Acoustic and Aerodynamic Characteristics of Choral Singers

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Summary: Objectives. The study aimed to investigate and compare the acoustic and aerodynamic characteristics of choral singers and nonsingers.

Method. Twenty choral singers and 20 nonsingers in the age range of 20−30 years with no vocal pathology participated in the study. For acoustic analysis, the voice sample was recorded and analyzed using *Praat software* (Phonetic Sciences, University of Amsterdam, Amsterdam, Netherlands) version 6.0.33 and for aerodynamic evaluation, *Helios 401 PC based spirometer* (Recorders & Medicare System Pvt. Ltd., Panchkula, Haryana, India) was used.

Results. The results from acoustic analysis of female groups revealed higher F0 in singers than nonsingers; higher jitter, shimmer, and noise-to-harmonics ratio (NHR) values were obtained for nonsingers compared to singers. Results from acoustic analysis of male groups revealed significantly higher F0 in singers than nonsingers and significantly higher shimmer and NHR values for nonsingers compared to singers. Results from aerodynamic analysis for both male and female groups revealed higher vital capacity, forced vital capacity, and slow vital capacity in singers than nonsingers.

Conclusion. The results revealed better control over phonatory and respiratory subsystems among singers compared to nonsingers, although the singers were untrained. This could be possible due to the fact that long-term singing practices involving vocal modulation and changes in the breathing pattern, better respiratory control during the expiratory phase among singers. However, as the participants of the singing group are untrained, further studies are required to compare the acoustic and the aerodynamic characteristics with trained singers.

Key Words: Choral singers−Acoustic analysis−Aerodynamic evaluation−Vital capacity−Fundamental frequency.

INTRODUCTION

Singing needs more delicate and defined control over respiratory, phonatory, and resonatory subsystems, and the coordination between these systems has a major impact on the quality of voice production in singers compared to nonsingers, where singers need to depend on the respiratory system for longer duration of voice production.[1] Professional singers have variable vocal demands and require the most sophisticated analysis for continuous monitoring of vocal system. For instance, in Carnatic singing, presentation for music was given more importance compared to quality and appeal of the singer's voice while for a light music singer, in a concert, they should not only have a good and appealing voice but they also have to compete with the other accompanying instruments.[2] Sundberg[1] suggested that the skill to reduce effort while singing and still achieving a "good" singing voice is a typical difference between trained and untrained singer.

There is a possibility that due to differences in the usage of speech subsystems by trained, untrained, and nonsingers, these varied structural changes result in variability in the vocal output. Numerous studies have been carried out to compare the acoustic, aerodynamic, and perceptual parameters among trained singers and nonsingers. The results have revealed presence of vibrato, singer's formants, low jitter values, changes in fundamental frequency and maximum phonation frequency range, and increased vocal range and phonation time in trained singers compared to nonsingers.[3−6] Few Indian studies compared trained singers (Carnatic classical) and nonsingers. The results suggested presence of optimum pitch, higher fundamental frequency while singing, overall increased Dysphonia Severity Index, elevated highest fundamental frequency, and maximum phonation in trained singers compared to nonsingers.[7−9] Researchers have also found that the untrained singers have higher incidences of vocal issues such as hard glottal attacks, overarticulation, excessive loudness, throat clearing, overparticipation in singing, and improper breath support.[5]

Choral/choir singing is one of the traditional ways of singing through vocal music performed largely at religious places, school, and community by a group of untrained singers who learned singing by observation and feedback from fellow singers. Choral singing demands high level of variations in frequency and intensity to match the singing group, which will in turn put increased demands on the respiratory and phonatory systems and the coordination between two subsystems. Sometimes these variations in frequency and intensity may go beyond their optimal capacity, which may cause damage to speech subsystems if adequate care is not taken.

In India, choral singing is majorly practiced in churches by a group of men and women in the age range of 14−40 years, and these individuals received minimal or no formal training in singing; also, the choral conductors are mostly self-trained. The frequency of the practice ranges from 2 to 3 times per week and 2 to 4 hours with a break in between the practice sessions. This frequency increases during occasions of festivals.[10] Indian choral music most commonly divide voices solely on the basis of vocal range and are divided into high and low voices within each gender (soprano, alto, tenor, and bass). One group may sing the basic melody of the music (ie, soprano) while the other group sings the harmony (alto, tenor, and bass), which are complementary lines of music that make up

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the chords. Most commonly, the mixed type of choral singing is practiced in Indian scenario, which consists of both male and female voices. In addition, these choral singers tend to incorporate few of the western elements such as chord singing, harmony, *etc* in Indian music. However, few of the variations practiced in Western choral singing such as boy sopranos and male singers singing alto and baritone are not observed in Indian choral singing.

Reddy et al[11] investigated the smoothened cepstral peak prominence during phonation and continuous speech among choral singers and nonsingers, and they found that although choral singers do not have any formal training for singing, they still had enhanced vocal quality with rich harmonic structure in comparison with nonsingers. Irzaldy et al[12] investigated lung vital capacity (VC) of individuals who were choir singers and nonsingers, the results revealed that lung VC and forced vital capacity (FVC) of choir singers were significantly higher than nonsingers; inspiratory capacity of choir singers was higher but did not vary significantly from nonsingers.

Zoramsiami[10] assessed the vocal demands and practiced vocal habits of Mizo choral singers from Mizoram, a northeast state in India. As similar to the rest of India, Mizo choral singing is also associated with church and Christianity. The traditional style of Mizo singing was very gentle, and the tune was limited to the low pitch range, and after Christianity, the traditional Mizo singing came in contact with Western style, which brought a lot of variation in the musical notes. The songs sung by the choir include the traditional songs, translated Western Hymns—minor and major chorus songs which has one to three octaves in the singing scale. As most of the Mizo choral singers do not undergo any formal singing training, this study was carried out to investigate the awareness regarding vocal practices and vocal hygiene in the Mizo choral singers. They had considered 72 Mizo choral singers (33 men and 39 women) in the age range of 21−39 years with at least 2 years of experience. A questionnaire was administered with 37 questions, which were divided into four domains (general health and lifestyle, vocal habits, voice conservation, and singing related). The results of this study suggested that majority of the choral singers do not warm-up before choral performance; the commonly used warm-up exercises included taking a deep breath and exhale, singing a musical note, and singing a song, which has high notes and lip trill; majority of the choral singers tend to sing out of their limit range while performing in a choir, and a very few practices to improve their vocal quality.

Although choral singing has been in practice in India for several years, the number of singers involved has been increasing from past two decades. Trained singers have better control over the necessary muscles required for phonation and regulating capacity over the respiratory system, which is not seen in untrained singers such as choir/choral singers. As these singers are untrained to make high level of variations in frequency and intensity compared to that of trained singers, these individuals are at risk of voice disorders frequently. Limited number of studies has been done to understand the respiratory, phonatory, and resonatory characteristics of choral singers, which may throw light on vocal health. Hence, there is a need to study the acoustic and the aerodynamic characteristics of these individuals. The study was conducted with two objectives, the first objective of the study was to investigate the acoustic characteristics of choral singers and compare these with nonsingers, and the second objective was to investigate the aerodynamic characteristics of choral singers and compare these with nonsingers.

METHOD

Participants

A total of 20 untrained choral singers (10 men, 10 women) with 5 years of choral singing experience and 20 nonsingers (10 men, 10 women) in the age range of 20−30 years participated in the study. The demographic data from both groups were collected using Inventory for Professional voice users.[13] All the choral singers were from the same choir group where the frequency of practice ranged from 2 to 3 times per week and for 3 to 4 hours each time; none of the choral singers had undergone any kind of formal singing training; they practiced singing under the guidance of a common choral conductor; and most of the time, they performed mixed type of choral singing. The participants with no complaints of upper respiratory tract infection and no voice or hearing problem on the day of recording were included in the study. The following were the inclusion criteria for selecting the participants (1) the voice samples of all the singers and nonsingers were perceptually analyzed by two speech language pathologists using grade, roughness, breathiness, asthenia, and strain scale; and the participants with subjectively normal voice (ie, G0R0B0A0S0) were considered for the study; (2) the individuals had to undergo laryngological evaluation using direct endoscopic to rule out the presence of any kind of ear infection, upper respiratory tract infection, or voice pathology; (3) the individuals had no history of oromotor, communicative, neurological, sensorimotor, and cognitive impairment.

Procedure

For acoustic analysis, all participants were made to sit comfortably and were instructed to produce a sustained phonation of /a/ vowel for 5 seconds, and the samples were recorded using *Praat software* version 6.0.33 with a sampling frequency of 44,100 Hz with a unidirectional dynamic microphone placed at 10 cm distance from the mouth in an acoustically treated chamber. The recorded samples were analyzed using *Praat software* version 6.0.33 for fundamental frequency (F0), jitter%, shimmer%, and the noise-to-harmonics ratio (NHR). For aerodynamic evaluation, participants were made to sit in upright position and *Helios 401 PC based spirometer* was used to measure the inspiration and expiration forces (VC, FVC, and slow vital capacity [SVC]). To measure VC, the participants were instructed to inhale as deeply as possible, and then expel as much air as possible into the mouthpiece; for FVC, the participants were asked to take a deep breath in, as large as possible, and blow steadily for as long as possible until no air is left out; for SVC, the participants were instructed to inspire slowly and maximally, and then exhale slowly and maximally. The data of

acoustic and aerodynamic parameters were tabulated and analyzed using independent sample *t* test in *SPSS software* version 16.0 (SPSS Inc., Chicago, IL) to compare the results between choral singers and nonsingers.

RESULTS

Acoustic characteristics of choral singers and nonsingers

The means and standard deviations (SDs) were calculated for the acoustic parameters, and independent sample *t* test was done to compare female choral singers and nonsingers; the results are summarized in Table 1. The results from acoustic analysis of female groups revealed higher F0 in choral singers (M = 212.07 Hz) than nonsingers (M = 203.61 Hz), although the difference was not statistically significant [t(18) = 0.53, $P > 0.05$]; however, higher jitter values were obtained for nonsingers (M = 0.083) compared to choral singers (M = 0.63) even though the difference was not statistically significant [t(18) = 0.81, $P > 0.05$]; higher shimmer values were obtained for nonsingers (M = 3.02) compared to choral singers (M = 2.73), although the difference was not statistically significant [t(18) = 0.89, $P > 0.05$]; NHR values were higher for nonsingers (M = 0.07) compared to choral singers (M = 0.04), although the difference was not statistically significant [t(18) = 0.61, $P > 0.05$].

The means and SDs were calculated for the acoustic parameters, and independent sample *t* test was done to compare male choral singers and nonsingers; the results are summarized in Table 2. The results revealed higher F0 in choral singers (M = 162.03 Hz) than nonsingers (M = 120.21 Hz), and the difference was statistically significant [t(18) = 6.29, $P < 0.05$]; however, no significant difference [t(18) = 0.211, $P > 0.05$] was found for jitter values for nonsingers (M = 0.30) compared to choral singers (M = 0.31); higher shimmer values for nonsingers (M = 4.21) compared to choral singers (M = 3.34), and the difference was statistically significant [t(18) = 3.82, $P < 0.05$]; higher NHR values for nonsingers (M = 0.05) compared to choral singers (M = 0.02), and the difference was statistically significant [t(18) = 2.44, $P < 0.05$].

Aerodynamic characteristics of choral singers and nonsingers

The means and SDs were calculated for the aerodynamic parameters, and independent sample *t* test was done to compare female choral singers and nonsingers; the results are summarized in Table 3. The results revealed higher VC in choral singers (M = 2.88 L) than nonsingers (M = 2.16 L) with a statistically significant difference between the two groups [t(18) = 3.966, $P < 0.05$]; FVC was found to be higher for choral singers (M = 2.726 L) compared to nonsingers (M = 2.572 L); however,

TABLE 1.
Means and Standard Deviations of Acoustic Parameters in Female Choral Singers and Nonsingers

				Independent *t* test		
Acoustic Parameters	Group	Mean	SD	t	df	Sig.
F0	Choral singers	212.07	49.53	0.533	18	0.60
	Nonsingers	203.61	8.13			
Jitter	Choral singers	0.63	0.30	−0.817	18	0.42
	Nonsingers	0.83	0.73			
Shimmer	Choral singers	2.73	0.05	−0.893	18	0.38
	Nonsingers	3.02	0.97			
Noise-to-harmonics ratio	Choral singers	0.04	0.08	−0.616	18	0.54
	Nonsingers	0.07	0.08			

Abbreviations: df, degrees of freedom; Sig., *p*-value.

TABLE 2.
Mean and Standard Deviation of Acoustic Parameters in Male Choral Singers and Nonsingers

				Independent *t* test		
Acoustic Parameters	Group	Mean	SD	t	df	Sig.
F0	Choral singers	162.03	19.63	6.29	18	<0.001
	Nonsingers	120.21	7.47			
Jitter	Choral singers	0.31	0.20	0.211	18	0.835
	Nonsingers	0.30	0.13			
Shimmer	Choral singers	3.34	1.05	−3.82	18	0.001
	Nonsingers	4.21	1.84			
Noise-to-harmonics ratio	Choral singers	0.02	0.015	−2.44	18	0.025
	Nonsingers	0.05	0.040			

Abbreviations: df, degrees of freedom; Sig., *p*-value.

TABLE 3.
Mean and Standard Deviation of Aerodynamic Parameters in Female Choral Singers and Nonsingers

				Independent *t* test		
Aerodynamic Parameters	Group	Mean	SD	t	df	Sig.
VC	Choral singers	2.88	0.59	5.96	18	<0.001
	Nonsingers	1.46	0.45			
FVC	Choral singers	2.72	0.46	0.577	18	0.571
	Nonsingers	2.57	0.70			
SVC	Choral singers	3.00	0.43	3.65	18	0.002
	Nonsingers	2.04	0.70			

Abbreviations: df, degrees of freedom; Sig., *p*-value.

TABLE 4.
Means and Standard Deviations of Aerodynamic Parameters in Male Choral Singers and Nonsingers

				Independent *t* test		
Aerodynamic Parameters	Group	Mean	SD	t	df	Sig.
VC	Choral singers	2.89	1.02	−0.54	18	0.59
	Nonsingers	2.67	0.81			
FVC	Choral singers	3.14	0.89	1.34	18	0.19
	Nonsingers	3.55	0.34			
SVC	Choral singers	3.34	1.37	−1.32	18	0.20
	Nonsingers	2.70	0.66			

Abbreviations: df, degrees of freedom; Sig., *p*-value.

the difference was statistically not significant [$t(18) = 0.577$, $P > 0.05$]; SVC was also found to be higher in choral singer group (M = 3.002 L) compared to nonsingers (M = 2.04 L), and the difference was statistically significant [$t(18) = 3.65$, $P < 0.05$].

The means and SDs were calculated for the aerodynamic parameters, and independent sample *t* test was done to compare male choral singers and nonsingers; the results are summarized in Table 4. Results of aerodynamic analysis for male group revealed higher VC in choral singers (M = 2.89 L) than nonsingers (M = 2.67 L); however, the difference was statistically not significant [$t(18) = 0.542$, $P > 0.05$]; FVC was found to be higher for nonsingers (M = 3.55 L) compared to choral singers (M = 3.314 L), although the difference was not statistically significant [$t(18) = 1.345$, $P > 0.05$]; SVC was also found to be higher in choral singers (M = 3.34 L) compared to nonsingers (M = 2.70 L); however, the difference was not statistically significant [$t(18) = 1.328$, $P > 0.05$].

DISCUSSION

The present study aimed at investigating the acoustic and the aerodynamic characteristics of choral singers and nonsingers. The first objective was to study the acoustic characteristics of choral singers and compare these with nonsingers. The results of the acoustic analysis revealed no significant difference between choral singers and nonsingers on fundamental frequency in females, whereas significant differences were found in males. There was no significant difference between female choral singers and nonsingers on jitter%, shimmer%, and NHR, whereas a significant difference was found between choral singers and nonsingers in males for shimmer% and NHR. The increased F0 was seen in both males and females choral singers compared to nonsingers, and this could be due to the continuous practice of voice modulation of high-frequency sounds during choral singing even though this is not learned through formal singing training. Mendes et al[6] performed a longitudinal study of voice majors in college and found increased maximum phonation frequency range, which suggested that voice majors with ongoing vocal training were able to increase their singing F0 range. The lower perturbation measures and NHR in choral singers compared to nonsingers indicate better control of phonatory and respiratory system resulting in improved voice quality because of long-term singing habits among choral singers.

The second objective was to explore the aerodynamic characteristics of choral singers and compare these with nonsingers. Aerodynamic analysis of choral singers and nonsingers revealed increased lung volume capacities in choral singers as seen with high VC, FVC, and SVC compared to nonsingers. This could be due to the fact that choral singing task, similar to other types of singing, demands better respiratory control especially during the expiratory phase.

Long-term singing practices modify breathing pattern among singers resulting in enhanced control over the muscles involved in respiration such as the diaphragm and external intercostal muscles during inhalation and exhalation. In contrast to normal breathing, when breathing while singing, the diaphragm contracts more deeply than usual and meanwhile,

the external intercostals muscles contract to lift and expand the ribcage. Further, the exhalation muscles contract and compress the abdominal viscera helping singers to sustain rib expansion for a longer duration. Singing training helps singers to balance the inhalation and the exhalation phases to maintain consistent subglottic pressure and glottal flow to sustain the singing.[14] Irzaldy et al also found that average lung VC of choir singers was significantly higher (3.12 L) than that of nonsingers (2.73 L). There was a significant difference between choral singers and nonsingers for FVC, but for inspiratory capacity, there was no significant difference. This increase in VC in choral singers has been attributed to an increase in strength of expiratory muscles because of singing.[12]

CONCLUSIONS

The present study was carried out to investigate the differences in acoustic and in aerodynamic parameters, and the results revealed better control over phonatory and respiratory subsystems among choral singers compared to nonsingers in the Indian context, although the choral singers were untrained. This could be possible due to the fact that long-term singing practices result in better control over vocal modulation and expiratory phase as revealed through frequency and perturbation measures as well as by increased lung capacities among singers. As the participants of the present study majorly practice Indian choral singing, the results of this study can only be generalized to the Indian context. Further, as the participants of the choral singing group are untrained, more studies are required to compare the acoustic and the aerodynamic parameters with trained choral singers in the Indian context. Future research should be focused on understanding the long-term effects of untrained singing practices on the vocal health of these individuals, which will help speech-language pathologists to assess and to treat the voice disorders among untrained choral singers.

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