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Chest and Head Registers in Carnatic Singers and Non-Singers Using Linear Predictive Coding (LPC): A Comparative Study

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***Abstract*: The present study aimed to compare the head and chest registers in trained Carnatic singers and non-singers in the age range 20 to 30 years using Linear Predictive Coding (LPC). Forty non-singers and forty trained Carnatic singers were selected after being informally assessed using a questionnaire developed for professional voice users to check for any vocal abnormalities. Each subject was asked to produce five successive /a/ sounds in their chest and head registers, and recordings were then analyzed using LPC. Results of the study showed that head and chest registers showed a significant difference from Formants F0 to F4 in all trained Carnatic singers. Comparison between singers and non-singers showed a significant difference in head register observed from F1 to F3. Study concludes that head register is higher than chest register in all trained Carnatic singers.**

***Keywords*: Carnatic singers, Chest register, Gender, Head register, LPC, Non-singers.**

1. Introduction

Singing is a sensory motor phenomenon that requires a balanced physical ability. Maintaining a better quality and a wider range of voices for a longer period of time is a must for singers. A voice of singing is the basic element of a song. Every singer's voice has certain specific acoustic features that distinguish their individuality.

Singing is dominated by vowels because they are produced with open vocal tract configurations that allow a continuous flow of sound. On the other hand, most consonants, in one way or another, require a severe constriction of the vocal tract and cause a partial or complete interruption of the sound stream. Thus, the musical features that characterize singing are largely expressed through the precise control of the vocal tract during the production of vocals.

Indian classical music is the Indian Subcontinent's classical music. There are two main traditions to it. The North Indian tradition of classical music is called Hindustani and Carnatic is called the South Indian language. Indian classical music has two basic components, namely raga and tala. The swara-and tala-based raga tests the time-cycle. Perfection of speaking precedes development of singing and placing of the voice is an important skill learnt by a Carnatic singer through his/her formal training.

The chest register is usually used in normal speech and encompasses lower frequencies. Head register is used to sing notes with F0s much higher than that of normal speech in the range of 400-800 Hz. Singing in head register leads to the perception of a lighter, softer voice quality. In order to realize if the singers learn how to use different register it is very important to compare differences in the formant frequencies of head and chest register.

A study was done on the Chest-to-Head Register Transition in Singing Voice by taking vowel utterances [a] singing database recorded by three groups of singers; Altos, Mezzo, and Soprano. Singers sang each utterance in such a way that they began with sung vowel [a], using chest voice, then changed to head voice at the end. Extracting the six characteristics and observing the change occurred near the transition area, and they found the second harmonic H2 to be the dominant harmonic in the chest register because the first F1 supports the second harmonic H2. In the head register, on the other hand, they found that the first formant decreases and no longer supports the second harmonic and therefore begins to support the first harmonic [1].

Another study on the comparison of registers carried out by [2] showed that the fundamental frequency of chest and head register always have a higher energy in F0 when compared to the other formants and head register using singing notes with F0 much higher than chest register

Another study showed that simultaneous recordings of TA and cricothyroid (CT) muscle activity, video-endoscopy, and audio were obtained from seven female singers during the

production of a variety of midrange pitches in the chest, chest, head mix, and head registers, and that Spectral tilt increased as subjects moved from the chest to the chest to the head mix and finally to the head register. For the same pitch phonation, subjects increased TA muscle activity and vocal fold adduction as they moved the register from the head to the head mix to the chest, particularly during the production of higher frequencies. CT activity appeared to be more related to pitch than to registry control. [3]

Vocal training can be attributed to the distinctions in the physiological, acoustic, and perceptual parameters found in singers' voices when compared to the voices of non-singers. Singing experience and vocal training essentially improves the singing efficiency.

A comparative study between trained and untrained vocalists conducted by [4], [5] revealed that trained adult vocalists have the capability to produce greater speaking frequency and intensity ranges and generally tend to have higher speaking fundamental frequency than untrained individuals.

There are only very few studies done on Carnatic classical music singers. Among those studies, not even one study has been done comparing chest and head register of trained Carnatic singers and untrained singers using Linear Predictive Coding (LPC). These current study aim to compare the difference between head and chest registers in trained singer's vs. performance of non-singers. The performance difference across gender in trained singer also studied

2. Method

A total of 80 participants were selected for the study. 40 trained Carnatic classical singers and 40 untrained singers, consisting of 20 males and 20 females in each group as shown in Appendix B. The 40 trained singers were selected from Shadkala Govinda Marar Smaraka Kala Samithi Ramamangalam and Radha Lakshmi Vilasam College of Music and Fine Arts, Tripunithura. Consent forms were taken from each of the participants. Ethical Guidelines for Bio-Behavioural Research, AIISH (2009) was followed for the study.

Participants were selected within the age range of 20 to 30 years with Carnatic classical singing experience of greater than 5 years and had a vocal practice of 4 to 5 hours per day. Participants who have not undergone any kind of musical training were selected for the category of untrained singers. Participants who did not show any sign of speech, language, vocal, sensory motor problems at the time of recording were included in the study. Each professionally trained Carnatic singers was informally assessed using a questionnaire developed for Professional voice users by [6] to check for any vocal abnormalities. Participants who showed regular intake of alcohol and smoking were excluded from the study. All recordings were carried out in a quiet environment with the participants seated in a comfortable supine position. The speech sample was recorded with a microphone placed 10cm away from the participants' mouth. Each participant was instructed to produce 5 successive singleton |a| for at least three seconds at a high pitch: refers to head register and low pitch: refers to chest register. Initially, HP 91U442V1 laptop was used to record the production of |a| vowel using chest voice (chest register) and head voice (head register) for each participant. Later, LPC on PRAAT software was used to view the formants.

The sound samples are were then analysed with the linear predictive coding using the PRAAT (Version 6.0.43) software at a sampling rate of 24 kHz. After recording, the samples were stored on the hard disk of the HP laptop using PRAAT software at the sampling rate of 24 kHz for further analysis. The total time taken to record the speech samples from each subject was 5-10 minutes approximately. LPC spectrum is a kind of spectrum that is used to make an estimate of the formant peaks without being confused by looking at the harmonics. Usually Small samples of the signal are taken for LPC analysis because it's always better to take the spectrum of the small sample instead of selecting the whole.

3. Results and Discussion

The descriptive statistics of Mean, standard deviation and median was computed for all parameters. The data was subjected to Shapiro Wilks test for normality. The results revealed that the data is significantly deviating from normal distribution (i.e., $p<0.05$). Therefore, a non-parametric Mann Whitney U test was carried out to determine the significant difference between singers and non-singers for the parameters of head and chest registers. The same test was carried out to determine the significant difference between males and females also.

The comparison of head and chest register in singers are as follows:

Table 1
Descriptive statistics of singer's chest vs head register

Groups	N	Mean	SD	Median
C_F0	40	75.510	9.45	76.3
H_F0	40	82.667	8.1	85.4
C_F1	40	64.490	11.7	66.6
H_F1	40	74.575	9.2	75.6
C_F2	40	49.308	11.4	52.3
H_F2	40	56.873	9.6	56.8
C_F3	38	42.637	11.6	44.8
H_F3	38	47.858	10.85	49.3
C_F4	26	33.796	11.3	35.0
H_F4	33	40.855	10.47	42.2
C_F5	14	37.514	8.3	37.8
H_F5	23	37.570	11.3	37.7
C_F6	2	40.300	4.0	40.3
H_F6	13	36.992	10.0	39.4

Note: C-chest, H-head, N-no. of participants, SD-standard deviation, F0-fundamental frequency, F1-formant 1, F2-formant 2, F3-formant 3, F4-formant 4, F5-formant5, F6-formant 6

It was observed from Table 1, the overall median value obtained by the trained singers' decreases for chest and head register as it goes from F 1 – F6. However, there is a slight increase in the chest register value than head register at Formant 6. A total of 40 singers reduced to 14 and 23 trained singers, of

who were able to exhibit significant F5 in the chest and head registers respectively. And a total of 2 and 13 trained singers were able to exhibit significant F6 in the chest and head registers significantly.

Median value obtained for F0 was 76.3 dB (SD±9.45) for chest register and 85.4 dB (SD±8.1) for head register respectively. The reason for this is because the fundamental frequency of chest and head register always has a higher energy in F0 when compared to the other formants and head register using singing notes with F0 much higher than chest register [2] which is also evident in Table 1.

Median value obtained for Formant 1 by the trained singers for Chest register was 66.6 dB (SD±11.7), Formant 2 was 52.3 dB (SD±11.4), Formant 3 was 44.8 dB (SD±11.6) Formant 4 was 35.0dB (SD±11.3), Formant 5 was 37.8dB (SD±8.3) and Formant 6 was 40.3dB (SD±4.0).

Median value obtained for Formant 1 by the trained singers for Head register was 75.6 dB (SD±9.2), Formant 2 was 56.8 dB (SD±9.6), Formant 3 was 49.3 dB (SD±10.85), Formant 4 was 42.2 dB (SD±10.47), Formant 5 was 37.7dB (SD±11.3) and Formant 6 was 39.4dB (SD±10.0).

From Table 1, it's also observed that out of the 40 Carnatic trained singers only 2 singers produced chest registers up to Formant 6 and only 13 singers produce head register up to Formant 6. It implies that only particular singers are getting higher formants up to Formant 6 may be because of their higher level of vocal training and year of experience when compared to other singers. [5]

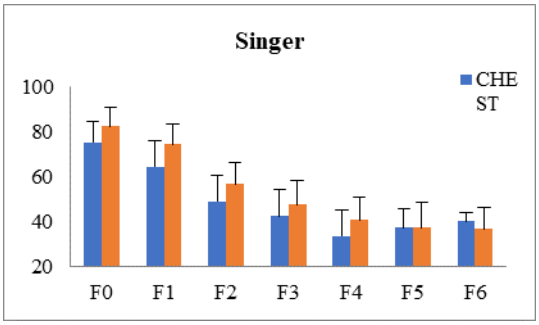

Fig. 1. Chest and Head register in Trained Carnatic singers

Statistical analysis was done using Mann Whitney U test (Non-Parametric test) to determine if there is a statistically significant difference between the formant values of head and chest registers. Table 2 shows the level of significance obtained using Mann Whitney U test.

From Table 2, the results of the statistical analysis revealed that a significant difference was present between the chest and head register of trained Carnatic singers from F0 to F4 (p<0.05 & p<0.01) except for formant 5 which does not show any significant difference between head and chest register (p>0.05) revealing that the head register is greater than the chest register in trained singers. The findings of the present study are supported by the fact that manipulations of vocal registers are dependent upon laryngeal muscle activity [7] stated the laryngeal muscle activity for voiced sounds tend to be lesser for chest register and greater for head register especially in trained classical singers. Chest register phonation is perceived to be more pressed than head register and glottal adduction is known to be firmer in chest register [8].

Table 2
Level of significance for head and chest registers in singers

Groups	|z|	p- value
C_F0	5.034	**0.000****
H_F0		
C_F1	5.222	**0.000****
H_F1		
C_F2	4.073	**0.000****
H_F2		
C_F3	2.255	**0.024***
H_F3		
C_F4	3.068	**0.002****
H_F4		
C_F5	1.334	0.182
H_F5		
C_F6	-	-
H_F6		

*Indicates significant p<0.05 **indicates significant p<0.01

A. To compare the chest and head register of trained male singers

Table 3
Descriptive statistics of trained male singers' chest and head register

Frequencies	n	Mean	SD	Median
C_F0	20	79.80	7.16	79.95
H_F0	20	85.87	6.48	86.25
C_F1	20	67.82	8.84	70.10
H_F1	20	75.32	10.29	78.00
C_F2	20	50.64	8.89	52.25
H_F2	20	55.22	9.64	55.40
C_F3	19	44.12	9.67	47.00
H_F3	20	45.84	11.63	44.35
C_F4	10	31.82	11.37	35.25
H_F4	17	37.01	10.51	40.00
C_F5	4	36.38	4.57	36.25
H_F5	9	37.31	11.20	42.20

Note: C-chest, H-head, N-No. of participants, SD-standard deviation, F0-fundamental frequency, F1-formant 1, F2-formant 2, F3-formant 3, F4-formant 4, F5-formant 5

Table 3 compares the head and chest register of 20 trained male singers. From the Table 3 it is evident that head register has more energy when compared to chest register in all formants and the overall median value obtained by the trained male singers' decreases for chest and head register as it goes from F 1 – F5. However, there is a slight increase in the chest register value than head register at Formant 3. It is also observed that out of the 20 Carnatic male trained singers only 4 singers produced chest registers up to Formant 5 and only 9 singers produce head register up to Formant 5.

Median value obtained by the males trained singer for chest register on F0 was 80 dB (SD±7.2) and Head register was 86.3dB (SD±6.5). The fundamental frequency of chest and head register has higher energy when compared to other formants [2].

Median value obtained for Formant 1 by the trained male

singers for Chest register was 70.10dB (SD±8.84), Formant 2 was 52.25 dB (SD±8.89), Formant 3 was 47.0 dB (SD±9.67), Formant 4 was 35.25 dB (SD±11.37) and Formant 5 was 36.25dB (SD±4.57).

Median value obtained for Formant 1 by the trained singers for Head register was 78.00 dB (SD±10.29), Formant 2 was 55.40 dB (SD±9.64), Formant 3 was 44.35dB (SD±11.63), Formant 4 was 40.0 dB (SD±10.51) and Formant 5 was 42.20dB (SD±11.20).

From the figure 2 it is evident that the median value is higher for head register when compared to chest register. Both the values decreased from F1 to F5 respectively.

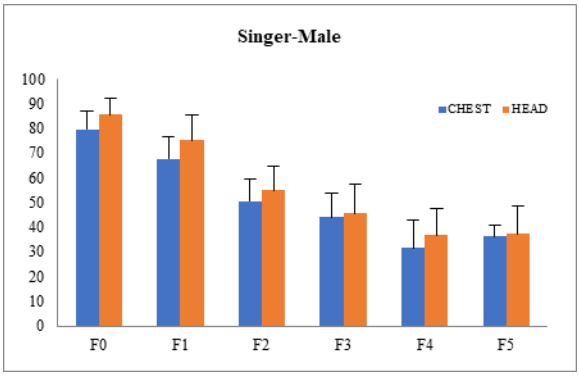

Fig. 2. Trained Male Carnatic Singers Chest Register and Head Register

Statistical analysis was done using Mann Whitney U test (Non-Parametric test) to determine if there is a statistically significant difference between the formant values of head and chest registers of trained male singers. Table 4 shows the level of significance obtained using Mann Whitney U test.

Table 4
Mann Whitney U test; Head and Chest register in Male trained singers

Frequencies	|Z|	*p*-value
C_F0	3.585	**0.000****
H_F0		
C_F1	3.435	**0.001****
H_F1		
C_F2	2.091	**0.036***
H_F2		
C_F3	0.805	0.421
H_F3		
C_F4	2.310	**0.021***
H_F4		
C_F5	1.095	0.273
H_F5		

*indicates significant $p<0.05$ **indicates significant $p<0.01$

Table 4, revealed a significant difference present between the chest and head register of trained male singers on F0, F1, F2 and F4 ($p<0.05$ & $p<0.01$) Contrary to Formant 3 and Formant 5, which do not show any significant difference between head and chest registers ($p>0.05$) revealing that the head register is greater than the chest register even in trained male singers.

The findings of the current study are supported by the fact that in male singers there is a presence of greater energy in high partials of the head register which is due to the more efficient conversion of the air flow to acoustic energy when compared to other forms of registers. This efficient production is reflected in the lower air flow rate for head register and is primarily a result of the firmer closure of the glottis [9].

Increase in the intensity of F1 and f2 could be because of the increased jaw opening size along with the changes in the tongue height especially while producing the vowel /a/ and the amount of tongue constriction and the area of the front cavity which affects the formant 2 [10].

The numbers of participants in F1 and F2 (that are total 20 males) are greater than those participants in the subsequent formants. Thereby, the intensity in F1 and F2 in head register is comparatively significant. Findings of the study can be supported by [11] western study on professional male singers stating that sopranos had generally higher vowel formant frequencies than mezzo- sopranos that was also dependent on the smaller vocal tract volume in the former singing style. Research has shown that sopranos are largely sung in the head register, and mezzo- sopranos are primarily sung in the chest register. Hence, indicating that some of the participants performed a singing style that revealed a higher intensity.

B. The comparison of head and chest register in trained female singers

Table 5
Descriptive statistics of female singer's chest and head register

Groups	n	Mean	SD	Median
C_F0	20	71.22	9.7	70.7
H_F0	20	79.47	8.4	80.0
C_F1	20	61.17	13.4	65.0
H_F1	20	73.84	8.1	71.3
C_F2	20	47.98	13.6	52.4
H_F2	20	58.53	9.5	61.6
C_F3	19	41.15	13.4	41.0
H_F3	18	50.11	9.7	52.4
C_F4	16	35.03	11.5	33.7
H_F4	16	44.94	9.0	47.7
C_F5	10	37.97	9.6	40.9
H_F5	14	37.74	11.8	37.3
C_F6	2	40.30	4.0	40.3
H_F6	9	35.78	10.0	31.3

Note: C-chest, H-head, N-no. of participants, SD-standard deviation, F0-fundamental frequency, F1-formant 1, F2-formant 2, F3-formant 3, F4-formant 4, F5-formant5, F6-formant 6

It was observed from Table 5 and Figure 3, the overall median value obtained by the trained female singers' decreases for chest and head register as it goes down from F1. However, there is a slight increase in the chest register value than head register at Formant 6. A total of 20 singers reduced to 10 and 14 trained singers, of who were able to exhibit significant F5 in the chest and head registers respectively. And a total of 2 and 9 trained singers were able to exhibit significant F6 in the chest and head registers significantly.

Median value obtained for F0 was 70.7 dB (SD±9.7) for chest register and 80.0 dB (SD±8.4) for head register respectively. The fundamental frequencies of chest and head

register have higher energy when compared to other formants [2].

Median value obtained for Formant 1 by the trained female singers for Chest register was 65.0 dB (SD±13.4), Formant 2 was 52.4 dB (SD±13.6), Formant 3 was 41.0 dB (SD±13.4) Formant 4 was 33.7dB (SD±11.5), Formant 5 was 40.9dB (SD±9.6) and Formant 6 was 40.3dB (SD±4.0).

Median value obtained for Formant 1 by the trained female singers for Head register was 71.3dB (SD±8.1), Formant 2 was 61.6 dB (SD±9.5), Formant 3 was 52.4 dB (SD±9.7), Formant 4 was 47.7dB (SD±9.0), Formant 5 was 37.3dB (SD±11.8) and Formant 6 was 31.3 (SD±10.0).

From Figure 3, it is evident that the median value is higher for head register when compared to chest register from F0 – F4. Formant after F4 shows a slight increase in chest register.

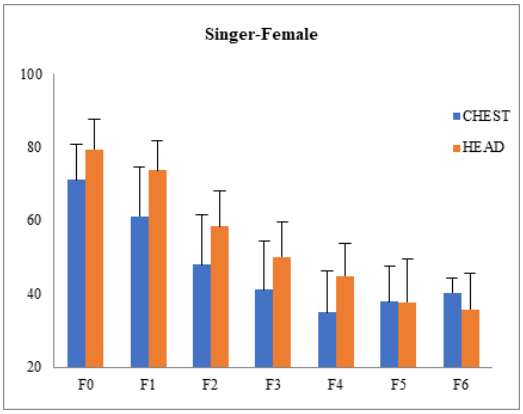

Fig. 3. Chest and Head register in Trained Female Carnatic singers

Statistical analysis was done using Mann Whitney U test (Non-Parametric test) to determine if there is a statistically significant difference between the formant values of head and chest registers. Table 6 shows the level of significance obtained using Mann Whitney U test.'

Table 6
Level of significance of trained female singers

Frequencies	|Z|	*p*-value
C_F0	3.547	**0.000****
H_F0		
C_F1	3.883	**0.000****
H_F1		
C_F2	3.584	**0.000***
H_F2		
C_F3	2.504	**0.012***
H_F3		
C_F4	2.202	**0.028***
H_F4		
C_F5	.980	0.327
H_F5		

*Indicates significant at p< 0.05 ** Indicates significant at p<0.01

Table 6 results revealed that a significant difference was present between the chest and head register of trained female Carnatic singers from F0 to F4 (p<0.05 & p<0.01) except for Formant 5 which does not show any significant difference between head and chest register (p>0.05). The study thus concludes that the head register is greater than the chest registers even in trained female singers. Similar results were obtained by [12] study on the comparison of female head and chest registers.

Previous literature shows that certain acoustic differences are present between the head and chest registers that are dependent on measurements of the glottal source spectrum in vowels. Findings of this study can be supported by Sundberg (1975) results, stating the amplitude of the higher formants and increases in pitch tend to be accompanied by increases in jaw opening. Female singers' cricothyroid muscle activity is more dominant than thyroarytenoid muscle activity. That is cricothyroid muscle dominates the thyroarytenoid muscle during singing especially for female singers [13].

C. Comparison of Chest register and Head register in Carnatic trained singers and non-singer

Table 7
Descriptive statistics of chest register and head register of singers and non-singers

Groups	Variables	n	Mean	SD	Median
C_F0	Singer	40	75.510	9.45	76.3
C_F0	Non singer	40	70.920	5.46	71.8
H_F0	Singer	40	82.667	8.08	85.4
H_F0	Non singer	40	73.880	5.8	73.4
C_F1	Singer	40	64.490	11.7	66.6
C_F1	Non singer	40	64.170	8.7	65.4
H_F1	Singer	40	74.575	9.17	75.6
H_F1	Non singer	40	67.153	9.7	68.3
C_F2	Singer	40	49.308	11.4	52.3
C_F2	Non singer	40	48.540	10.8	46.9
H_F2	Singer	40	56.873	9.6	56.8
H_F2	Non-singer	40	50.634	12.6	52.3
C_F3	Singer	38	42.637	11.6	44.8
C_F3	Non singer	32	40.975	9.0	40.0
H_F3	Singer	38	47.858	10.85	49.3
H_F3	Non-singer	35	40.808	10.63	40.1
C_F4	Singer	26	33.796	11.3	35.0
C_F4	Non singer	6	42.250	9.35	42.5
H_F4	Singer	33	40.855	10.47	42.2
H_F4	Non-singer	11	39.836	8.9	41.8
C_F5	Singer	14	37.514	8.3	37.8
C_F5	Non singer	0	-	-	-
H_F5	Singer	23	37.570	11.3	37.7
H_F5	Non-singer	2	36.450	4.2	36.5
C_F6	Singer	2	40.300	4.0	40.3
C_F6	Non singer	0	-	-	-
H_F6	Singer	13	36.992	9.8	39.4
H_F6	Non-singer	0	-	-	-
C_F7	Singer	0	-	-	-
C_F7	Non-singer	0	-	-	-
H_F7	Singer	5	33.520	9.8	29.7
H_F7	Non-singer	0	-	-	-
C_F8	Singer	0	-	-	-
C_F8	Non-singer	0	-	-	-
H_F8	Singer	2	37.600	9.5	37.6
H_F8	Non-singer	0	-	-	-

Note: C-chest, H-head, N-no. of participants, SD-standard deviation, F0-fundamental frequency, F1-formant 1, F2-formant 2, F3-formant 3, F4-formant 4, F5-formant 5, F6-formant 6, F7-formant7, F8- formant

From Table 7 it is observed that the number of singers

reduced from a total of 40 to 2 and 13 singers of who were able to exhibit values for F6 in the chest and head registers respectively. On the other hand, non-singers reduced from a total of 40 to 6 and 11 of who were able to exhibit the values of F4 in the chest and head registers.

Median value obtained for F0 was 76.3 dB (SD±9.45) for chest register and 85.4 dB (SD±8.08) for head register in singers and Median value obtained for F0 was 71.8 dB (SD±5.46) for chest register and 73.4 dB (SD±5.8) for head register for non-singers respectively. The fundamental frequency of both chest register and head register have higher energy in singers than in non-singers. It is also observed from Table 4.7, that the overall median value of chest and head register obtained by the trained singers are higher when compared to non-singers. This could be due to the fact that untrained singers have a physiological difference in the production configuration that affect both airflow and the nature of vocal fold vibration during phonation is different from that of singers [1]. Also there is a tendency for non-singers to produce soft phonation that is associated with a lower formant frequency. This could be because of the differences in larynx height and jaw and mouth opening of non-singers when compared to singers [14].

Median value obtained for F1 was 66.6 dB (SD±11.7) for chest register in singers and 65.4 dB (SD±8.7) for non-singers, F2 was 52.3 dB (SD±11.4) for chest register in singers and 46.9dB (SD±10.8) for non-singers, , F3 was 44.8 dB (SD±11.6) for chest register in singers and 40.0 dB (SD±9.0) for non-singers, , F4 was 35.0 dB (SD±11.3) for chest register in singers and for non-singers the median value was obtained only till F4 which is 42.5 dB (SD±9.35).Median value obtained forF5 was 37.8 dB (SD±8.3) and F6 was 40.3 dB (SD±4.0)for chest register in singers.

Median value obtained for F1 was 75.6 dB (SD±9.17) for head register in singers and 68.3 dB (SD±9.7) for non-singers, F2 was 56.8 dB (SD±9.6) for head register in singers and 52.3dB (SD±12.6) for non-singers, F3 was 49.3 dB (SD±10.85) for head register in singers and 40.1 dB (SD±10.63) for non-singers, F4 was 42.2 dB (SD±10.47) for head register in singers and 41.8 dB (SD±8.9) for non-singers, F5 was 37.7 dB (SD±11.3) for head register in singers and for non-singers the median value was obtained only tillF5 which is 36.5 dB (SD±4.2).Median value obtained for F6 was 39.4 dB (SD±9.8), F7 was 29.7dB (SD±9.8) and F8 was 37.6 dB (SD±9.5)for head register in singers.

Table 7 data reveal that few singers were able to exhibit till Formant6 and Formant 8 in chest and head registers respectively. Non-singers, however, did not show the presence of higher formants. This finding can be supported by the study done by [15] stating that singers are significantly more efficient than non-singers in certain conditions because singers show significantly higher subglottic pressure and resistance values. Alterations in the length, stiffness, shape combined with changes in airflow and resonance permit singers to produce great ranges of vocal quality, pitch and intensity [7].

Statistical analysis was done using Mann Whitney U test (Non-Parametric test) documented in Table 8, to determine if there is a statistically significant difference between the formant values of head and chest registers in singers and non-singers.

Table 8
Level of significance of chest register and head register of singers and non-singers

Frequency	|z|	p- value
C_F0	2.950	**0.003****
H_F0	4.600	**0.000****
C_F1	0.765	0.444
H_F1	3.690	**0.000****
C_F2	0.467	0.967
H_F2	2.232	**0.026***
C_F3	0.967	0.334
H_F3	2.705	**0.007****
C_F4	1.883	0.060
H_F4	0.488	0.626
C_F5	-	-
H_F5	0.200	0.841
C_F6	-	-
H_F6	-	-
C_F6	-	-
H_F7	-	-
C_F6	-	-
H_F8	-	-

* Indicates significant at $p< 0.05$ ** Indicates significant at $p<0.01$

Table 8 results revealed that a significant difference was present between the chest and head register of trained singers and non-singers F0 ($p<0.05$ & $p<0.01$). Results also suggest that only the head register of singers and non-singers showed a significant difference, observed from F1 to F3. The reason for this could be because while phonating in head register there is always a higher concentration of energy present around the lower formants. This finding are in support with the study done by [12] wherein study suggest that opera singers have more energy concentration in singing voices than in speaking voice.

The reason that the singers showed elevated mean F0 value than non-singers could be because of the presence of a wider frequency range and their training years, they can produce the sound without straining their voice. Another remarkable difference is that singers increased voice pitch less than the non-singers [16]. Similar result was documented [17] in male and female choral singers and non-singers, wherein the increased F0 was observed specifically in all choral singers, and this could be due to the continuous practice of voice modulation of high-frequency sounds during choral singing [4] studied how voice training affected the speaking voice of voice majors. Results of their study noted few trends in the speaking F0 and segment durations [5] also studied the speaking voice of trained singers. The results revealed that singers had a significantly higher speaking mean F0 than non-singers.

Therefore, the findings of this study represent perceived differences between the trained Carnatic singers and non-singers. This could be because singers often use a slightly higher subglottal pressure than the non-singers in loud phonation at high fundamental frequencies. Peak airflow tends

to decrease with rising fundamental frequency in the non-singers, while in the actively working singers' loud phonation the opposite tendency if observed. It was considered that the vocal folds of a trained voice were able to support and sustain a higher subglottal pressure when compared to non-singers [18].

4. Conclusion

The study thus concluded that the perceived differences between the trained Carnatic singers and non-singers with significance in F1, F2 and F3 are seen in the head register than chest register. Linear Predictive Coding gives a good estimation of voice classification dependent on the formant frequencies, however there are fewer research in studying vocal registers using such conventional methods. This led to the limitations of a dearth of research to support the current findings. In the field of Speech-Language Pathology, changes in the mean singer's frequency range along with other perceptual tests can help to identify any clinically harmful vocal changes in trained singers. The study has limitations of its own, with regard to the generalization of the results obtained; findings of the current study are confined to only Carnatic singers.

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