Original Research Article

Study of Fractional Deviation of Resonating Length of Vocal Track for Different Vowels

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Abstract

The vocal tract is an acoustical tube, which has been estimated from the resonant properties of a tube. The fractional deviation is the deviation of the actual vocal tract length from the resonating vocal tract length. In this paper, we have studied the estimation of fractional deviation of effective resonating length of the vocal tract for different vowels. First, measure the formant frequency of different vowels of Garhwali (Hindi) and Nepali speakers. The calculated value of the resonating length of the vocal track and the fractional deviation of effective resonating length for different vowels are estimated. The average length of the vocal tract of Nepali and Garhwali (Hindi) male speakers is 17.70 cm and 18.12 cm, and for female speakers, 15.28 cm and 15.02 cm, respectively. The average ratio of the length of the vocal tract of male to female speakers is 1.16 and 1.21 for Nepali and Garhwali (Hindi) speakers. The fractional deviation of central vowels /a/ and /ʌ/ have a great value, but fronts (/i/, /ɪ/, /ɛ/, /e/) and back (/ɔ/, /o/, /ʊ/, /u/) vowels have the lowest values.

Keywords: Vocal tract, Resonating, Front, Central, Back, Vowels, Speakers, Fractional deviation

Introduction

The vocal tract is an acoustical tube having a non-uniform cross-sectional area. This is terminated by the lip at one end and the vocal cord constriction at the top of the trachea at the other end. Variation of speech production also depends upon the length of the vocal tract. This length also varies with age and grows, approximately from 8 cm at birth to 16 cm in adulthood [1–3]. The approximation variation of length of the vocal tract of adults from 13 cm to 20 cm. The cross-sectional area in the forward portion of the tract can be varied from zero to upwards of 20 cm^2. The length of the vocal tract is fully comparable to the wavelength of sound in air

at audible frequencies. Voice sounds are produced due to the vibration of the vocal cord. Vowel sounds are produced by excitation of the vocal tract. The resonance frequency of the oral part of the vocal tract is called Formant frequency [4,5].

In speech perception, the vocal tract length normalization is done, and descriptive studies of language phonetic systems rely on vowel normalization algorithms to compare speech produced by different talkers or groups of talkers [6]. The acoustic consequences of vocal tract length differences are removed from vowel measurements by scaling vowel formant measurements by ΔF [7]. The vocal tract length is the second largest source of formant frequency variability overall after phonemic identity, accounting for up to 18% [8]. The estimation of the spacing of successive formant pairs has been shown to correlate well with both vocal tract length and body size in human males [9]. It has been used extensively in the literature as a predictor of body size in a variety of other animals, including domestic dogs [10], rhesus macaques [11], red deer [12], and colobus monkeys [13]. The length of the vocal tract is a dynamic characteristic that changes over short timescales due to the shape of a tongue, lip rounding, and height of the larynx. By the articulatory model, the vocal tract length for adult males was 16.93 cm, and for females, 14.10 cm was measured [14]. The length of the vocal tract is a static character that is invariant for a given speaker and can be measured.

The present study focuses on the estimation of vocal tract length for different vowels from formant frequency, F_1.

Theory

The velocity of sound for the speaker is:

$$v = v_0 + 0.6\,x\,\theta \tag{1}$$

where v_0 be the speed of sound (331m/s) at 0 °C and θ be the temperature of the body (37 °C).

Vocal tract length is estimated from the resonant properties of a tube which is assumed to be lossless and uniform in cross-sectional area along its length, with glottal termination and radiation impedance being idealized.

The relation between formant frequency and vocal tract length under this condition is:

$$L = \frac{(2n-1)\,v}{4F_n} \tag{2}$$

where n = 1, 2, 3, 4, ... and L is the length of the vocal tract, v is the speed of sound and F_n be the n^{th} formant frequency.

For n = 1, the first formant frequency, F_1 is the first—resonance frequency of a lossless uniform vocal tract of length L. The term length represents the distance along the longitudinal axis of the vocal tract, which is extending from the glottis to the lips given by

$$L = \frac{v}{4F_1} \tag{3}$$

Considering the vocal tract as a closed organ pipe, the frequency of fundamental mode gives the first formant frequency.

If δ is the fractional deviation of actual frequency F from the resonating frequency F_r then

$$\delta = \frac{F - F_r}{F_r} \tag{4}$$

where F is the actual frequency and F_r is the resonating frequency then,

$$F = \frac{v}{4L} \tag{5}$$

and

$$F_r = \frac{v}{4L_r} \tag{6}$$

$$\delta = \frac{L_r - L}{L} \tag{7}$$

This equation gives the fractional deviation (δ) of actual vocal tract length L from the resonating vocal tract length, L_r.

Subjects

Twenty subjects (10 males and 10 females) of 20-30 years (adult) were considered. These 20 subjects were selected on the criteria that they had the Garhwali dialect of Hindi as their mother tongue, were able to read Garhwali, and had normal speech, language, and hearing functions.

Table 1 Classification of Nepali and Garhwali (Hindi) vowels

	Front		Central	Back	
High	I, i				U, u
Mid		e, ɛ		O, Ɔ	
Low			Λ, a		

Test materials and Procedure

In the present study, the ten vowels of the Garhwali Hindi language as listed in Table 1, i.e., /ʌ/, /a/, /ɪ/, /i/, /ʊ/, /u/, /e/, /ɛ/, /o/ and /ɔ/ were analyzed. The vowels were in the environment of 15 consonants /p, p^h, b, b^h; t, t^h, d, d^h; ʈ, $ʈ^h$, ɖ; k, k^h, g, g^h/ the test material consists of a list of 150 meaningful monosyllabic words with a /VC/ formant. Each test word consisted of one of the 10 vowels as V and one of the 15 consonants as C, and each of these sentences was written on flash cards.

At first, we calculate the velocity of sound at 37 °C (body temperature). Then, by measuring the formant frequency of different vowels with the help of Praat software, we calculate the length of the vocal tract.

Results and Discussion

The length of the vocal tract for a different vowel is calculated with the help of their first formant frequency and sound velocity at human body temperature. The respective lengths of the vocal tract for Nepali and Garhwali male speakers for different vowels are explained in Table 2 as follows.

For front vowels, /i/ = 21.83 cm, 21.66 cm, /ɪ/ = 21.15 cm, 20.99 cm, /ɛ/ = 18.04 cm, 19.29 cm, /e/ = 17.26 cm, 19.01 cm. For back vowels, /ɔ/ = 17.33 cm, 17.26 cm, /o/ = 17.75 cm, 17.61 cm, /ʊ/ = 18.34 cm, 20.09 cm, /u/ = 18.73 cm, 19.77 cm, and central vowels /a/ = 12.57 cm, 12.06 cm and /ʌ/ = 14.01 cm, 13.45 cm.

Table 2 Average value of formant frequencies and vocal tract length (VTL) of Nepali and Garhwali Hindi vowels for male speakers

Classification	Vowels	For Nepali Speakers		For Garhwali (Hindi) Speakers		Correlation of formant frequency	Correlation of VTL
		F_1	Vocal tract length (cm)	F_1	Vocal tract length (cm)		
Front vowel	/i/	405	21.83	408	21.66	0.97	0.96
	/ɪ/	418	21.15	421	20.99		
	/ɛ/	490	18.04	465	19.29		
	/e/	512	17.26	458	19.01		
Central vowel	/a/	703	12.57	733	12.06		
	/ʌ/	631	14.01	657	13.45		
Back vowel	/ɔ/	510	17.33	512	17.26		
	/o/	498	17.75	502	17.61		
	/ʊ/	482	18.34	440	20.09		
	/u/	472	18.73	447	19.77		

The correlation of vocal tract length (VTL) between Nepali and Garhwali (Hindi) male speakers is 0.96, and for female speakers is 0.98. The fractional deviation of VTL from the average value of the vocal tract of Nepali and Garhwali male speakers is explained in Table 3 as follows. For front vowel /i/ = -0.23, -0.22, /I/ = -0.20, -0.20, /ɛ/ = -0.06, -0.11, /e/ = -0.02, -0.12. Back vowels /ɔ/ = -0.02, -0.02, /O/ = -0.05, -0.04, /U/ = -0.08, -0.16, /u/ = -0.01, -0.14, and central vowels /a/ = 0.35, 0.40 and /ʌ/ = 0.21, 0.26, respectively.

Table 3 Fractional deviation of the average value of vocal tract length of Nepali and Garhwali Hindi vowels of male speakers

Classification	Vowels	For Nepali Speakers		For Garhwali (Hindi) Speakers		Correlation of fractional deviation
		Vocal tract length (cm)	Fractional Deviation	Vocal tract length (cm)	Fractional Deviation	
Front vowel	/i/	21.83	-0.23	21.66	-0.22	0.97
	/I/	21.15	-0.20	20.99	-0.20	
	/ɛ/	18.04	-0.06	19.29	-0.11	
	/e/	17.26	-0.02	19.01	-0.12	
Central vowel	/a/	12.57	0.35	12.06	0.40	
	/ʌ/	14.01	0.21	13.45	0.26	
Back vowel	/ɔ/	17.33	-0.02	17.26	-0.02	
	/O/	17.75	-0.05	17.61	-0.04	
	/U/	18.34	-0.08	20.09	-0.16	
	/u/	18.73	-0.10	19.77	-0.14	
	Avg.	17.70	-0.04	18.12	-0.07	

From Table 4, the length of the vocal tract of female speakers of Nepali and Garhwali speakers for front vowels /i/ = 19.51 cm, 18.42 cm, /I/ = 18.85 cm, 18.08 cm, /ɛ/ = 14.59 cm, 15.53 cm, /e/ = 14.30 cm, 14.73 cm. For back vowels /ɔ/ = 15.19 cm, 14.26 cm, /O/ = 15.37 cm, 14.78 cm, /U/ = 16.80 cm, 16.93 cm, /u/ = 16.71 cm, 16.71 cm, and central vowels /a/ = 9.88 cm, 9.55 cm and /ʌ/ = 11.65 cm, 11.23 cm.

Table 4 Average value of formant frequencies and vocal tract length (VTL) of Nepali and Garhwali Hindi vowels for female speakers

Classification	Vowels	For Nepali Speakers		For Garhwali (Hindi) Speakers		Correlation of formant frequency	Correlation of VTL
		F_1	Vocal tract length (cm)	F_1	Vocal tract length (cm)		
Front vowel	/i/	453	19.51	480	18.42	0.99	0.98
	/I/	469	18.85	489	18.08		
	/ɛ/	606	14.59	569	15.53		
	/e/	618	14.30	600	14.73		
Central vowel	/a/	895	9.88	926	9.55		
	/Λ/	759	11.65	786	11.23		
Back vowel	/Ɔ/	582	15.19	620	14.26		
	/O/	575	15.37	598	14.78		
	/U/	526	16.80	522	16.93		
	/u/	529	16.71	529	16.71		

Table 5 Fractional deviation of the average value of vocal tract length of Nepali and Garhwali Hindi vowels of female speakers

Classification	Vowels	For Nepali Speakers		For Garhwali (Hindi) Speakers		Correlation of fractional deviation
		Vocal tract length (cm)	Fractional Deviation	Vocal tract length (cm)	Fractional Deviation	
Front vowel	/i/	19.51	-0.28	18.42	-0.23	0.98
	/I/	18.85	-0.25	18.08	-0.23	
	/ɛ/	14.59	-0.03	15.53	-0.10	
	/e/	14.30	-0.02	14.73	-0.04	
Central vowel	/a/	9.88	0.43	9.55	0.48	
	/Λ/	11.65	0.21	11.23	0.25	
Back vowel	/Ɔ/	15.19	-0.07	14.26	-0.01	
	/O/	15.37	-0.08	14.78	-0.05	
	/U/	16.80	-0.16	16.93	-0.17	
	/u/	16.71	-0.16	16.71	-0.16	
	Avg.	15.28	-0.08	15.02	-0.06	

The correlation of fractional deviation of VTL between Nepali and Garhwali (Hindi) male speakers is 0.97. From Table 5, the fractional deviation of VTL from the average value of a vocal tract of female speakers of Nepali and Garhwali speakers for front vowels /i/ = -0.28, -0.23, /I/ = -0.25, -0.23, /ɛ/ = -0.03, -0.10, /e/ = -0.02, -0.04. Back vowels /ɔ/ = -0.07, -0.01, /O/ = -0.08, -0.05, /U/ = -0.16, -0.17, /u/ = -0.16, -0.16 and central vowels /a/ = 0.43, 0.48 and /ʌ/ = 0.21, 0.25, respectively.

The correlation of fractional deviation of VTL between Nepali and Garhwali (Hindi) female speakers is 0.98. For Nepali and Garhwali (Hindi) male and female speakers, the fractional deviation of central vowels /a/ and /ʌ/ have greater than zero ($\delta > 0$), but other front vowels /i/, /I/, /ɛ/, /e/ and back vowels /ɔ/, /O/, /U/, /u/ have less than zero ($\delta < 0$). If the fractional deviation $\delta > 0$, then resonating lengths of the vocal tract $L_r > L$, and if the fractional deviation $\delta < 0$, then the resonant length of the vocal tract $L_r < L$. The central vowels /a/ and /ʌ/ have greater fractional deviation. The front vowels /ɛ/, /e/, and back vowels /ɔ/, /O/ have the lowest fractional deviation, so these front vowels have a more corrected effective VTL than other vowels.

Table 6 predicts the average VTL for Nepali and Garhwali (Hindi) male speakers as 17.70 cm and 18.12 cm, respectively, while for female speakers, the averages are 15.28 cm and 15.02 cm, respectively. Male speakers have a longer vocal tract than female speakers. The average male-to-female VTL ratio is 1.16 for Nepali speakers and 1.21 for Garhwali (Hindi) speakers. VTL increases when producing front vowels (/i/, /I/, /ɛ/, /e/) and back vowels (/ɔ/, /O/, /U/, /u/) compared to central vowels (/a/, /ʌ/). Among these, front vowels (/i/ and /I/) exhibit the longest VTL, whereas central vowels (/a/ and /ʌ/) have the shortest VTL for both male and female speakers.

Table 6 Ratio of average value vocal tract length of Nepali and Garhwali Hindi vowels of male to female speakers

Classification	Vowels	For Nepali Speakers		Ratio	For Garhwali (Hindi) Speakers		Ratio
		Vocal tract length for male (cm)	Vocal tract length for female (cm)		Vocal tract length for male (cm)	Vocal tract length for female (cm)	
Front vowel	/i/	21.83	19.51	1.12	21.66	18.42	1.18
	/I/	21.15	18.85	1.12	20.99	18.08	1.16
	/ɛ/	18.04	14.59	1.24	19.29	15.53	1.24
	/e/	17.26	14.30	1.21	19.01	14.73	1.29
Central vowel	/a/	12.57	9.88	1.27	12.06	9.55	1.26
	/ʌ/	14.01	11.65	1.20	13.45	11.23	1.19
Back vowel	/ɔ/	17.33	15.19	1.14	17.26	14.26	1.21
	/O/	17.75	15.37	1.15	17.61	14.78	1.19
	/U/	18.34	16.80	1.09	20.09	16.93	1.19
	/u/	18.73	16.71	1.12	19.77	16.71	1.18
	Avg.	17.70	15.28	1.16	18.12	15.02	1.21

Conclusion

This study examined the variation in VTL among Nepali and Garhwali (Hindi) male and female speakers. The results indicate that for male speakers, VTL ranges from 17.26 cm to 21.83 cm for front vowels, 17.26 cm to 20.09 cm for back vowels, and 12.06 cm to 14.01 cm for central vowels. Similarly, for female speakers, VTL varies from 14.30 cm to 19.51 cm for front vowels, 14.26 cm to 16.93 cm for back vowels, and 9.55 cm to 11.65 cm for central vowels.

Central vowels (/a/ and /ʌ/) show greater fractional deviation than other vowels, suggesting that their effective VTL is less stable. In contrast, front vowels (/i/, /I/, /ɛ/, /e/) and back vowels (/ɔ/, /O/, /U/, /u/) exhibit the lowest fractional deviation, indicating a more consistent effective VTL. The study primarily focuses on Nepali and Garhwali (Hindi) speakers, limiting its generalizability to other languages or dialects. The analysis is based on specific vowel sounds, and further research could explore consonants or diphthongs. The study does not account for individual anatomical variations beyond gender differences. Future studies could benefit from a larger sample size and advanced imaging techniques for more precise VTL measurements.

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