

## Comparative Acoustic-Phonetic Analysis of Retroflex Consonants of Some Indian Languages

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### ABSTRACT

Retroflexion is an important phonological category in many Indian languages. This paper puts forward an effort made to present the findings of acoustic characteristics of retroflex sounds that significantly describe and differentiate them from other sounds. The retroflex sounds /ɽ/, /ɽʰ/, /ɖ/, /ɖʰ/, /ɽ /, /ɽʰ/, /ɳ /, /ʂ/ are acoustically analysed for three Indian languages i.e. Hindi, Nepali and Punjabi. Selected words containing each of these consonants in embedded in VCV positions were recorded by 50 native male and female speakers of each of these three languages. Parameters such as spectral properties of burst, formant transition(shifts), duration etc. were analysed. It has been observed that the formants F2, F3 and F4 of the burst and adjoining transitions, particularly the rising of F2 and falling of F3, F4 are significant. The minimal differences between F2 and F3 values, strong release of burst, shorter duration of silence and VOTs are noteworthy. The retroflex sounds /ɽ /and /ɽʰ/ which appear in medial and final positions of any word are mostly heard as rhotic /r/. Some of the linguistic differences observed include /ɳ/ pronounced as /n/ and /ɽ/ as /r/ in Nepali whereas /ɽʰ/ pronounced as /ɖʰ/ in Punjabi.

Keywords: Retroflex, Formant transition, Acoustic-Phonetic analysis

### 1. INTRODUCTION

Hindi is known for its large consonant inventory that features a four way contrast for voicing and aspiration. This includes a full retroflex family of stops which contrasts with full dental stop series in addition to few more retroflex consonants [1,2,7]. The origin of retroflex is found in Sanskrit and consecutively other languages of Indo-Aryan family. Retroflex consonants are produced in a variety of forms depending upon the shape of the tongue. The tongue may be either flat or concave or even with the tip curled back. The point of contact on the tongue may be with the tip (apical), with the blade (laminar) or with the underside of the tongue (subapical) (refer **Figure 1**).

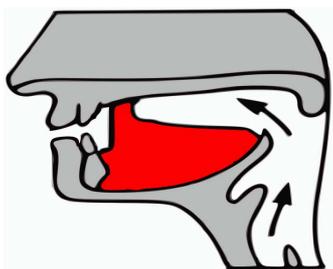
Hindi, Punjabi and Nepali belong to same language family i.e. Indo-Aryan. Punjabi language is spoken dominantly in the northern region of India, parts of Pakistan and also in few major countries like Canada. The stop consonant system of Punjabi is similar to that of Hindi and other Indo-Aryan languages, but the voiced aspirated series has been replaced by tones [9,17]. Nepali is primarily spoken in Nepal and in some regions of India and Bhutan. It has 20 obstruent's. Pokharel (2) claimed that the production of Nepalese retroflex stops is 'apico-alveolar', that is there is no curling backward movement of the tongue and the segment is articulated directly at the alveolar ridge, rather than further back in the vocal tract. This is in

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contrast to the most of Indo-Aryan retroflex stops. Hindi retroflex consonants are generally apical post alveolar, with a somewhat concave tongue.



**Figure1.** Articulation of retroflex consonants (1)

The main objective of the present study is to provide detail analysis of features of retroflex sounds and in this context measure the similarity and dissimilarity between three languages i.e. Hindi, Punjabi and Nepali. The paper is organized as: section 2 presents the methodology used for corpus design and analysis. The statistics of parameters and the results of analysis are presented in section 3. The conclusion of the work is presented in section 4.

## 2. METHODOLOGY

### 2.1 Design of Corpus

**Table 1** outlines the retroflex sounds of Hindi, Punjabi and Nepali used in this study. The sounds /t/, /t<sup>h</sup>/, /d/ and /d<sup>h</sup>/ are common to all the three languages. The sounds /r/ and /r<sup>h</sup>/ are special sounds that occur in Hindi only. The sounds /ɳ/, /ɽ/, /ɽ<sup>h</sup>/ does not appear in the initial position of any word in Hindi and Punjabi. The unvoiced fricative /ʂ/ is pronounced clearly in Hindi and not in other two languages. We have however, asked the speakers of Punjabi and Nepali also to utter these sounds in the VCV contexts and compared their characteristics with those of Hindi sounds.

**Table 1 – Retroflex of Hindi, Punjabi & Nepali**

Manner of Articulation	Hindi (L1)	Punjabi (L2)	Nepali (L3)
Unvoiced unaspirated plosive	/t/ <sup>८</sup>	/t/ <sup>੮</sup>	/t/ <sup>८</sup>
Unvoiced aspirated plosive	/t <sup>h</sup> / <sup>०</sup>	/t <sup>h</sup> / <sup>੦</sup>	/t <sup>h</sup> / <sup>०</sup>
Voiced unaspirated plosive	/d/ <sup>५</sup>	/d/ <sup>੫</sup>	/d/ <sup>५</sup>
Voiced aspirated plosive	/d <sup>h</sup> / <sup>६</sup>	/t/ <sup>੬</sup>	/d <sup>h</sup> / <sup>६</sup>
Voiced unaspirated nasal	/ɳ/ <sup>७</sup>	/ɳ/ <sup>੭</sup>	
Unvoiced aspirated fricative	/ʂ/ <sup>९</sup>		
Flap voiced unaspirated	/ɽ/ <sup>५</sup>	/ɽ/ <sup>੫</sup>	
Flap voiced aspirated	/ɽ <sup>h</sup> / <sup>६</sup>		

Guided by the aim of the study all retroflex consonants were embedded in the vowel-consonant-vowel context using three cardinal vowels /a/, /i/, /u/. The corpus was recorded by 50 native speakers of the languages under study. All the utterances were recorded on a portable sound recorder H4N and sampled at 16 bit, 44.1KHz sampling rate.

## 2.2 Acoustic Analysis:

The recorded samples were analysed using PRAAT and WAVESURFER Software. The desired words were first segmented and stored in separate files. The acoustic analysis consists of extracting formant frequencies at different positions along with durational measures in different vowel context. The value of formants have been measured at four different positions i.e. in steady state and terminating point of the preceding vowel, the beginning (during the burst of plosives) and the steady state of the following vowels, shown in **figure 2**.

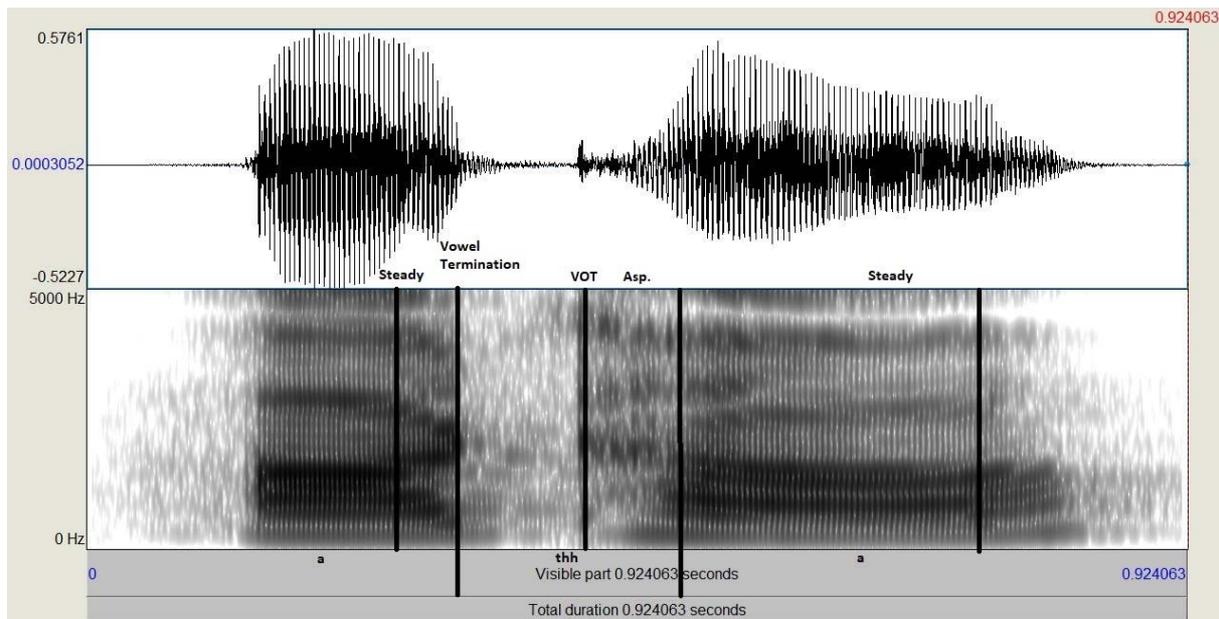


Figure 2- Measuring points of retroflexion characteristics (word a<sup>h</sup>a)

Pronounced by a male speaker

For durational measures the duration of gap, VOT duration, VOT along with aspiration and VOT with voiced aspiration have been measured for each retroflex sound.

## 3. Frequency Measurements and Results

For detailed analysis of acoustic parameters, the utterances were analysed using PRAAT and WAVESURFER software tools. Fig 3 shows spectrogram of the four stop retroflex consonant in VCV context. To obtain the steady state and formant values at the terminating points in the consonants, the formant measures are obtained for all the speakers in context of three vowels /a/, /i/, /u/. With the values obtained at four different positions the differences between F1, F2 i.e. (F2-F1), between F2 and F3 i.e. (F3-F2) and between F3 and F4 i.e.(F4-F3) is computed. These values are averaged over individual vowels. **Table 2** presents these values and the standard deviation at different position for three languages.

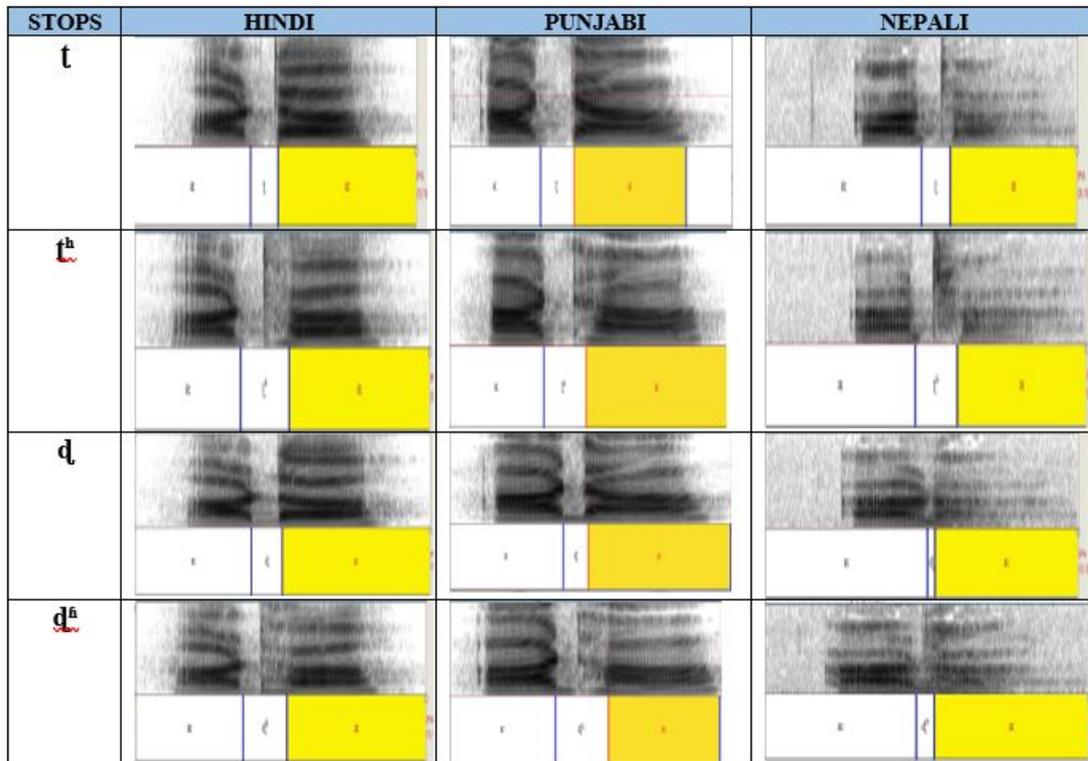


Figure 3- Spectrogram of stop consonants

The transition of formants in the preceding and following vowels are quite significant clues in the distinction of retroflex consonants, which distinguishes them from other categories of consonant sounds. It can be observed that the transition between F2-F3 and F3-F4 is the largest for Nepali followed by Hindi language, and is the smallest for Punjabi. It may be presumed that the degree of retroflexion in Punjabi is higher than Hindi and among the three Nepali has the least retroflexion. In particular, the rising of F2 and lowering of F3 and F4 in case of central and back vowels is evident from the spectrogram (refer **Figure 3**). In case of preceding vowel /a/ context, the formant F2 and F3 tend to merge with each other. This phenomenon is consistent in all the three languages.

**Table 2- Formant transition measurement of retroflex (stop consonants) in three languages**

Position	Transition	Language	/aa/	SD	/i/	SD	/u/	SD
P_SS	F2-F1	L1	400.98	14.50	1982.98	32.35	430.28	37.43
		L2	469.60	17.25	2371.81	62.49	336.74	112.06
		L3	595.51	60.93	1910.35	67.11	524.24	28.27
	F3-F2	L1	1353.19	46.85	315.28	109.23	1863.75	122.73
		L2	1452.50	30.55	454.11	40.07	1805.12	374.38
		L3	1505.36	150.27	607.17	445.21	1789.63	32.74
	F4-F3	L1	913.76	41.89	1235.64	235.55	1140.40	132.17
		L2	1378.29	75.27	773.62	35.59	1121.01	266.24

		<b>L3</b>	573.89	104.48	1684.87	403.8	1706.21	211.65
<b>P_V</b>	<b>F2-F1</b>	<b>L1</b>	987.92	82.84	1890.64	73.87	685.78	24.92
		<b>L2</b>	1273.59	84.86	2045.00	45.10	745.24	57.46
		<b>L3</b>	910.62	140.40	1587.21	237.92	720.66	47.18
	<b>F3-F2</b>	<b>L1</b>	640.88	352.71	397.11	30.45	1182.49	43.41
		<b>L2</b>	277.61	139.84	421.96	110.67	1088.39	206.33
		<b>L3</b>	643.45	308.20	467.72	243.69	1490.44	163.97
	<b>F4-F3</b>	<b>L1</b>	999.30	318.14	789.81	231.05	940.77	64.66
		<b>L2</b>	1347.42	88.63	363.01	71.46	940.32	89.24
		<b>L3</b>	1412.66	379.20	1582.13	148.33	1260.32	113.70
<b>F_V</b>	<b>F2-F1</b>	<b>L1</b>	851.33	184.10	1804.62	86.76	985.25	268.62
		<b>L2</b>	926.31	377.46	2278.58	111.91	669.49	162.90
		<b>L3</b>	815.78	123.29	2094.64	145.16	746.88	302.07
	<b>F3-F2</b>	<b>L1</b>	1025.74	124.82	515.98	70.27	1174.86	270.69
		<b>L2</b>	1135.18	187.56	483.53	44.98	1420.82	594.54
		<b>L3</b>	732.72	387.98	468.98	88.63	1273.88	62.71
	<b>F4-F3</b>	<b>L1</b>	1091.07	184.43	978.20	128.77	1105.31	91.42
		<b>L2</b>	1327.02	271.25	877.49	37.39	1078.74	136.33
		<b>L3</b>	1275.93	168.21	880.84	194.06	1260.16	217.50
<b>F_SS</b>	<b>F2-F1</b>	<b>L1</b>	552.66	41.76	1896.22	85.29	513.77	38.38
		<b>L2</b>	528.36	44.95	2392.19	31.52	492.49	16.31
		<b>L3</b>	597.51	58.01	1911.42	20.59	675.56	41.71
	<b>F3-F2</b>	<b>L1</b>	1164.05	110.57	499.59	30.14	1673.43	128.43
		<b>L2</b>	1180.01	143.48	389.00	49.99	1739.42	593.37
		<b>L3</b>	1499.09	125.15	921.68	177.09	1451.12	51.49
	<b>F4-F3</b>	<b>L1</b>	1126.80	77.79	1025.15	145.34	1240.61	120.96
		<b>L2</b>	1474.01	148.46	823.71	25.89	898.40	361.13
		<b>L3</b>	1014.19	76.01	1554.07	118.57	2086.29	483.14

*P\_SS = Steady state of previous vowel, P\_V = Termination of the previous vowel,*

*F\_V = Initial values at the following vowel, F\_SS = Steady state values at the following vowel.*

It can be further observed that the changes in formants and formant transitions of the retroflex consonants (belonging to same place of articulation) are only slightly affected by the changes in the manner of production of these consonants i.e. due to aspiration or voicing or voiced aspirations.

Fig. 4 shows the spectrogram of other retroflex consonants which appear in Hindi but not in Nepali. The sounds /ŋ/ and /ɽ/ appear in Punjabi also. We asked the speakers of all the languages to pronounce all these consonants. Measurements of formant frequencies at all the four positions (Fig. 2) were done for all the utterances. The major finding show that for Hindi speakers their characteristics match with the retroflex

category quite well and in Punjabi the characteristics of /ɳ/ and /ʈ/ matches also. However the sound /ʈʰ/ becomes closer to /ʈ/ and /ʂ/ becomes closer to /s/. Similarly in Nepali the sounds does not show their retroflex character and they become closer to other categories of sound e.g. /ɳ/ closer to /n/, /ʂ/ closer to /s/, /ʈ/ and /ʈʰ/ closer to /d/.

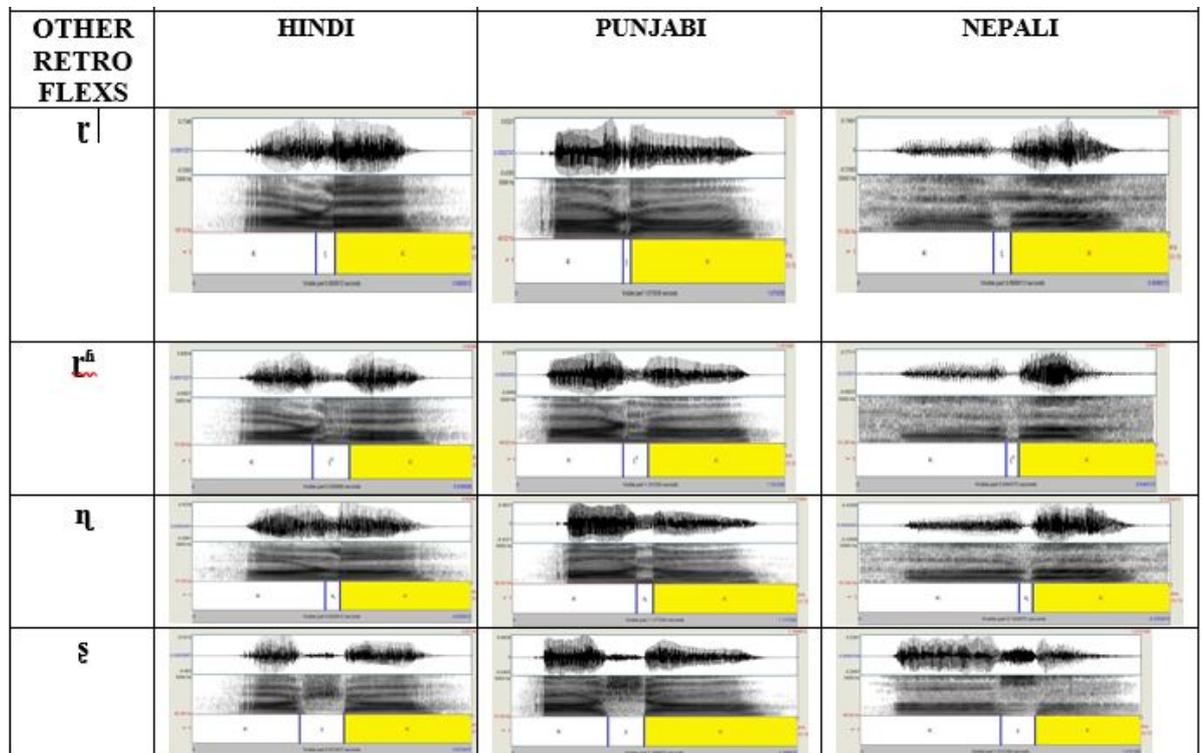


Figure 4- Spectrogram of other retroflex consonants

#### 4. Durational Measures and Results

In addition to frequency parameters several durational measures are obtained by averaging the values over the three vowels separately. The average total duration of gap and VOT/Aspiration for all consonants is same in different vowel contexts, presented below in Table 3.

Table 3- Average Total duration of stop consonants

Consonants	HINDI			PUNJABI			NEPALI		
	Gap	VOT+Aspiration	Total	Gap	VOT+Aspiration	Total	Gap	VOT+Aspiration	Total
ʈ	76.7	11.7	88.3	90.0	10.3	100.3	133.3	10.3	143.7
ʈʰ	63.7	63.3	127.0	86.0	71.3	157.3	106.0	63.0	169.0
d	71.3	7.0	78.3	66.3	9.0	75.3	117.0	7.0	124.0
dʰ	59.0	97.3	156.3	76.0	91.7	167.7	110.3	65.3	175.7
ʈ	59.7		59.7	40.7		40.7	104.5		104.5
ʈʰ	100.0		100.0	91.3		91.3	100.7		100.7
ɳ	63.0		63.0	91.3		91.3	45.5		45.5
ʂ	125.7		125.7	184.0		184.0	154.0		154.0

The detailed analysis of the durational measures under different conditions is outlined in Table 4. The analysis of retroflex duration highlights the dissimilarity among the languages.

Table4-Retroflex duration in three different languages

Durational Measures	Hindi (L1)	Punjabi (L2)	Nepali (L3)
Gap	ड (d̪) > ट (t) > ठ (tʰ) > ढ (dʱ)	ट(t) > ठ (tʰ) > ढ (dʱ) > ड (d̪)	ट (t) > ड (d̪) > ढ (dʱ) > ठ (tʰ)
VOT/VOT+ Aspiration	ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪)	ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪)	ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪)
Total Duration	ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪)	ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪)	ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪)

The total duration of retroflex consonants in VCV context shows that it is higher for Nepali followed by Punjabi and Hindi. It shows Nepali speakers take more time in articulating these consonants compared to the speakers of other two languages. However, duration follows the same order in all the languages i.e. ढ (dʱ) > ठ (tʰ) > ट (t) > ड (d̪). It is obvious that the duration of aspiration is much higher than the duration of VOT in unaspirated consonants. For other retroflex consonants studied the analysis outline the following relation in different languages: in Hindi, ष (/ʃ/) > ढ (/tʰ/) > ण (/ɳ/) > ड (/ɖ/), for Punjabi, ष (/ʃ/) > ढ (/tʰ/) > ण (/ɳ/) > ड (/ɖ/) and for Nepali, ष (/ʃ/) > ढ (/tʰ/) > ण (/ɳ/) > ड (/ɖ/).

The duration of fricative retroflex sound which is unvoiced sibilant having apical post alveolar articulation is higher than the other sounds. In Punjabi, the sound ष (/ʃ/) and ढ (/tʰ/) does not occur as retroflex sounds; ष (/ʃ/) becomes स (/s/) and ढ (/tʰ/) is generally replaced by ड (/ɖ/). Hence their properties do not match with retroflex consonants. Similarly in Nepali, these sounds are not pronounced as retroflex sounds but ष (/ʃ/) as स (/s/) and ढ (/tʰ/) as ड (/ɖ/) somewhat closer to ढ (/d/) and ड (/ɖ/).

## 5. Conclusions

The Articulation of the retroflex sounds is very clearly reflected in their acoustic characteristics and the co-articulation effects in proceeding and following vowels. These Characteristics can be distinguished from the other categories of sounds such as dental etc. In particular the position of the burst frequencies, transition of the formants of the previous and following vowels particularly of second, third and fourth formants show very specific transition associated with retroflex consonants. In particular F2 rising and F3 and F4 falling in all cases for all the languages.

These observations are in agreement with the results reported earlier by references [14,15] for Hindi and [47] for Nepali and [17] for Punjabi. There are some differences among Hindi, Punjabi and Nepali. While all the three languages have all the four retroflex stops, our results have shown that the other retroflex sounds which appear in Hindi but not in other languages show their characteristics as non-retroflex consonants. For example the nasal retroflex /ɳ/ appears to be closer to /n/ and /ʃ/ closer to /S/, /ɽ/ and /tʰ/ closer to /d/ in Nepali. Similarly /ʃ/ appears to be pronounced as /s/ in Punjabi, which indicates that Nepali speakers articulate these sounds slower than the other two languages.

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