A Preliminary Acoustic Study of Nasalized Vowels in Punjabi

Le Xuan Chan
International Christian University

1 Introduction

The Indo-Aryan language of Punjabi is widely spoken in Pakistan and India, as well as by immigrant communities found in other countries (Hussain et al., 2019). The sound system of Punjabi listed in Hussain et al. (2019), which reports on the Lyallpuri variety of Punjabi spoken in Pakistan, consists of of 42 phonemes, which are 10 vowels, 29 consonants, and 2 semivowels. In another study (Chan et al., 2020) both /a/ and /ɑ/ were found for low vowels, but it was concluded that [a] is a possible allophone for /a/, and it does not concern the present study.

Shackle (2003) reports on Modern Standard Punjabi (MSP) as spoken in India, but while there are differences between Indian Punjabi and Pakistani Punjabi, the vowels listed in Shackle (2003) is the same with that in Hussain et al. (2019). Of the 10 vowels, there are 3 central vowels /ɪ, ʊ, ə/ and 7 peripheral vowels /i, e, ɛ, u, o, ɔ, a/. Regarding nasalization, both Shackle (2003) and Hussain et al. (2019) report that nasalization of vowels is phonemic and contrastive but only for peripheral vowels. Central vowels such as /ɪ, ʊ, ə/ do not show oral and nasal contrast.

Both papers, however, do not discuss the acoustic properties and qualities of the vowels. Singh & Dutta (2011) provides a formant analysis on non-nasal, or oral vowels in Punjabi, but does not provide any information on the nasalized counterpart of these vowels.

What is absent from all these papers is a more in-depth acoustic analysis of nasalized vowels. Hence, this paper attempts to address that topic, investigating the acoustic cues for vowel nasalization in Punjabi, and comparing them with their oral counterparts.

2 Literature Review

One of the main acoustic properties of nasal sonorants such as /n/ and /ŋ/ are anti-resonances, otherwise known as "zeros", which manifest as a "dip" in the spectrum (Tabain, 2019). Even though they are sonorants and airflow is not completely stopped as it would for an obstruent, there is a noticeable loss of spectral energy due to the sinuses that exist within the nasal cavity. These characteristics can be applied to nasalized vowels as well, though because vowels themselves possess their own spectral identity, analysis of these characteristics becomes more complicated.

In House & Steven's (1956) model study of nasalized vowels, several cues were found for the nasalization of oral vowels. Firstly, the effect of damping is greater for nasalized vowels in comparison to their oral counterparts as the size of the nasal cavity is smaller than the oral cavity, and hence radiates lesser sound energy. This is supported by the loss of spectral energy seen in nasals as described above. Secondly, there is the presence of the aforementioned anti-resonances occurring at around 700-1800 Hz. These two cues are somewhat similar and expected as they are seen in nasal sounds as well.

Thirdly, vowel height has an effect on the degree of nasalization as well; The effect of nasalization on high vowels such as /i/ and /u/ were greater, while the effects of nasalization on low vowels such as /a/ were, with central vowels like /ɛ/ and /ɔ/ in between the two poles. This difference is ascribed to vowel identity - the tongue has to achieve a certain configuration for the produced sound to be recognizable as that sound. From the data, it can be inferred that the opening of the velopharyngeal port to induce nasality is achieved more easily for high vowels as compared to low vowels.

Fourthly, there occurs what House & Stevens (1956) describes as a "broadening and flattening of peaks in the vowel spectra" (p. 225). This description of the spectral shape is also seen in Maeda (1982), who reported a global flattening in the first and second formant region of the spectra. These reports are also matched in seen in Hattori et al. (1958), which described one of the cues for vowel nasalization in Japanese as the occurrence of "comparatively weak and diffuse components between the formants of the vowels", which took place particularly between 1000-2500 Hz.

Finally, there is the lowering of intensity of the first formant, F1. This was first proposed in Delattre (1954), and then confirmed in the simulation study performed in House & Stevens (1956).

In addition to the cues described above, Feng & Castelli (1996) proposed a "nasal target" that has to be achieved when producing nasalized vowels. The paper observed that the lowering of the velum to allow airflow into the nasal cavity results in a configuration similar to an /ŋ/ nasal consonant, and this configuration is the nasal target that is achieved and allows for a vowel to be perceived as nasalized. Hence, the paper conceptualizes the production of nasalized vowels as not a static configuration of the oral tract, but rather, a dynamic trend that begins with an oral configuration (presumably to perpetuate vowel identity) and ends in a configuration similar to the sound.

Hence, in the present paper, the questions regarding nasalized vowels in Punjabi are as follows:
1. Do anti-resonances occur at 700-1800 Hz?
2. Is there a lowering of intensity in F1 of nasalized vowels?
3. Is there a "flattening" of the spectra of nasalized vowels relative to their oral counterparts?
4. If the realization of nasalization takes place as a "dynamic trend", then are the effects of nasalization greater towards the end of the vowel?
5. Are there any noticeable differences between high vowels and low vowels in terms of nasalization?

3 Research Methodology

The language consultant of this paper is a male native Western Punjabi speaker in his 30s, from the town of Shezad in the Islamabad district of Pakistan. However, as Urdu is the official language in Pakistan, the medium of instruction for the consultant in school was Urdu until the 10th grade and English from then onwards. Hence, he uses Urdu and English in formal settings, and uses Punjabi in casuals setting amongst friends and family, and also with colleagues informally if they are also Punjabi speakers. It is worth noting that his father is a native speaker of the Pothowari dialect of Punjabi, though our consultant states that he himself is a native speaker of the standard variety of Punjabi.

All data collection was conducted remotely via elicitation sessions performed through online Zoom meetings, and the consultant was equipped with the necessary equipment. A TASCAM DR-100 MK-III recorder, set at 44.1 kHz with 16-bit depth, mono, was used to record the elicitation sessions from the consultant. The TASCAM recorder was connected to a head-worn SHURE WH30 unidirectional microphone with an XLR connector, which was worn by the consultant during the elicitations. The distance between the microphone and the mouth of the consultant was at around 10 cm.

The stimuli used in this paper are nasal minimal pairs as listed in p.10 of Hussain et al. (2019), which are shown below in Table 1.

Table 1: Minimal Pairs of Nasalized Vowels

	Oral Vowels	Nasalized Vowels
a	ga *'sing'*	gã *cow*
ɛ	hɛ *'is'*	hɛ *'What?'*
u	kəru *'he will do'*	kərũ *'I shall do'*
i	pʰəɽi *'grasped'*	pʰəɽĩ *'grasp (imperative)'*
ɔ	sɔ *'hundred'*	sɔ̃ *'sleep'*
u	t͡ʃu *'milking'*	t͡ʃũ *'from'*
e	t͡ʃupe *'sucked'*	t͡ʃupẽ *'suck (imperative)'*

The speaker was shown the list and asked to produce each word in isolation to confirm that he knew these Punjabi words. Sentences were then made up using each of these words, and care was taken to avoid any conjugation or inflections on the target words in order to preserve the minimal pairs as well as the nasal sounds in these words. There was a total of 16 sentences. The sentences were then randomized using Google Sheets and shown to the speaker during the elicitation sessions, and each sentence was repeated twice.

The recordings where then processed and visualized, and annotated using Praat (Boersma & Weenink, 2020). Waveforms, spectrograms, formant values, as well as spectral slices were captured, and the details of these sounds will be discussed below.

4 Results

Of the 7 minimal pairs taken from Hussain et al. (2019) shown in Table 1, the data elicited for 3 of those pairs were found to be unsuitable for analysis, which are shaded in the table below.

Table 2: Unusable Minimal Pairs

	Oral Vowels	Nasalized Vowels
a	ga *'sing'*	gã *cow*
ɛ	hɛ *'is'*	hɛ *'What?'*
u	kəru *'he will do'*	kərũ *'I shall do'*
i	pʰəɽi *'grasped'*	pʰəɽĩ *'grasp (imperative)'*
ɔ	sɔ *'hundred'*	sɔ̃ *'sleep'*
u	t͡ʃu *'milking'*	t͡ʃũ *'from'*
e	t͡ʃupe *'sucked'*	t͡ʃupẽ *'suck (imperative)'*

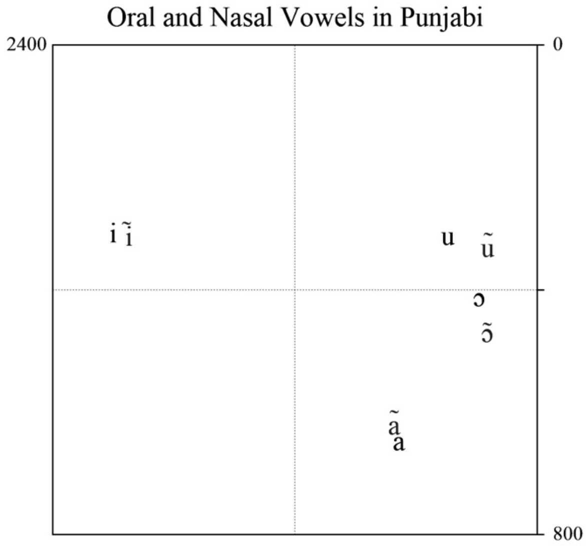
Firstly for /t͡ʃũ/ and /t͡ʃu/, as well as /t͡ʃupe/ and /t͡ʃupẽ/, different vowels were produced by the speaker. The oral counterpart of /t͡ʃũ/ was produced as /t͡ʃo/, while the nasal counterpart of /t͡ʃupẽ/ was produced as /t͡ʃupĩ/ instead. The change in vowel identity meant that spectral comparisons would be unsuitable for these vowels. In the case of /hɛ/ and /hɛ̃/, one (/hɛ/) is a copula used commonly as sentence-endings, while the other (/hɛ̃/) is an exclamation used to express incredulity, and hence it would be unfair to compare the acoustic qualities of these two words as one is usually slurred, shortened and produced with less intensity while the other is usually lengthened and produced with great intensity.

4.1 *Formant Values* Thus, the present study will focus on these vowels: /i/ and /ĩ/, /u/ and /ũ/, /ɔ/ and /ɔ̃/, and /a/ and /ã/, as shown in Table 2. Firstly, the F1 and F2 values of these vowels were recorded, and then plotted out on a vowel chart using Praat. The formant values are shown in Table 3 and vowel chart in Figure 1 shows the positions of these vowels as plotted out.

Table 3: F1 and F2 Values of Vowels

Vowel	F1	F2
i	310.86	2200.33
ĩ	315.02	2140.99
u	314.81	966.23
ũ	333.93	818.24
ɔ̃	414.76	848.47
ɔ̃	472.70	819.09
a	649.77	1147.13
ã	623.39	1164.87

Figure 1: Plots of Oral and Nasal Vowels in Punjabi



As can be seen, there is no significant difference between the F1 and F2 values of the nasalized vowels when compared to the oral vowels. When plotted, there is also no significant difference between the nasalized and oral vowels. Hence, it is possible to claim that place of articulation is not a cue for nasalization of vowels in Punjabi.

4.2 *Spectral Analysis* For spectral analysis, spectral slices were taken at two points of the nasalized vowels - initial and end - and at one point for their oral counterparts in the middle of the vowel. The spectrums for each vowel are shown and discussed below:

4.2.1 */a/ and /ã/*

Figure 2: Spectrum of /a/

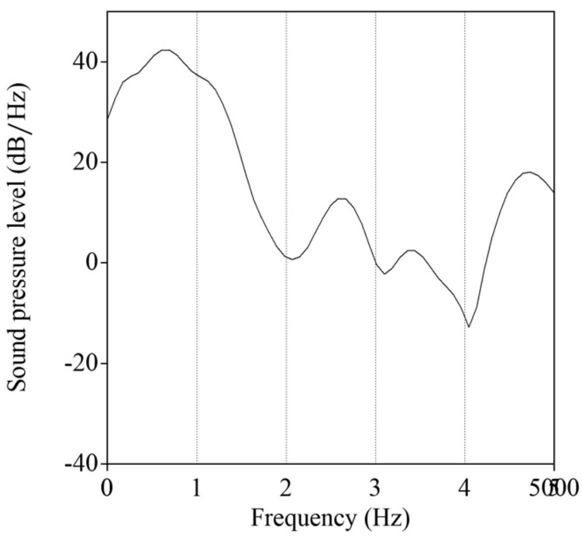


Figure 3: Spectrum of /ã/ initial

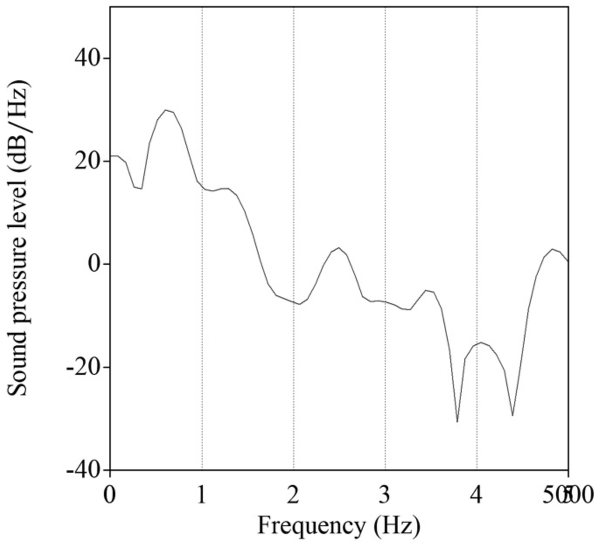
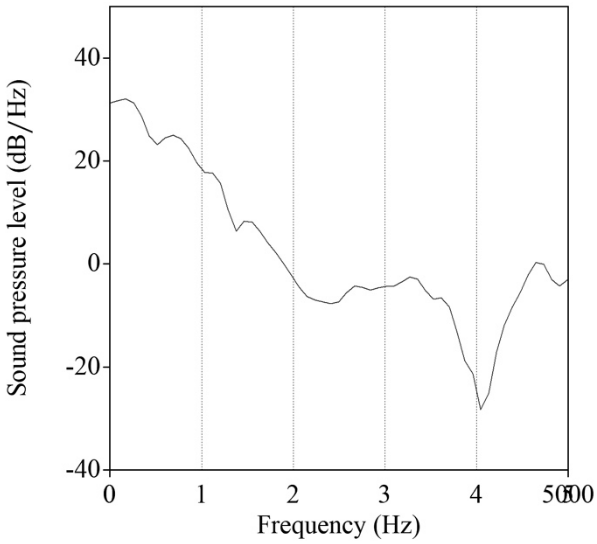


Figure 4: Spectrum of /ã/ end



As can be seen, the peaks in the spectrum of the oral /a/ is more well-defined than its nasal counterparts. The spectral slice taken at the beginning of the nasal /a/ does exhibit "broadening" and "flattening" as described by House & Stevens (1956). This flattening becomes more obvious at the end of the vowel, as seen in the third spectral slice. F1 intensity was 42.3 db for the oral /a/, 30 db at the beginning of /ã/, and 24 db at the beginning of /ã/. This is consistent with House & Stevens (1956), as intensity of F1 is lowered in the nasalized vowel compared to the oral vowel. Additionally, we see that intensity of F1 of the nasalized vowel is also lower at the end of the vowel compared to the beginning of the vowel. Anti-resonances around 700–1800 Hz, however, were not found in both spectral slices of /ã/.

4.2.2 */ɔ/ and /ɔ̃/*

Figure 5: Spectrum of /ɔ/

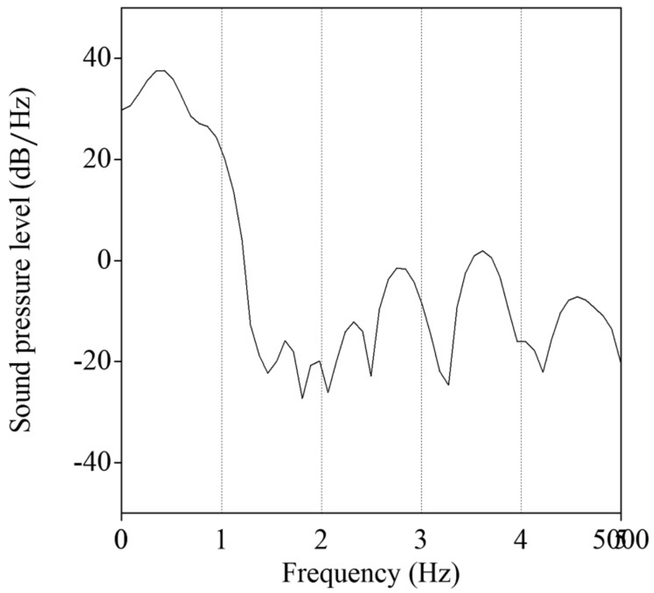


Figure 6: Spectrum of /ɔ̃/ initial

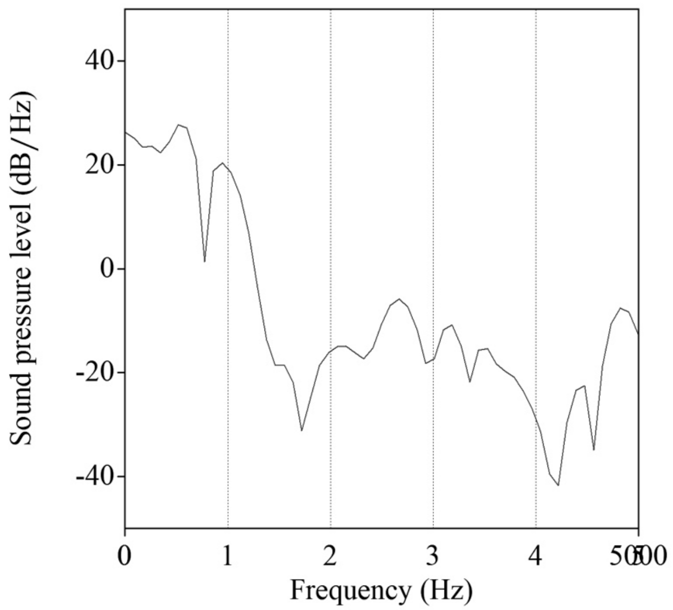
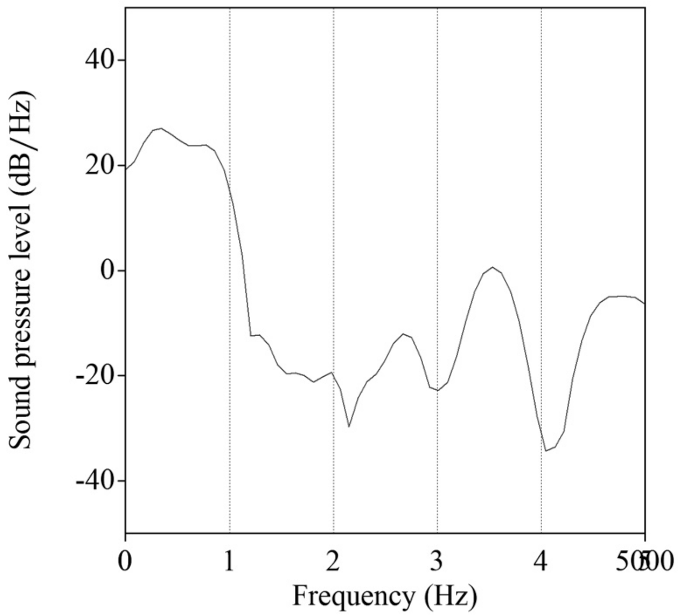


Figure 7: Spectrum of /ɔ̃/ end



Similar to the pattern seen in /a/ and /ã/, here we also see the flattening and smoothening of the peaks in /ɔ̃/ as compared to /ɔ/. The spectral slice taken at the end of /ɔ̃/ also shows more flattening than that taken at the beginning. Additionally, an anti-resonance occurred in the beginning of /ɔ̃/ at 864Hz. It is unsure whether the dips seen 1765 Hz in the beginning and 2104 Hz can be construed as anti-resonances, because they are also the non-resonant frequencies of the oral vowel. F1 intensity was the highest for /ɔ/ at 37.6 db, 27 db at the beginning and 26.7 db at the end of /ɔ̃/. Here, the F1 intensity difference between oral and nasalized vowel is seen, but the difference between the beginning and the end of the nasalized vowel does not seem to be significant, and as such, can be attributed to just natural loss of acoustic energy towards the end of the word.

4.2.3 */i/ and /ĩ/*

Figure 8: Spectrum of /i/

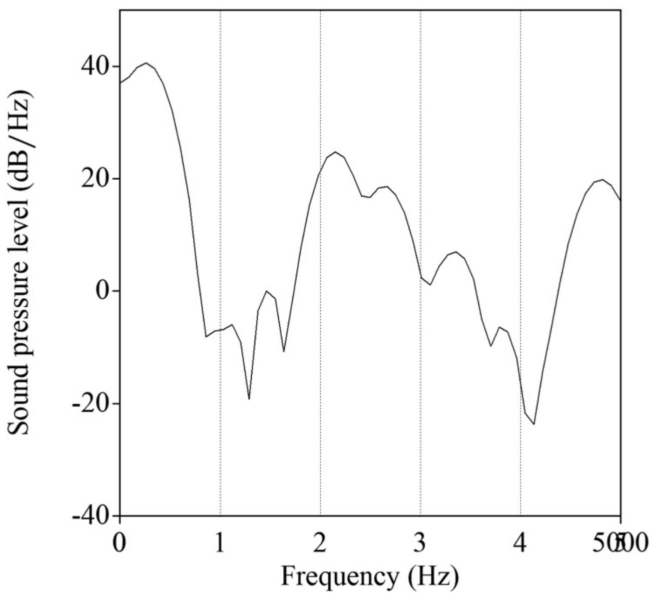


Figure 9: Spectrum of /ĩ/ initial

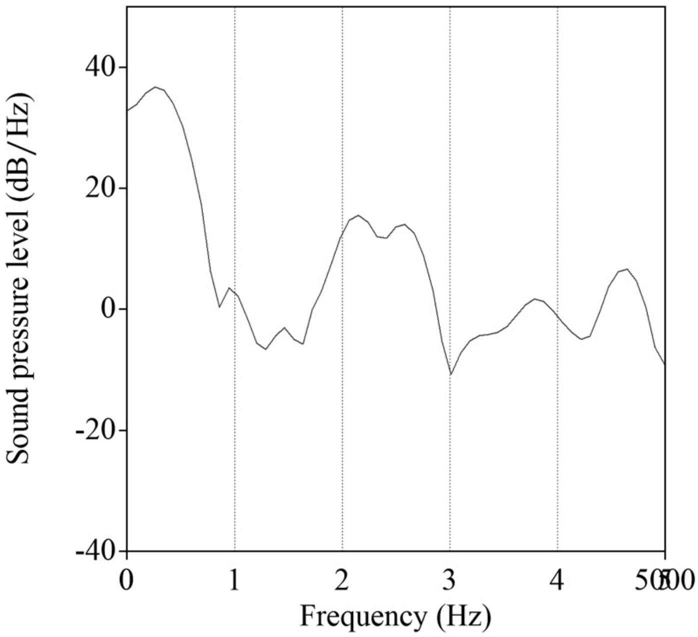
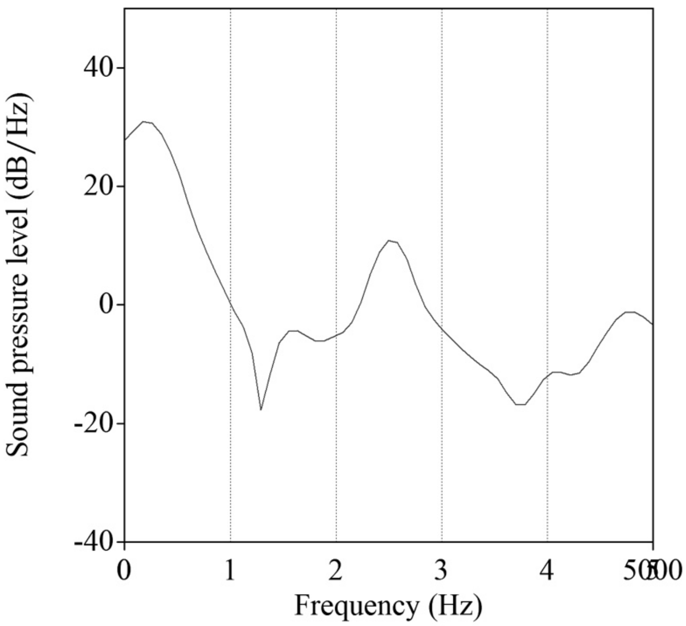


Figure 10: Spectrum of /ĩ/ end



The spectral slices shown here follow the same patterns are the previous 2 vowels. The peaks in the spectra of /i/ are more obvious well-define, whereas we see flattening and spreading in the beginning of /ĩ/, and even more at the end. There appears to be a dip in the spectrum at the end of /ĩ/, at 1291 Hz, but it is unsure whether this can be construed as an anti-resonance, as the frequencies around that region are non-resonant frequencies shown in the oral /i/. F1 intensity was again the highest for the oral /i/ at 40 db, 36.7 db at the beginning of /ĩ/, and 29 db at the end of /ĩ/.

4.2.4 */u/ and /ũ/*

Figure 11: Spectrum of /u/

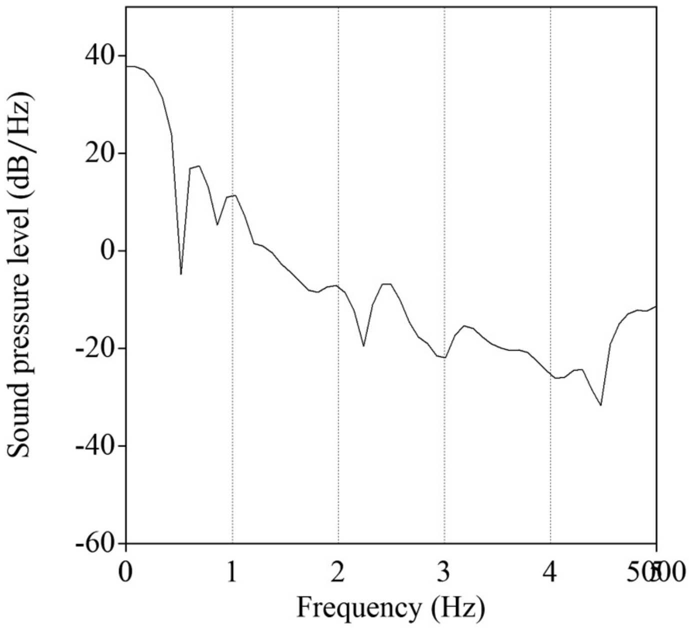


Figure 12: Spectrum of /ũ/ initial

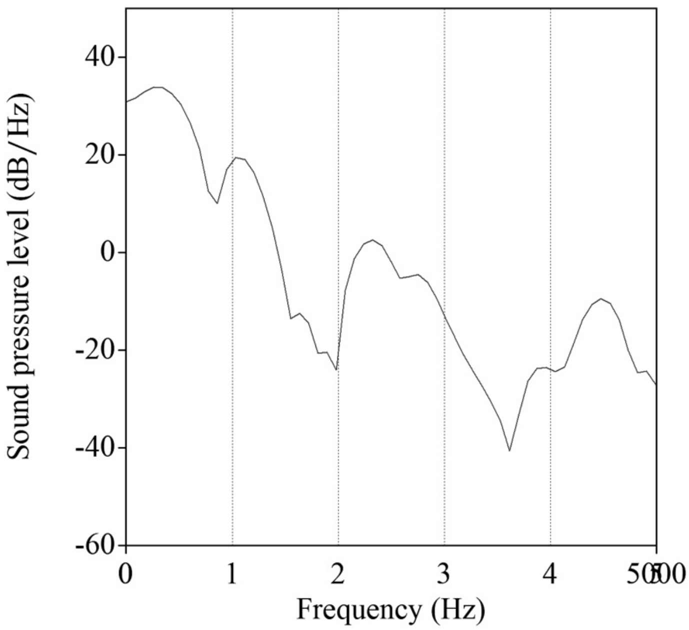
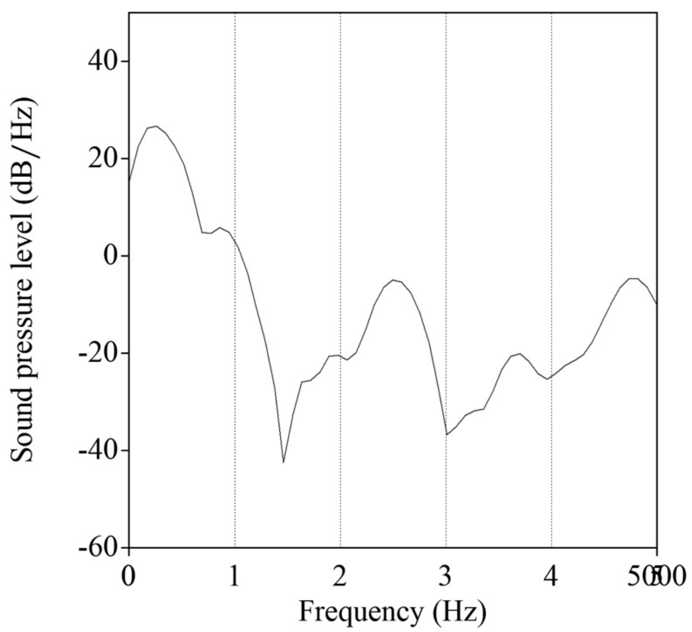


Figure 13: Spectrum of /ũ/ end



The shape of the spectra here display a pattern different to that seen in the 3 vowels above. In comparison to /ũ/, the peaks in the spectrum of /u/ are less defined. The spectrum at the end of /ũ/ does show some flattening in comparison to the beginning, but because the shape of the spectrum of the oral /u/, nothing conclusive can be said of the overall shape of the spectra. However, we do see an anti-resonance occurring in the spectrum taken at the end of /ũ/, at 1489 Hz. This dip is not seen in both the other spectra, and hence can be attributed to the effect of nasalization. The pattern of F1 intensity for this vowel remains the same as the previous vowels, with the highest for /u/ at 37.8 db, followed by 30 db at the beginning of /ũ/ and 24 db at the end of /ũ/.

4.3 *Overall Intensity* Overall intensity was also measured for these vowels. The mean intensity of the oral vowels were recorded for comparison, while intensity was recorded at three different points in the nasalized vowels - initial, middle, and end. The results are as below:

Table 4: Overall Intensity of Vowels

	Oral	**Nasalized Initial**	**Nasalized Mid**	**Nasalized End**
i	75 db	71 db	70 db	68 db
u	73 db	69 db	68 db	65 db
ɔ	72 db	69 db	68 db	66 db
a	71 db	70.4 db	70.3 db	69 db

As can be seen, overall intensity was higher for all oral vowels in comparison to their nasal counterparts, with differences ranging from 3-7db. Intensity also fell progressively for the nasalized vowels, with intensity highest at the beginning, and lowest at the end. The range of lowering was between 1-4 db. When comparing between oral and nasal configurations, overall intensity fell the least for central back vowel /ɔ/, a difference of 0.6-2 db. This is the case too when comparing nasalized initial with nasalized end, with a difference of 1.6 db.

4.4 *Vowel Length* The vowel lengths of these vowels were also measured and recorded. The results are as below:

Table 5: Vowel Length of Vowels

	Oral	**Nasalized**
i	205 ms	251 ms
u	105 ms	171 ms
ɔ	68 ms	110 ms
a	139 ms	148 ms

As can be seen, the vowel length for oral vowels were generally shorter than their nasal counterparts. Interestingly, the central back vowel /ɔ/ had the shortest difference at 9ms, while the other vowels had differences of around 40-60ms.

5 Discussion

In terms of cues for vowel nasalization in Punjabi, the only constant spectral property observed in all vowels was the lowering of intensity of the first formant, F1. The intensity of F1 was also lowered from vowel-initial to vowel-end for all nasalized vowels. The "broadening and flattening of peaks in the vowel spectra" as described by House & Stevens (1956) was observed in the nasalized versions of all vowels, with the exception of /ũ/. For the other vowels, this flattening was also seen to occur greater towards the end of the nasalized vowels. In terms of anti-resonance, anti-resonances were found at the end for all nasalized vowels except /ɔ̃/ and /ã/. For /ɔ̃/, the anti-resonance was observed in the initial part of the vowel. For /ã/, there were no anti-resonances observed. Though not all vowels had similar characteristics in the spectra, it can be postulated that all three cues examined in this study - F1 lowering, flattening of spectrum peaks, anti-resonances - are cues for nasalized vowels in Punjabi, with F1 lowering being the strongest cue. The reason for the differences in other areas might be attributed to different vowel qualities. The absence of an anti-resonance in /ã/, for example, might be attributed to its vowel height, as House & Stevens (1956) noted that the effect of nasalization is greater on high vowels and weaker on low vowels.

Overall intensity might be another strong cue for nasalized vowels in Punjabi, as nasalized vowels had lower intensities compared to their oral counterpart. This is also consistent with what House & Stevens (1956) states, that the effect of damping is greater in nasals than orals, because the nasal cavity is smaller and hence is a weaker resonator compared to the oral cavity. In addition, the presence of sinuses in the naval cavity only serve to dampen the signal more.

Vowel length might be another cue for nasalized vowels in Punjabi as well, as nasalized vowels were generally longer than their oral counterpart. One possibility of this is that nasalized vowels require more time to shift from the oral configuration to achieve the pharyngonasal configuration referred to as the nasal target by Feng & Castelli (1996). Although more data would be required to confirm the existence of such a nasal target in Punjabi, from the data shown above it is evident that the effects of nasalization were seen stronger towards the end of the nasalized vowels than the beginning. F1 was lower in the end than in the beginning for all nasalized vowels, and the flattening and spreading of formant peaks was also greater at the end. In addition, overall intensity of the nasalized vowels were also lower at the end than at the beginning. All this does seem to suggest that the configuration in the beginning of the nasalized vowels are more similar to that of an oral vowel, and nasalization takes place as the vowel progresses, which does lend support to Feng & Castelli's (1996) statement that vowel nasalization is a dynamic trend beginning in an oral configuration and ending in a pharyngonasal one.

The only possible exception to this notion, however, is seen in /ɔ̃/. As aforementioned, it is the only nasalized vowel that had an anti-resonance occurring in the beginning of the vowel, and F1 lowering did not take place between initial and end of the vowel. It was also shown in Table 4 and Table 5 that lowering of overall intensity was the least for /ɔ̃/, and the difference of vowel length between /ɔ/ and /ɔ̃/ was the shortest at only 9 ms. What this seems to suggest that the effects of nasalization take place early on in the initial stages of the vowel. This might explain the short vowel length difference of 9 ms; If the nasal target was already achieved early on in the vowel, there would be no need to lengthen the vowel. Perhaps, the early onset of nasalization for /ɔ̃/ is related to its position as a central vowel. However, more data is necessary to confirm this.

6 Conclusion and Future Considerations

In this study, comparisons were made between the oral and nasalized versions of 4 peripheral vowels in Punjabi, namely /a/, /i/, /u/, and /ɔ/. The results show that in Punjabi, F1 lowering, overall intensity lowering, and vowel lengthening are possible cues for nasalization in Punjabi. In addition, there is also evidence of other cues such as peak flattening in the spectra, as well as the occurrence of anti-resonances, but these cues might be affected and occur differently due to varying vowel qualities. It was also established that the effects of nasalization is greater towards the end of the nasalized vowels, with the exception of /ɔ̃/.

Due to unavoidable limitations, the present study only managed to study 4 out of 7 peripheral vowels in Punjabi, as produced by only one speaker. It would be worth studying the other peripheral vowels and their nasal counterparts as well in future studies, as well as increasing the number of speakers consulted to get a wider sample size. At present, this study provides results that suggest several cues for vowel nasalization in Punjabi, but a more complete experiment with more data would be required for a conclusive argument. A sonogram to measure nasal airflow during the production of nasalized vowels would also be worth conducting as part of a future study, as it would provide more concrete, physical evidence of nasality.

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