Vowel Lowering Effect of Pharyngeal and Uvular Consonants in Squliq Atayal

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High vowel in Squliq Atayal has been alleged to be lowered when occurring adjacent to pharyngeal and uvular consonants /h/ and /q/ (Egerod, 1966; Li, 1980; Rau, 1992). However, the observed lowering of the high vowels are heavily based on auditory transcription with no further examination on its underlying mechanism. The present study investigates the patterns of the vowel lowering effect in Squliq Atayal through acoustic and articulatory analyses, specifically for high front vowel /i/ that is either preceded or followed by /h/ and /q/. Recordings and Ultrasound data were collected from one native speaker of Squliq Atayal. The acoustic results show a vowel lowering effect interacts with syllable structure, while the lowered vowel is still distinguishable from phonemic /e/ and /ya/. Ultrasound data confirm that for the vowel in /ih/, the tongue is more retracted toward the pharynx with a still clear palatal constriction, forming a double bunched tongue shape. This suggests that the vowel quality of /i/ is affected by the following consonants, though remaining contrastive from another phoneme /e/ as acoustic analysis has indicated. For vowels in /iq/, however, the SSANOVA results show no clear retraction, possibly due to a transient transition from /i/ to /q/. In sum, the present study provides acoustic and articulatory evidences showing that in Squliq Atayal, the high front vowel /i/ is lowered when followed by post-velar coda and this lowering may be resulted from articulatory gestures. We conjecture that the tongue root of /i/ is retracted possibly due to an anticipatory coarticulation. The fact that the retracted /i/ is not identical with /e/ acoustically and articulatory may provide important insight into the decision of writing system.

Keyword: Squliq Atayal, high vowel lowering, pharyngeal fricative, uvular stop, ultrasound

1. Introduction

High vowel in Squliq Atayal has been alleged to be lowered when occurring adjacent to pharyngeal and uvular consonants /h/ and /q/ (Egerod, 1966; Li, 1980; Lu, 2005; Rau, 1992). However, the direction of observed lowering effect is not consistent and the lowered vowel seems to be documented differently across studies, possibly due to dialectal difference or diachronic development. Intriguingly, although the earliest documentation of lowering effect in Atayal can be traced back to almost a century ago (Ogawa & Asai, 1935), we can still observe variations of this lowered vowel in more recent studies, showing that this lowering effect is not stable and the vowel may not have transformed to other phonemic vowels, such as /e/, as previous studies have suggested. Despite the divergent views on the vowel lowering effect, it remains unclear what exact factors trigger the vowel lowering because the documentations in previous studies were heavily based on auditory transcription with no further examination on its underlying mechanism.

In view of the lack of more detailed investigation, the present study addresses this issue by acoustic and articulatory analysis to further provide evidence for vowel lowering. Specifically, the high front vowel /i/ was examined when preceded or followed by /h/ and /q/ considering its higher variation than the high vowel /u/. Given the analyses of formant values and ultrasound images, the current study aimed to investigate whether the vowel lowering effect has an articulatory grounding (e.g., conflicting tongue gestures) and whether the final output of lowered vowel is distinguishable from other phonemic vowels. The acoustic results showed that F1 was higher for /i/ when followed by pharyngeal and uvular consonants, suggesting a vowel lowering effect. Crucially, this alternation was affected by syllable types because the vowel lowering only occurred in close syllables. This constraint is not reported in previous studies. Although the F1 was higher for /i/ followed by pharyngeal and uvular coda, it still differed with that of /ehV/ and /yaq/, suggesting that this vowel may still be distinguishable from phonemic /e/ and /ya/. Ultrasound data confirmed that for the vowel in /ih/, the tongue was more retracted toward the pharynx with a still clear palatal constriction, suggesting that the vowel quality of /i/ was affected by

the tongue gestures of following consonants, though remaining contrastive from another phoneme /e/ as acoustic analysis has indicated. For the vowel in /iq/, however, the SSANOVA results showed no clear retraction, possibly due to the transient transition from /i/ to /q/. In sum, the present study provides acoustic and articulatory evidence showing that in Squliq Atayal, the high front vowel /i/ is lowered when followed by post-velar coda and this lowering may be resulted from articulatory gestures. We conjecture that the tongue root of /i/ is retracted possibly due to an anticipatory coarticulation. Our finding that lowered mid vowel in /ih/ segment is discriminable from the phonemic /e/ in both acoustic and articulatory aspects may offer more insight into the orthographic representations of these words.

2. Literature review

Vowel lowering effect adjacent to post-velar consonants occurs in many Austronesian languages and is conditioned by syllable type (Blust, 2013). The most common pattern is for vowels in closed syllables to be lower than those in open syllables. For example, in the Uma Juman dialect of Kayan in Borneo, the high vowels are lowered before word-final glottal stop and fricative, such as *laki?* [lakeʔ] 'male' and *hivih* [hiveh] 'lower lip'. McDonnell (2008) also stated that in Besemah, a Malayic language in Sumatra, high vowels /i/ and /u/ are surfaced as [i] and [u] in open syllables, but undergo lowering to [e] and [o] when followed by glottal conditioning consonant [ʔ,h]. Although the vowel lowering in Atayal has not been reported to associate with syllable types in literature as will be discussed in below, our preliminary observations found that, at least for the dialect of our informant, the occurrence of vowel lowering is related to syllable types in a way similar to the abovementioned Austronesian languages. In this dialect of Squliq Atayal, the high vowel /i/ is lowered when followed by post-velar coda, whereas the underlying /i/ is realized in open syllables.

Studies of Austronesian languages in Taiwan have also reported similar vowel lowering effects of post-velar consonants. De Busser (2009) indicated that in Takivatan Bunun, the high front vowel /i/ is lowered when preceded or followed by a uvular stop /q/. In Bunun literature, although earlier studies have regarded Takivatan Bunun to have only three vowels(Chen, 2009; Li, 1988), later study claimed that the mid vowels /e, o/ should also be included as phonemic vowels (Jiang, 2012). However, these studies mainly relied on impressionistic transcription, so Chang (2020) investigated the acoustic features of high vowel /i, u/ and mid vowel /e, o/, specifically when these vowels are followed by /q/ in order to see whether the lowered high vowels are discriminable from those reportedly phonemic /e, o/. The formant results showed that high vowels were nearly neutralized to mid vowels for most of the tokens and thus provides acoustic evidence for the issues of phonemic mid vowels.

In Atayal, the vowel lowering occurs when the high vowel /i/ or /u/ is adjacent to the pharyngeal fricative /h/ and uvular stop/q/ (Egerod, 1966; Li, 1980; Lu, 2005; Rau, 1992). Similar to the problem in Bunun, although the vowel lowering effect in Atayal has been reported in several studies, the statements of this lowering effect have mainly been drawn from impressionistic transcription and the phonemic status of derived vowels /e, o/ still remains unclear. In fact, the high front vowel /i/ is not even reported to become /e/ in some studies. The studies that have reported vowel lowering effect for /i/ are listed in Table 1 with their observed environment and the final output of lowered vowel.

Table 1. Summary of previous studies on vowel lowering in Atayal

	/ih/	/hi/	/iq/	/qi/
Egerod (1966)	[iᵊ] or [iᵋ]	[ɛ]	[iᵊ]	[ɛ]
Li (1980)	[e]	[e]	-	-
Rau (1992)	-	-	[ɛᵊ]	[ɛᵊ]
Lu (2005)	[e]	[e]	[ja]	-

Although all of these four studies have indicated that /i/ is lowered when adjacent to either /h/ or /q/, it can be seen in Table 1 that not all combinations of /i/ and /h, q/ were provided with examples.

Furthermore, the outcome of vowel lowering is differently documented, some considered it to be a schwa insertion, others considered it to be a mid vowel, while still others suggested it as the combination of a glide and a low vowel. Another issue that was not clearly specified in these studies is that, if the lowered vowel was documented as [e], whether this derived mid vowel is identical to the phonemic /e/ in words such as *behuy* [behui] 'wind'. Despite not being specifically stated in the article, according to the symbols used in Li (1980), the lowered vowel in /ih/ or /iq/ segment is different with the phonemic /e/ derived from /ay/ in earlier pronunciations. On the other hand, Rau (1992) treated these two kinds of mid vowels both as the phonemic /e/.

In view of the lack of qualitative evidence to determine the occurring environment and the role of the lowered vowel, the present study aim to provide a more comprehensive explanation of the vowel lowering effect in Atayal by investigating the acoustic and articulatory aspects of high front vowel /i/ that is affected by the preceding or following post-velar consonants /h, q/.

3. Methodology

One native speaker of Squliq Atayal (Female, 52y) from Jianshi Township, Hsinchu county was recorded. This data was first transcribed in IPA and then analyzed in acoustic and articulatory analyses.

The transcription and acoustic analysis were based on recording using Zoom H4n Pro and the ultrasound data was collected using a portable ultrasound machine (CGM PUS5100) with a transvaginal electronic curved array probe (CLA 651). The informant sat upright wearing an Articulate Instruments (2008) ultrasound stabilization headset. The frame rate for the ultrasound videos was set at 40 fps for two recordings (containing /ih/, /ihV/, /hi/, /qi/, /ehV/, and /yaq/ segments, see below) and 25 fps for one recording (containing /iq/ and /iqV/ segments).

The stimuli consist of words containing one of the following eight segments: /ih/, /iq/, /ihV/, /iqV/, /hi/, /qi/, /ehV/, /yaq/. The /ihV/ and /iqV/ segments were selected to investigate whether /h, q/ in the next syllable also have effects on the high front vowel /i/ and if so, whether this effect is different from that of /h, q/ in coda position. The /ehV/ and /yaq/ segments were adopted due to our preliminary observations that vowels in /ih/ and /iq/ are likely to become [e] and [ja] for this dialect, so they are included for comparison. Initially, the /eh/ segment was considered to be included, but the /eh/ segment only occurs in two words and one of them may not even be a phonemic /eh/, but a /ih/ annotated as /eh/ (*sbzih*/*sbzeh*), so alternatively, the /ehV/ segment was adopted. Note that it is possible that the vowel in /ehV/ is not affected by the following pharyngeal fricative, since /h/ is the onset of the next syllable. In this case, it is more appropriate to regard /ehV/ segment simply as /e/ segment, which is nevertheless another possible baseline for the modified vowel in /ih/ segment. Additionally, for acoustic analysis, the nominative marker for proper noun *i* was included to serve as a baseline of vowel /i/. The full list of stimuli with the number of tokens is presented in Appendix A. Some examples are listed below:

(1)	/ih/	bzih	'to return'	/iq/	maniq	'eat'
	/ihV/	bzihi	'to return' (PV)	/iqV/	nniqun	'food'
	/hi/	hiti	'to reduce' (PV)	/qi/	sqitan	'to cut' (PV)
	/ehV/	behuy	'wind'	/yaq/	psyaq	'laugh'

These segments were first manually labeled in Praat (Boersma & Weenink, 2021) and Montreal Forced Aligner (McAuliffe, Socolof, Mihuc, Wagner, & Sonderegger, 2017) were used to complete speech-text alignment. Pretrained English model is used as the acoustic model for alignment. For the acoustic analysis, the aligned textgrids were imported back to Praat to calculate formants. All formant values were extracted from the midpoint of the labeled vowel interval by default formant settings of Praat, which is 5500 Hz maximum frequency, 5 formants, 25 ms window length, and pre-emphasis from 50Hz. After the formant values were extracted and averaged, t tests were done to compare the F1 and F2 values. These eight segments were divided into three groups: (1) /i/, /ih/, /ihV/, and /ehV/, (2) /i/, /iq/, /iqV/,

and /yaq/, (3) /i/, /qi/, /hi/. These groups were designed for testing lowering effect of /i/ respectively when /i/ is (1) followed by pharyngeal fricative, (2) followed by uvular stop, and (3) preceded by pharyngeal fricative or uvular stop. Group (1) and (2) compared the three segments with /i/ with each other and then compared /ih/ and /iq/ respectively with /ehV/ and /yaq/. Group (3) compared /qi/ and /hi/ with /i/.

As for the articulatory analysis, the aligned textgrids were imported to Matlab (2020b) for video annotation and image capturing. The tongue contours were then manually annotated and optimized using Getcontours (Tiede & Whalen, 2015). All tongue contours were also extracted from the midpoint of the labeled vowel interval. The annotation results were generated in the Cartesian coordinate system, but later fit and converted into polar coordinate through smoothing spline analysis of variance (SSANOVA) with a 95% confidence interval around the predicted fit (Davidson, 2006; Gu, 2013). The ultrasound data was recorded from three elicitations, but due to the lack of consistent reference for contours to align across three elicitations, the present study can only present comparisons of: (1) /iq/ and /iqV/, (2) /ih/, /ihV/, /hi/, and /ehV/.

4. Results

4.1 Observations from auditory transcription

Before looking at the acoustic and articulatory results, some patterns can be first recognized from the transcription. First, when the high front vowel /i/ was followed by a pharyngeal fricative /h/ or uvular stop /q/, it became [e] and [ja] respectively, as can be seen from the following examples:

(2)	tapih	[ta.peh]	‘to invite’
	squliq	[sɨ.qu.ljaq]	‘human’

However, this leftward effect is limited to particular syllable structures. When the following /h/ or /q/ was in the next syllable, these consonants did not lower the preceding vowel /i/. To illustrate, the following example shows the same words from (2) with additional suffixes starting with a vowel:

(3)	tapihi	[ta.pi.hi]	‘to invite (PV)’
	sqliqun	[sɨ.qə.li.qun]	‘to marry’

As can be seen, when the word-final consonant /h/ or /q/ was followed by a suffix -un or -i, it became the onset of the next syllable because of the preference of CV structure in Atayal. In this case, although the pharyngeal and uvular consonants were still adjacent to /i/, they showed no lowering effect on the vowel. Accordingly, it seems that the /h/ and /q/ have to be in the same syllable with the high front vowel for vowel lowering to occur. However, on the other hand, when /i/ was preceded by /h/ or /q/, which inevitably made /h/ and /q/ tautosyllabic with the vowel, as a result of preferring CV structure, most of the tokens showed no vowel lowering. This can be seen in (4) below. Consequently, the environment that triggers vowel lowering is not simply when /h/ and /q/ are in the same syllable with the vowel, but these consonants also have to be in the coda position of that syllable.

(4)	hit	[hit]	‘reduce’
	saqit	[saqit]	‘cut’

Intriguingly, few tokens containing /hi/ or /qi/ segment seemed to be pronounced differently, showing some degree of lowering effect especially when the words were carried in a full sentence. These words are listed in (5). When the informant was instructed to clearly articulate the word independently, these words were pronounced without vowel lowering, but when the informant was asked to say the sentence

containing these words in normal speed, the high front vowel /i/ was lowered to [e] for both /hi/ and /qi/ segments in some tokens.

(5)	hiya'	[heja]	‘they (3S.NOM)’
	'laqi'	[ələqe]	‘child/children’
	smaqis	[smaqes]	‘to sew (AV)’
	sqisan	[sɨqesan]	‘to sew (LV)’

In addition, /qi/ segment appeared to undergo vowel lowering more often than /hi/ segments. In fact, the word sqitan was always pronounced as [sɨqetan] and the informant also indicated that the alternative pronunciation, [sɨqitan], is not correct. This kind of exception has not occurred in any words with /hi/ segment in the present study, suggesting that vowel lowering may already have taken effect on some words with /qi/ segment but not on words with /hi/ segment. In addition, according to the informant’s experience and her own acceptability, it is acceptable to pronounce the vowel as [e] in several words with /qi/ segment, as in (6), but not in words with /hi/, consistent with the observation that /qi/ is more likely to generate vowel lowering than /hi/.

(6)	qiway	[qiway]	‘to cover’
		[qeway]	
	qibuw	[qibuw]	‘to plow’
		[qebuw]	
	saqis	[saqis]	‘to sew’
		[saqes]	

4.2 Acoustic analysis

Table 2 reports the mean formant values at the midpoint of vowel for each segment. The comparisons between these segments and their corresponding t-test results are presented in Figure 1, 2 and 3.

Table 2. Summary of mean formant (measured from vowel midpoints). Standard deviations are in parentheses.

	ih	iq	ihV	iqV	i	qi	hi	yaq	ehV
F1	602	600	388	440	389	432	405	646	527
	(70)	(108)	(20)	(65)	(78)	(40)	(36)	(96)	(24)
F2	2224	2251	2497	2324	2355	2287	2689	2067	2217
	(179)	(206)	(257)	(456)	(469)	(315)	(370)	(117)	(218)

First, as can be seen in Figure 1 (a), F1 of the vowel in /ih/ segment was significantly higher than that of the vowel in both /i/ and /ihV/ segments. On the other hand, the F1 of the vowel in /ihV/ segment was not significantly different from that of the vowel in /i/. These results are consistent with the observations from transcription, since in the previous section we have suggested that the vowel in /ih/ was lowered but that of /ihV/ was not. More importantly, although these results indicated that the vowel in /ih/ was lowered, the F1 for /ih/ condition was still significantly different from that of /ehV/ condition, further suggesting that /ih/ may still be distinct from phonemic /e/. In fact, the F1 for /ih/ was higher, suggesting that the vowel height was even much lower than that of /e/. As for the F2 values in Figure 1 (b), the same pattern can be observed for the three segments /i/, /ih/, and /ihV/. The F2 for /ih/ condition was significantly different from that of the other two segments /i/ and /ihV/, whereas there is no significant difference between /i/ and /ihV/ conditions. The F2 of the vowel in /ehV/ segment showed no significant difference with that of /ih/, suggesting that the vowels in /ih/ and /ehV/ only differed in height but not in backness.

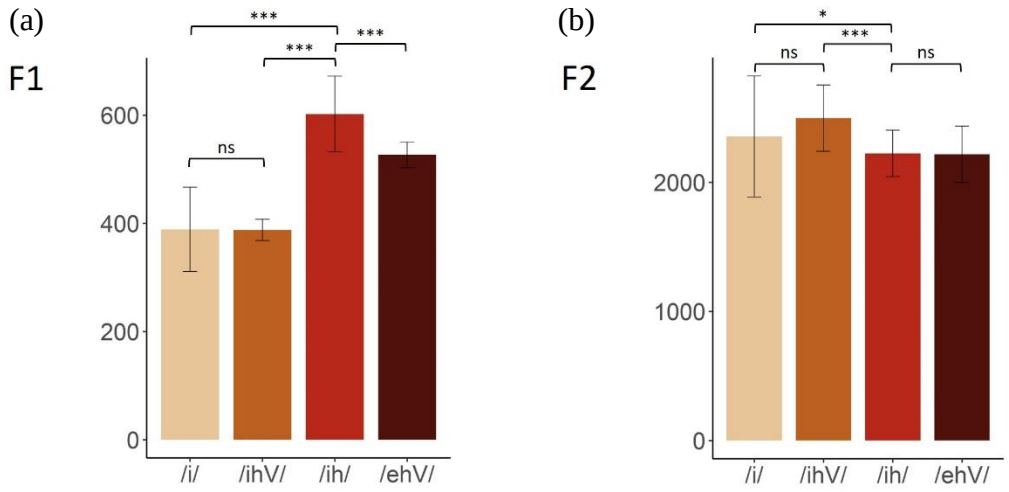

Figure 1. Mean F1 and F2 values for /i/, /ihV/, /ih/, and /ehV/ with corresponding t tests results

Figure 2 (a) presents the F1 results for /i/, /iqV/, /iq/, and /yaq/. Again, the F1 for /iq/ condition was significantly higher than that of /i/ and /iqV/ conditions, similar to what have been mentioned for /ih/. These results are also coherent with the observations from transcription, showing a lowering effect for the vowel in /iq/ segment. However, the F1 of /iqV/ condition was significantly higher than that of /i/, suggesting a lowering effect even for the vowel in /iqV/, which is not expected from our audio transcription. With regards to /yaq/ segment, when the F1 of /iq/ condition was compared with that of /yaq/ condition, there is a significant difference showing the F1 of /yaq/ was higher. This result shows that although the vowel in /iq/ was lowered, it may still be distinguishable from the phonemic glide and vowel combination [ja]. As for the F2 values presented in Figure 2 (b), pairwise comparisons between /i/, /iqV/, and /iq/ showed no significant differences, whereas the F2 for /iq/ condition was significantly higher than that of /yaq/. This latter significant result for /iq/ and /yaq/ again shows that the lowered vowel in /iq/ was still contrastive with phonemic [ja].

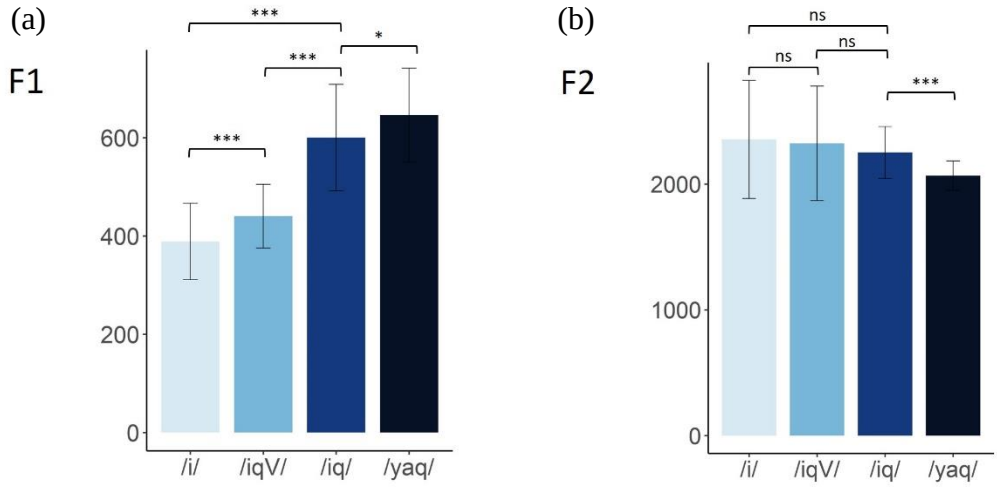

Figure 2. Mean F1 and F2 values for /i/, /iqV/, /iq/, and /yaq/ with corresponding t tests results

In the previous section, observations from transcription suggested that although most of words with /qi/ and /hi/ segments did not have vowel lowering effect, while the vowel in /qi/ is more acceptable than the vowel in /hi/ to become the lowered vowel [e]. This tendency was demonstrated in their F1 values, as can be seen in Figure 3 (a). Despite the F1 of both /qi/ and /hi/ conditions being higher than that of

/i/, only /qi/ showed a significant difference with /i/, suggesting a lower height for /i/ preceded by uvular stop. On the other hand, it can be seen in Figure 3 (b) that the mean F2 of /qi/ was not significantly different from that of /i/. However, the F2 result was somewhat unexpected for the /hi/ segment. The F2 of /hi/ condition was significantly higher than that of /i/, indicating that when the high front vowel /i/ is preceded by pharyngeal fricative, the tongue is pushed more forward than when it's alone.

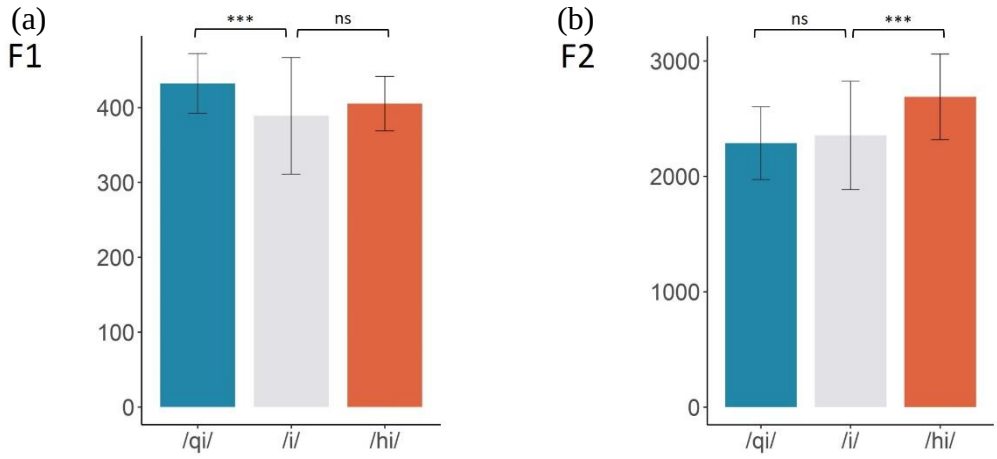

Figure 3. Mean F1 and F2 values for /i/, /qi/, and /hi/ with corresponding t tests results

In sum, results from acoustic analysis were in concordance with the observations from auditory transcription. The higher F1 values for both /ih/ and /iq/ segments as compared to F1 of single vowel /i/ suggests that indeed the high front vowel is affected by the following pharyngeal fricative and uvular stop. The results of /ihV/ and /iqV/ showed no significant difference with /i/ (except for the F1 of /iqV/, which can be justified by its significant difference with /iq/) further confirms that when the pharyngeal or uvular consonant is not in the same syllable with /i/, the lowering effect is not manifested and thus supports our conclusion in previous section that the high front vowel is lowered only when a pharyngeal fricative or uvular stop occurring in the coda position.

4.3 Articulatory analysis

The SSANOVA results are presented in Figure 4 and 5, with the tongue tip to the right of the figure. In Figure 4, it can be seen that the predicted fit of /ih/ (green line) was more retracted toward the pharynx in tongue root, while a clear palatal constriction can still be observed in the front part of the tongue, forming a double bunched tongue shape. In contrast, the fitted lines for /ihV/ and /hi/ (orange and yellow lines) showed no clear retraction and the peak of the contours were both higher than /ih/, confirming that pharyngeal fricative only shows lowering effect when it occurs in the coda position. Furthermore, the tongue contour for /ehV/ contrasted with that for /ih/ in height, but the direction of effect was not consistent with our acoustic result since the contour for /ih/ was higher instead of lower than that of /ehV/. Nevertheless, the current result still agrees with the idea that the lowered vowel in /ih/ is distinguishable from the phonemic [e] in /ehV/. Note that the fitted line for /ehV/ showed no clear retraction, suggesting that the vowel may not be affected by the following pharyngeal fricative, which is consistent with our concern mentioned in the method session, that the pharyngeal fricative has less influence on the [e] because it is the onset of the next syllable, so it may be more appropriate to regard the vowel of /ehV/ segment as single vowel /e/.

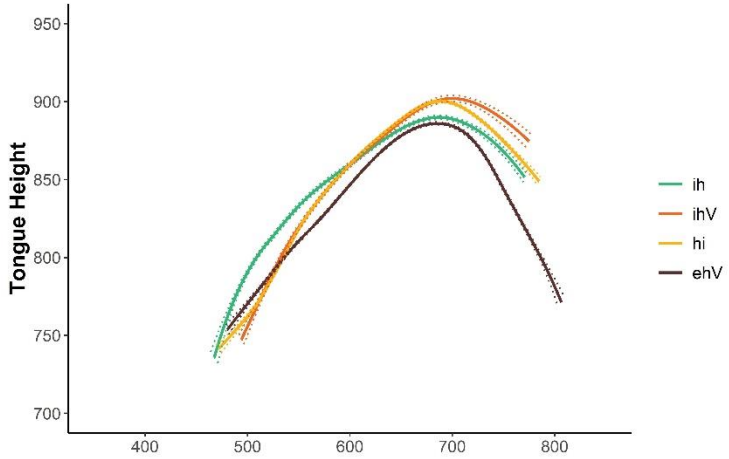

Figure 4. SSANOVA results for /ih/, /ihV/, /hi/ and /ehV/. Solid lines represent the predicted fits for the tongue contours and dashed lines around the fitted lines represent the 95% confidence interval. Tongue tip is on the right of the figure

On the other hand, the predicted fit for /iq/ showed no obvious difference with that for /iqV/, showing no lowering or retraction. This result is contrary to our expectation from auditory transcription and acoustic results indicating that the vowel in /iq/ was lowered than that of /iqV/. This unexpected result is possibly due to the transient transition from /i/ to /q/ and the fact that the frame rate of ultrasound videos for these two segments were 25 fps, making it more difficult to precisely capture the lowered tongue contours in the midpoint of the vowel. Nevertheless, the lowering effect can still be observed from the raw data of ultrasound images. The segment of /niq/ from one representative token of maniq 'to eat' is presented in Figure 6. As revealed by this figure, after the alveolar nasal closure of /n/, the underlying high front vowel /i/ was affected by following uvular stop /q/, showing a retraction of tongue root which consequently lowered the vowel, and then the tongue root was even higher and more retracted for the word-final unreleased /q/. Note that these contours are extracted from three consecutive frames, showing how rapid the tongue moved between constriction of /n/ to that of /q/ and further illustrate the difficulty to extract the tongue shape of lowered vowel in between.

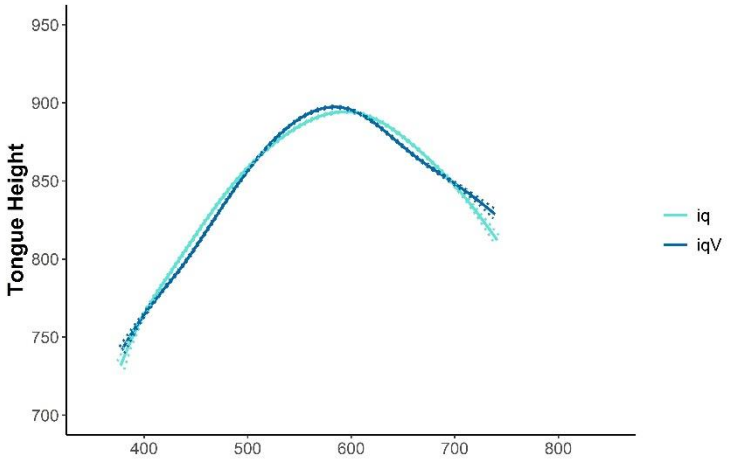

Figure 5. SSANOVA results for /iq/ and /iqV/. Solid lines represent the predicted fits for the tongue contours and dashed lines around the fitted lines represent the 95% confidence interval. Tongue tip is on the right of the figure

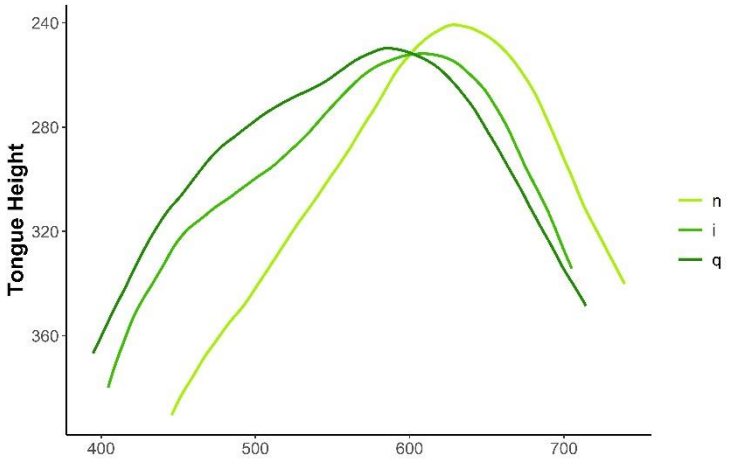

Figure 6. Raw tongue contours of /niq/ in maniq from three consecutive frames

5. Discussion

The present study investigated the vowel lowering effect of pharyngeal fricative /h/ and uvular stop /q/ in Atayal. Specifically, this paper focused on the lowering of high front vowel /i/ when occurring before or after /h /or /q/. According to auditory transcription, the high front vowel was lowered, as [e] and [ja], only when followed by pharyngeal or uvular coda. Nevertheless, some vowel lowering can also be observed for some tokens when /i/ is preceded by pharyngeal or uvular onset. In particular, the uvular onset seemed to be more acceptable than pharyngeal onset to elicit vowel lowering effect. As the acoustic results have revealed, the F1 values for /ih/ and /iq/ segments indeed were higher as compared to that of single vowel /i/, suggesting a vowel lowering effect consistent with our speculation. Furthermore, the vowel with uvular onset, rather than pharyngeal onset, showed a higher F1 than /i/. These results provided an acoustic evidence to support our observations that uvular onset is more likely to generate vowel lowering effect on following vowel. Moreover, the acoustic results additionally showed that the altered vowel for /i/ is still contrastive with phonemic /e/ and /ja/. As for the articulatory results, the lower, double-bunched tongue shape of /ih/ confirmed the lowering effect and its distinguishable status from [e]. However, the same pattern was not obtained from the tongue contour of /iq/, possibly due to its transient transition.

For the last point, the transient transition may not be the only reason why lowered tongue position was not captured in the present study. The exact timing of lowering may also interact with other factors such as stress, the preceding consonant, and even the beginning vowel of the next word. These factors were not controlled in the present study, which may further increase the variability of transition. Intriguingly, the same problem was not observed in the articulatory data for /ih/ segment. A straightforward explanation is that perhaps the pharyngeal consonant has different “demand” for the tongue movement from the uvular consonant. The constraints for /q/ may be stronger, especially because in the present study, the uvular consonant is a stop but the pharyngeal consonant is a fricative and a stop consonant requires a more complete constriction, thus resulted in a more rapid transition. Certainly, another apparent reason for the problematic articulatory data of /iq/ was that the frame rate was set at only 25 fps for this segment. In future study, besides controlling this technical issue, a possible solution is to look at the complete sequential movement of the tongue similar to what presented in Figure 6 and then fit these raw contours through SSANOVA, rather than just looking at the midpoint. Another improvement would be to include contours of /i/ as a baseline for our ultrasound study. For example, if our stimuli include /liq/ and /niq/ segments, then including words with segments /li/ and /ni/ can not only serve as a baseline for comparison, but the preceding consonants is also partially controlled.

Including the articulatory data of /i/ can also clarify whether the seemingly unaffected high front vowel in /ihV/, /ihq/, /qi/, and /hi/ indeed shows no vowel lowering.

Although the main focus of the present study is the /i/ followed or preceded by a /h/ or a /q/, an interesting exploration is to see what happens when the high front vowel is followed and preceded by a /h/ or a /q/ at the same time. In the current data, these following segments were also documented in the transcription:

(7)	/hiq/	twahiq	[twahjaq]	'far'
	/qih/	yaqih	[jaqeh]	'broken'
	/hihV/	hihip	[hihip]	'to lick'
	/qihV/	qihut	[qəhut]	'to obstruct'
		qihuy	[qehui]	'to dig'
		qihul	[qehun]	'to force sb. to do sth.'

Note that /qiq/ and /hih/ are not discussed here not merely because they were not included in our transcription, but in fact, none of the words in the online Atayal dictionary1 contains these segments.

As can be seen in (7), the /hiq/ segment in twahiq showed a lowering effect and the vowel turned into [ja], whereas the /qih/ segment in yaqih also showed vowel lowering and the vowel became [e]. These two observations are consistent with our conclusion that the pharyngeal and uvular codas have more influence on the vowel than the onsets, so the alternation for /hiq/ is identical with that of /iq/ and the one for /qih/ is identical with that of /ih/. As for the /hihV/, no lowering effect occurred, which is also consistent with previous results since if the second /h/ is followed by another vowel, it should become the onset of the next syllable and thus has less influence on the preceding vowel, and in addition, the pharyngeal onset is also indicated to have less influence on the vowel. In short, /hihV/ is like the combination of /hi/ and /ihV/, but none of these two segments have shown a strong vowel lowering effect.

The most intriguing part is about the /qihV/ segment. The vowel in /qihV/ was lowered to [e] for qihuy and qihul, whereas the vowel in qihut even turned into weak vowel [ə]. If /qihV/ is analyzed in a similar way as how /hihV/ is decomposed, it should be regarded as the combination of /qi/ and /ihV/ segments. Again, the /ihV/ has shown no clear vowel lowering effect, so the remaining /qi/ must be responsible for the lowering effect. However, only some tokens of /qi/ were pronounced with vowel lowering, different from what is observed here for /qihV/, in which all of the tokens (10 tokens for each word) showed a lowering effect. In other words, /qihV/ have a stronger vowel lowering effect than /qi/, despite they are both preceded by uvular onset. This is confirmed by the acoustic results of /qihV/, as in Figure 7, the F1 of /qihV/ was significantly higher than that of /qi/, but not significantly different from that of /ih/, the segment whose vowel was lowered as [e].

The only difference between /qihV/ and /qi/ is the following consonant in the next syllable, so it is appealing to suggest that the following pharyngeal onset also has slight lowering effect on the vowel in preceding syllable, but is not demonstrated when alone. When this weak effect is combined with that of /qi/, they together form a strong enough effect and thus influence vowel in all the tokens to be lowered. However, this issue is left for future research.

Another issue for future study is about words that seem to demonstrate vowel lowering, but the underlying vowel is never realized as a plain high front vowel /i/ in any situation. For example, the word

[1] The online dictionary (https://e-dictionary.apc.gov.tw/tay/Search.htm) maintained by the Council of Indigenous Peoples, Taiwan, R.O.C.

qulih ‘fish’ and roziq ‘eyes’ are pronounced respectively as [quleh] and [rozjaq], but these nouns are not succeeded by most of the, if not all, suffixes, so the vowel for these stems is always [e] or [ja], rather than /i/. In comparison with the word squliq ‘human’ [sɨquljaq], we know that the underlying vowel for this word is /i/ because when the stem is followed by the suffix -un, which is sqliqun ‘food’ [siqəliqun], the vowel returns to the high front vowel /i/. This raises the question about the orthographic representations of these words. Although these words are spelled with /ih/ or /iq/, perhaps suggesting that the phonemic /i/ is once realized, the vowel of these words may no longer be distinguishable from phonemic [e] or [ja]. In this case, the orthographic representations could be confusing for some Atayal users. However, if the vowel is still contrastive with the phonemic [e] or [ja] as our results have suggested, then there is important phonological concern to annotate the vowel as /i/ for these words. In fact, our informant suggested that to her, the vowel in qulih is still different from, for example, the first vowel of behuy. We have collected this kind of word with /iq/ spelling in the beginning of data collection, but later excluded due to the uncertainty of the orthographic representation’s validity. With more data of words with /ih/ spelling, the future study can further investigate the acoustic and articulatory quality of these words and provide more qualitative evidence for Atayal’s orthographic system.

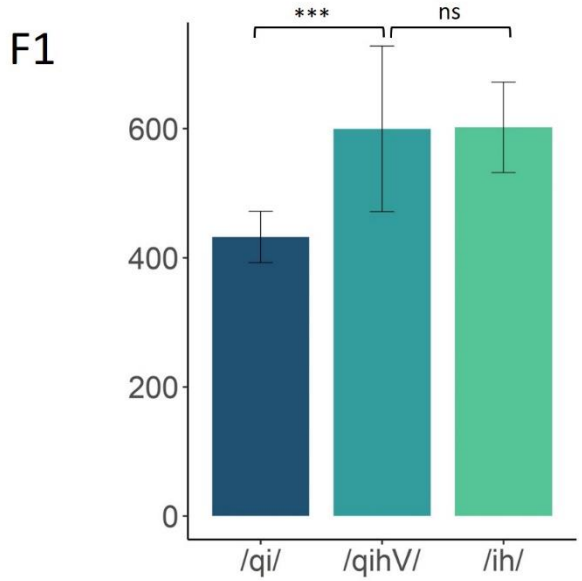

Figure 7. Mean F1 values for /qi/, /qihV/, and /ih/ with corresponding t tests results

Appendix

Orthography	meaning	Tokens
/ih/		
bzih	‘to return’	10
tapih	‘to invite’	10
bakih	‘to have a rash’	10
/iq/		
squliq	‘human’	13
maniq	‘to eat’	15
sgaliq	‘to tear’	21
mquriq	‘to steal (AV)’	19
biq	‘to give’	8
/ihV/		
bzihi	‘to return (PV)’	10
tapihi	‘to invite (PV)’	10
/iqV/		
sqliqun	‘to marry’	11
nniqun	‘food’	23
nniqan	‘the place to have meal’	4
sliqun	‘to tear (PV)’	13
qriqun	‘to steal (PV)’	21
biqi	‘to give (PV)’	15
/hi/		
bzihi	‘to return (PV)’	10
tapihi	‘to invite (PV)’	10
bahiy	‘to dry’	10
bhiran	‘to dry (PV)’	10
hit	‘to reduce’	11
hiti	‘to reduce (PV)’	10
hihip	‘to lick’	20 (two /hi/ segments)

hipan	‘to lick (LV)’	10
hrhil	‘saw’	10
hrhilan	‘to saw (LV)’	10
/qi/		
biqi	‘to give (PV)’	15
lqing	‘to hide’	20
lqingun	‘to hide (LV)’	10
qibuw	‘to plow’	14
qiway	‘to cover’	10
saqit	‘to cut’	10
sqitan	‘to cut (LV)’	11
psyaqi	‘to laugh (PV)’	10
/ehV/		
behuy	‘wind’	10
sehuy	‘taro’	10
tehuk	‘to arrive’	10
rehay	‘go to church’	9
/yaq/		
khzyaq	‘cold’	9
khzyaqan	‘to be freezed (LV)’	10
psyaq	‘laugh’	10
psyaqi	‘laugh (PV)’	10

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