obvious effect", i.e. cases in which the sequence was heard simply as [qi] or [iq], with no clear strategy used to make pronunciation easier. In contrast, Speaker 2 had relatively consistent strategies, and no cases that were coded as "no obvious effect" (see Bird & Leonard 2009 for further details).

The original goal of the current project was to take a direct look at the articulation of /qi/ and /iq/ sequences by Speaker 1 and Speaker 2 using ultrasound imaging, to answer two research questions, summarized in (3):

(3) Two research questions of the current study:
   a. What is the articulatory basis of the acoustic differences observed between speakers?
   b. For Speaker 1, what is the articulatory basis of cases coded auditorily as "no obvious effect"?

Unfortunately, Speaker 2's tongue did not image well, and his ultrasound recordings were not clear enough to analyze[3]. Therefore, the remainder of this paper focuses on Speaker 1, and on the second research question above. In particular, using ultrasound imaging, the project focused on looking for articulatory evidence as to why, in some cases, Speaker 1's pronunciations of /qi/ and /iq/ sequences tended to be heard as is, without any clear conflict resolution strategy.

3 Methodology

3.1 Speakers

As mentioned previously, the project originally included ultrasound recordings with two elders, both fluent SENĆOŦEN speakers. Speaker 1 was from the Tsartlip reserve in West Saanich; Speaker 2 was from the Tsawout

[3] Not all tongues are created equal when it comes to ultrasound imaging. In general, smaller individuals (women and children) have tongues that image better than larger individuals (men), although this is not always the case – and in fact was not the case in this study (Stone 2005).

reserve in East Saanich. Because of poor tongue imaging quality, Speaker 2's data were not used in the analysis.

3.2 Stimuli

The words analyzed for this project were elicited as part of a larger recording session that was designed to gain a general understanding of how uvular vs. velar consonants are articulated adjacent to different vowels. Words were extracted from Montler's (1991) *Classified Word List* and from a draft dictionary that the speakers had been working on. Table 1 provides the list of words used. This is clearly a small set, and one not very well controlled in terms of segmental and prosodic context. This is partly due to the relative infrequency of the target sequences within the language, and partly because of the nature of the larger recording session: it was important not to fatigue speakers with too many elicitations. In future research, more care will need to be taken to minimize these limitations.

Table 1. Stimuli (target sequences are bolded)

Sequence	Word	English gloss	Sequence	Word	English gloss
/qi/	/s**qi**mək'ʷ/ /s**qi**təw/ /ʃ**qi**təs/	octopus mermaid headband	/ki/	/**ki**ŋtʃa:tʃ/ /s**ki**ŋtʃa:tʃ/	Canada Canadian
/iq/	/t'ᶿ**iq**t/ /h**iq**ət/	ivory billed woodpecker to put something in the oven	/ik/	/ʃ**ik**əsew'txʷ/ /tʃ**ik**mən/	church iron

3.3 Experimental set-up

The experiment was conducted at the University of Victoria, in the Speech Research Laboratory. Ultrasound imagining was done using a GE logic e portable ultrasound machine with an 8C-RS convex transducer. The ultrasound video signal was captured directly onto a dedicated computer fitted with an EMS Xtreme RGB-E1 VGA/DVI capture card. The session was also audio-recorded using a Senheiser ME-55 directional microphone. The video and audio signals were mixed and captured in Sony Vegas.

Both speakers were present during the recording session[4]; Speaker 2 went through the experiment first, followed by Speaker 1. The speaker was seated in an optometry chair, with his head stabilized against the chair's head rest. The ultrasound probe was fixed to a table-top microphone stand, which was adjusted to hold the probe stable under the speaker's chin. Although this kind of

[4] As were a number of other interested community members.

set-up does not allow for detailed quantitative data analysis because of possible movement of the probe and/or the speaker's head, it was deemed sufficient for the qualitative analysis conducted here (cf. Gick et al. 2005). This set-up was deliberately chosen so as to ensure that speakers were comfortable during the recording session, this being our first priority.

Speakers were given the English translation of each target word and asked to pronounce the SENĆOŦEN word. Words were elicited in isolation, and each one was repeated three times.

3.4 Data analysis

The target /qi/ and /iq/ sequences were first transcribed (by the author, a trained phonetician), and coded in terms of whether they included a transitional vowel and/or a transitional fricative (based on auditory analysis). Target sequences were also analyzed acoustically using Praat's annotation function and an associated script: F1, F2 and F3 were automatically measured at 5%, 50% and 95% into the vowel. This provided measures of (a) the degree of vowel retraction adjacent to uvular consonants and (b) the extent to which a transitional element occurred between the vowel and the uvular consonant (indicated by unstable formants). In addition to formant values, various durational measurements were taken: the /qi ~ iq/ interval; the /q/ stop closure; the vowel. Finally, and most importantly for the current purposes, a qualitative analysis was conducted of tongue movement into, during, and out of the target /qi/ or /iq/ sequence, based on the ultrasound video. Section 4 below focuses on the ultrasound data analysis, i.e. on what the tongue actually does as it moves between the target sounds in /qi/ and /iq/ sequences.

4 Results

Qualitative analysis of tongue movement shows that Speaker 1 uses three different strategies for articulating /qi/ and /iq/ sequences, summarized in Table 2 (/qi/) and Table 3 (/iq/) below. In these tables, the first column provides the strategy; the second column provides the number of times the strategy was used in total; the last column provides the words in which the strategy was used and, in parentheses, the number of repetitions in which it was used out of the total number of repetitions of the word.

Table 2 Strategies used by Speaker 1 for pronouncing /qi/ sequences

Strategy	# of instances	words
q-compromise	6	s**qi**təw (3/3); ʃ**qi**təs (3/3)
Back-to-front tongue looping	2	s**qi**mək' (2/3)
i-compromise	1	s**qi**mək' (1/3)
Total	9	

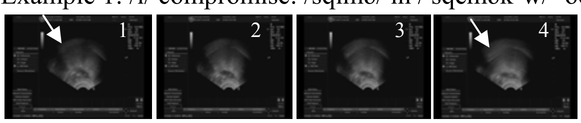
Table 3 Strategies used by Speaker 1 for pronouncing /iq/ sequences

Strategy	# of instances	words
Front-to-back tongue looping	5	t’$^{\theta}$**iq**t (3/3); h**iq**ət (2/3)
q-compromise	1	h**iq**ət (1/3)
Total	6	

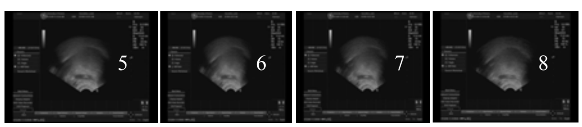
The following examples illustrate the strategies used. These examples consist of sequences of adjacent ultrasound frames. In these frames, the tongue contour is the white line towards the top of the scan; the tongue tip is on the right and the tongue root is on the left. The white arrows are used to point out the events described in the text below the frames.[5]

Example 1 below is of /i/ compromise: the /i/ in /ˈsqimək’w/ (‘octopus’) is retracted following the uvular /q/, pronounced as [e]. Note that the tongue does not ‘roll’ forward along the palate during the /q/ closure (frames 1-4) as it does in Example 4 below; rather, the tongue remains in the same basic position, other than at the back where the closure is created and then released.

Example 1: /i/ compromise: /sqimə/ in /ˈsqemək’w/ ‘octopus’



/q/ closure /q/ release

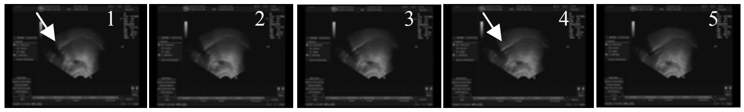


tongue fronting into retracted /i/ ([e]) /i/ release

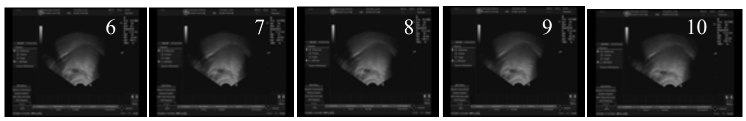
Example 2 illustrates /q/ compromise in /ˈsqitəw/ (‘mermaid’). As in Example 1, the tongue body remains in a relatively stable position during the /q/ closure (frames 1-4) rather than rolling forward along the palate as it does in Example 4.

[5] These stills are not terribly clear. Please contact the author to see the original videos.

Example 2: /q/ compromise: /sqi/ in /ˈsqitəw/ ‘mermaid’



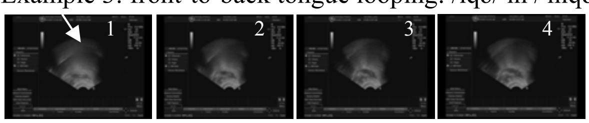
/q/ closure /q/ release tongue fronting…



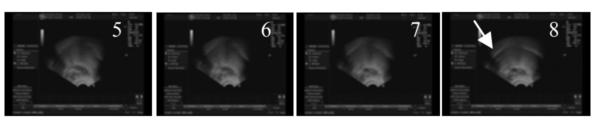
into /i/ /i/ release

Example 3 illustrates what is called here ‘front-to-back tongue looping’. The term ‘looping’ is borrowed from the literature on tongue motion in VCV[6] sequences, in which the tongue starts and ends in the same vowel position, but travels into and out of the consonant along different trajectories (Mooshammer et al. 1995 – see section 5 for further discussion). In this example, the /q/ closure is initially formed relatively far forward (frame 1; approximating [k]). The tongue then rolls backwards along the palate during the closure (frames 2-7) such that by the time the closure is released, it is much further back (frame 8; more typical of [q]).

Example 3: front-to-back tongue looping: /iqə/ in /ˈhiqət/ ‘put s.t. in the oven’



/q/ closure backward tongue movement…

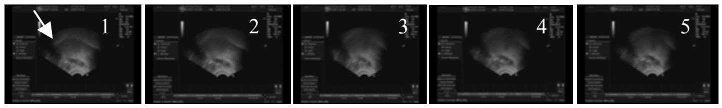


… along the palate /q/ release

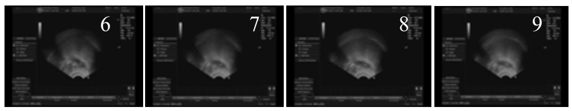
Example 4 also illustrates tongue looping, but in the reverse direction. This motion is called ‘back-to-front tongue looping’. In this case, the tongue closure is created relatively far back in the oral tract (frame 1); the tongue then rolls forward along the palate (frames 2-10) and is released much further forward into the /i/ position (frame 11).

[6] V = vowel (the same vowel before and after C); C = consonant.

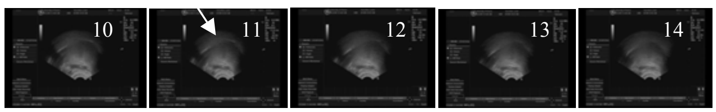
Example 4: back-to-front tongue looping: [sqi] in [ˈsqimək’w] ‘devil fish’



/q/ closure forward tongue movement…



… along the palate…



/q/ release and tongue fronting/raising into /i/

5 Discussion

The results show that even in the case of /qi/, where target words are relatively consistent in terms of segmental context (see Table 2 above), Speaker 1 uses different strategies to pronounce the sequence: i-compromise, q-compromise, and back-to-front tongue looping. This variation suggests that there is no single way of dealing with articulatory conflict, even for an individual speaker within a single language. Rather, articulatory conflicts are dealt with on the fly, using whatever strategy seems appropriate in the moment.

Perhaps the most interesting strategy used by Speaker 1, and one not previously attested, is tongue looping – forward in /qi/ and backwards in /iq/. As someone who has been attempting to pronounce words in various Salish languages for some time now, I have always had difficulty with sequences of uvular consonants adjacent to sounds with a further forward articulation (/i/, /s/, etc.). Seeing Speaker 1’s tongue looping strategy was a *Eureka!* moment for me – this was something I could understand and make my tongue do as well! As a result I am becoming much more comfortable pronouncing these sequences. From a very practical perspective, conducting this project has shown me what an effective teaching tool lingual ultrasound can be: getting a direct look at the tongue’s motion during speech allows learners to imitate this motion, thereby facilitating fluent pronunciation. Ultrasound imaging has previously been used as a tool in language teaching (Wilson & Gick 2006) and speech therapy (Bernhardt et al. 2005; Adler-Bock et al. 2007). However, it has not (that I know of) been used in the context of language revitalization, in the Pacific Northwest or elsewhere. Given that ultrasound technology is portable, non-invasive, and easy to use (Gick 2002), it has great potential in terms of teaching pronunciation, particularly in languages with strings of sounds that are challenging for language learners.

From a purely linguistic (phonetic) perspective, the tongue looping strategies observed here are also of interest. Based on cinefluographic data, Kent & Moll (1972), Mooshammer et al. (1995) and others describe an elliptical movement of the tongue in VCV sequences, in which the tongue follows an asymmetrical path into and out of the consonant: 1) from the initial vowel, the tongue moves predominantly *upwards* into the consonantal constriction, then 2) the tongue moves *forward* until the constriction is released, and finally 3) the tongue moves *downward*, and often *backwards*, into the final vowel. Focusing on the consonant /g/, Kent & Moll (1972) state: “As a consequence of these vertical and horizontal displacements, the locus of each tongue point during /g/ articulation tends to be roughly circular or elliptical” (p. 459). This movement of the tongue has been called ‘tongue looping’ (Mooshamer et al. 1995).

Although previous work on tongue looping has focused on velar consonants, Speaker 1’s speech shows us that the same kind of elliptical trajectory can be used to articulate uvular consonants. Furthermore, this movement effectively resolves the articulatory conflict posed by /i/ and /q/: because the tongue moves along the palate during the closure, both /i/ and /q/ targets can be achieved, without an audible transition between them. Thus, in answer to question (3b) posed above, the articulatory basis of /qi/ and /iq/ sequences auditorily coded as “no obvious effect” appears to be tongue looping, forward in /qi/ sequences and backwards in /iq/ sequences.

One of the things that is interesting about tongue looping as a strategy to resolve articulatory conflict is that the cues to the uvular stop are lost adjacent to /i/, because the closure is fronted adjacent to /i/ (see Examples 3 and 4). This means that *perceptually*, /q/ should be relatively difficult to distinguish from /k/ when adjacent to /i/. One might expect then that, over time, the /q/ ~ /k/ contrast would become neutralized adjacent to /i/ (see Blevins (2004) for a perception-based account of sound change). Future studies will explore whether or not other fluent speakers use tongue looping strategies to pronounce /iq/ and /qi/ sequences. If this turns out to be a common strategy, it will also be interesting to determine how /qi/ and /iq/ sequences are perceived, in particular by younger generations of SENĆOŦEN speakers and by language learners, to determine whether there is any evidence for neutralization in progress.

6 Conclusion

This paper has reported on an ultrasound study of the strategies used by one SENĆOŦEN speaker to pronounce /qi/ and /iq/ sequences, which involve articulatory conflict. Results show that, among other strategies, the speaker uses tongue looping: he rolls his tongue along the palate during the /q/ closure (forward for /qi/ and backwards for /iq/). This strategy allows him to fully achieve both /i/ and /q/ targets, without creating an audible transition between them. In terms of language acquisition, this study shows that lingual ultrasound has great potential as a tool for teaching learners to pronounce difficult sound sequences appropriately. In terms of phonetic theory, this study shows that elliptical tongue movement, previously observed in the articulation of velar consonants, is also used in the articulation of uvular consonants. In the latter case, it provides speakers with an additional strategy for resolving articulatory conflict. While the study is small in scope, it provides the basis for further research into the details of what strategies are used by speakers in cases of articulatory conflict, of how these strategies may vary depending on linguistic context, speaker, and language, and of what implications these strategies may have for the evolution of the language(s) in question.

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