VOCAL ECONOMY IN FEMALE TRAINED SINGERS AND NON SINGERS

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May, 2015

CERTIFICATE

This is to certify that this dissertation entitled "***Vocal Economy in Female Trained Singers and Non singers***" is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 13SLP015. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"*Vocal Economy in Female Trained Singers and Non singers*"** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"*Vocal Economy in Female Trained Singers and non singers*"** is the result of my own study under the guidance of Dr. K. Yeshoda, HOD, Department of Clinical Services, Reader in Speech Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore, **Registration No. 13SLP015**

May, 2015

Dedicated to,

AMMA, APPA, MINTU

&

Beloved Yeshoda madam

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Proverbs 3:5-6 "Trust in the LORD with all thine heart; and lean not unto thine own understanding."

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CHAPTER I

INTRODUCTION

"There is no instrument capable of producing a tone at all comparable to that of human voice: - and the glory of all other instruments consists in the nearness of their approach to its marvellous perfection" (Bassini,2008)

The human voice can be considered as the main mean of expression of mankind. Human beings are able to express their emotions, thoughts and observations in variegated and personal way and also possess the unique gift of spoken language. Voice conveys a kaleidoscope of emotional undercurrents such as joy, excitement, tranquillity, irritation, suspicion, true sympathy or lack of it, humour which softens the sly thrust, and the venom of hate. The human voice is a carrier of personality and identity (Greene, 1972).

In history, great personalities were identified and dominated around the globe through their invisible strength of voice (Thomas, Pankaja & Jayakumar, 2011). When the voice deteriorates as a result of strain or disease, the whole personality suffers with giving rise to feelings of inadequacy and insecurity. (Greene, 1972).

A well-functioning voice, however, is not straightforward, but voice problems are very common. Women are reported to have more voice problems than men (Russel, 1998) and this can be attributed to anatomical, physiological and hormonal reasons. Anatomical reasons are 20% larger anterior-posterior dimension of the male cartilage than that of the female (Kahane,1978) and greater membranous length of male vocal fold when compared to female,16 mm and 10 mm respectively (Kahane,1978). These two factors can explain the high fundamental frequency in females. Hirano (1983) reported greater percentage of collagen fibres in the male vocal folds than in the female, which may account for better endurance of the male laryngeal structures (Fung, 1981).

The higher prevalence of voice problems in females has been attributed to higher fundamental frequency (F0) (Rantala & Vilkman, 1999), which naturally implies that whatever loading mechanisms are related to the vocal fold vibration, the number of their repeated occurrence for a specific time period is about double in females compared to males. Gender-related differences in the laryngeal structure (Titze, 1989), in vocal fold tissue and molecular structure (Titze, 1994) and hormonal factors (Virolainen, Tuohimaa, Aitasalo, Kyttä & Vanharanta-Hiltune, 1986; Newman, Butler, Hammond, Gray, 2000) could also contribute to the higher prevalence of voice problems in females (Virolainen et al, 1986; Newman et al, 2000; Titze, 1999).

Voice disorders in those who depend upon good speech for living – the teacher, salesman, actor or singers- produce quite obvious anxieties on account of serious professional and economic hazards involved (Greene, 1972). A professional voice user can be defined as "an individual who depends on a consistent and appealing voice quality as a main tool in their employment" (Hazlett, Duffy & Moorhead, 2009). Professional singers are one such group of individuals who spend years in vocal training to improve their voice quality.

Carnatic singers are those who learnt Carnatic style of music, which is a system of music commonly associated with the southern part of the Indian subcontinent, with its area roughly confined to four modern states of India like Andhra Pradesh, Karnataka, Kerala, and Tamil Nadu. An accomplished music teacher, "guru" trains the students and usually starts by the age of 5-6 years. The training is usually on a one-to-one basis. The training is structured in such a way that right notes called ''swaras'' is focussed in initial training followed by a stage where they learn to sing different compositions called ''ragas''. The main base for the classical music is these "ragas". The rhythmic structure of each composition is called as ‘‘tala’’. Typically, the compositions are within 2–2.5 octaves. Carnatic classical singers adjust their base pitch called ‘‘aadhara shruthi’’ depending on the ‘‘raga’’. Based on the ‘‘aadhara shruthi’’, the other notes in the composition are adjusted. Like Western classical singers, Carnatic singers undergo regular training and practice to achieve proficiency in singing (Arunachalam, Boominathan &Mahalingam, 2014). There is an exquisite tradition in Classical Carnatic music and examinations are conducted for Junior, Senior and Vidwat levels (Girish &Rajasudhakar, 2011).

A larger spectrum of singers have tendencies to expose their voices to elevated risk factors and not preserving their vocal systems from the impact of excessive vocal usage(Van der Merwe , Van Tonder , Pretorius & Crous H,1996; Broaddus-Lawrence, Treole, McCabb, Allen& Toppin,2000). Major voice risk factors are (i) using the voice without rest (ii) voice usage in nonfavorable organic or environmental conditions (iii) using the voice in an effortful manner, and (iv) reserving a limited time to recover after illness that affects the voice(Vilkman, Lauri, Alku, Sala & Sihvo,1997;Timmermans, De bodt, Wuyts,Van de heyning, 2003) As a consequence, singers may be prone to develop vocal cumulative effects of symptoms related with vocal fatigue, a condition associated with excessive voice demands placed on speakers, in which loss of phonatory abilities develops, as phonatory effort increases(McCabe,2002).

“Voice fatigue is typically described as an array of self-reported symptoms related to the overtaxing of the larynx, leading to a chronic subjective sensation of voicing tiredness that tends to increase with voicing activity, and in many cases progresses with time” (Timmermans , Vanderwegen & De bodt .,2005; Braun-Janzen & Zeine ,2009; Mattiske , Oates , Greenwood ,1998;Welham & Maclagan ,2004 ;Verdolini & Ramig ,2001). These symptoms are perceived as changes and irregularities in the quality of voice, including restricted intensity and frequency ranges (Kitch & Oates, 1994; Titze, 1999; Verdolini, 1999, Hillman &Mehta, 2011). The literature reveals that vocal fatigue symptoms may have a detrimental impact on economic and vocational goals of professional and preprofessional voice users, and consequently effect their quality of life and psychological well being (Kitch &, Oates, 1994;Titze ,1999;Verdolini,1999;Behlau & Oliveira ,2009).

"Economy" according to Oxford English Dictionary is "careful use of available resources". "Vocal economy" is relatively a new term, according to Berry, Verdolini, Montequin, Hess, Chan & Titze (2001) can be defined as" the ratio between voice output (decibels) and intraglottal impact stress (kilopascal) under constant subglottic pressure and frequency conditions". Many studies attempted to quantify vocal economy, as this would be helpful for intensive voice users like professional voice users, especially singers.

One such attempt was to introduce a term "Quasi Output Cost Ratio" (Laukkannen & Kankare, 2012; Berry, Montequin, Verdolini, Hess, Chan & Titze, 2001; Master, Guzman & Dowdall,2013)

$$QOCR = [SPL (dB)/CQ\ EGG] * [T/T\ 0\ ]$$

where SPL is the sound pressure level, CQ EGG is the CQ measured from electroglottogram (EGG) signal, T is the period length, and T0 is the period length for the mean F0 in speech (0.005 seconds in females and 0.01 seconds in males). The applicability of this formula was researched in various professional voice users like teachers (Laukkannen et al, 2009) and actresses (Master et al, 2013) which yielded positive signal for further researches.

Need for the study

Professional singers are unique group of professional voice users in whom even subtle differences in voice could create greater impact. Singers spend a lot of time in developing their voices through practice and training to meet their voice expectations. So there is need to know the vocal economy in these groups of professional voice users where demand for high quality is demanded. Excessive voice use may accompany greater level of impact stress on Lamina Propria (Jiang& Titze, 1994; Horacek, Laukkanen & Sidlof, 2007) and singers are no different. But systematic training for many years could make their vocal structures resistant to impact stress and this factor has to be researched. So vocal economy has to be compared between trained singers and untrained non singers to find the differences. QOCR is relatively new measure to assess vocal economy. So, there is an increased need to check the validity of the measure in different populations before its application in clinical setup. It is proved that higher QOCR values imply better vocal economy. Therefore, vocal training might be useful in enhancing QOCR values signifying vocal economy. The present study is planned to examine this statement.

CHAPTER II

REVIEW OF LITERATURE

"Our voices influence nearly every part of human interaction and culture….." (Greene, 1967).

Voice can be considered as the musical sound produced by vibration of the vocal cords in the larynx by air from the lungs. Quite apart from the word chosen to express thoughts, control of voice is an essential component in the individual's ability to adjust to social situations, to make good contact and maintain equilibrium in relation to the audience whether it be one or many (Greene, 1967).

According to Koufman and Isaacson (1991), professional voice users are those individuals who are directly dependent on vocal communication for their livelihood. They put forth a classification for classifying the professional voice users:

Level 1: Professional Elite vocal performer (professional singers and professional actors). Even the slightest voice problems immediately endanger the exercise of their profession and also constitute a hazard to the personal career. Cancellation results in loss of money and endangers the engagement (stage appearance, concerts).

Level 2: Semi- professional Elite vocal performer (singing and acting students). Voice problems protract their professional training; cancellation will result in the loss of money.

Level 3: Professional Voice User (teachers, priests, salesmen, and telephone operators). Voice problems are impediment to the pursuit of their profession, prolonged illness will in some cases, lead to serious problems as dismissal and vocational training.

Level 4: Semi-professional voice user (students, teachers, choir singers). Voice problems hinder the professional training, or have consequences in the leisure time activity of choir singing.

According to classification, Professional singers are a group of professional voice users who are the most affected by subtle changes with their voices. Singing is a sensory motor phenomenon that requires particular physical skills and when these skills are developed in a sensitive performer, it becomes an art and involves high degree coordination of the vocal mechanism. Communication is the goal of every singer and it is made possible by the effective interaction of intellectual, psychological and acoustic factors (Bunch, 1982).

There is a general expectation that a singer always perform at his/her best, with a strong, pure, and clear voice with good range and unique character. Minor changes in the voice quality are immediately scrutinised, far more than is expected. So, they are expected to economise the voice use so that there could be better vocal efficiency.

Vocal economy is a term which emerged from this perspective. Vocal economy is defined as the ratio between voice output (decibels) and intraglottal impact stress (kilopascal) under constant subglottic pressure and frequency conditions. This is a way of measuring the maximum vocal output with the least amount of stress on the larynx. High fundamental frequency (F0), high sound pressure level (SPL), and high glottal adduction are assumed to increase the degree of impact stress on vocal fold tissues. So, the possibility of vocal fold trauma is plausible.

High sound pressure level (SPL) and high Fundamental frequency (F0) (Jiang & Titze, 1994) are considered to increase when there is high impact stress on the vocal folds. "Impact stress" is defined as the "force per unit area" which is a borrowed term from Physics. This concept was applied to voice production to describe how strongly the vocal folds collide during vibration. It has been considered as one of the main factor of vocal loading and cause for hyper functional voice disorders like vocal nodules (Titze, 1994). Therefore, Impact stress can be considered as the price of decibels. So, this price of decibels increases loudness and pitch of voice and leads to hyper functional phonation.

Various reseaches had emerged to quantify the vocal economy. However, Verdolini et al, 1998 obtained results suggesting that the closed quotient (CQ, closed time/period length), gained from the electroglottogram, correlates with Impact stress. In his experiment, two larynges were excised and mounted on a micrometer for varying the vocal fold length. Vocal fold vibrations were induced using a humidifier (ConchaTherm III heater-humidifier, Respiratory Care, Inc). An open-ended manometer (Dwyer No. 1211) was used to measure the subglottic pressure. The impact stress was measured in kPa at the anteroposterior midpoint of the membranous vocal folds. Impact stress was measured using a round, Precision Measurement Type 060 piezoresistive transducer (Ann Arbor, Michigan) with a frequency response from DC to 50 kHz and a dynamic range of 050 psi (approximately 0-345kPa).

Electroglottogram (EGG) was measured using (SynchroVoice Inc.) from the mounted larynges. Tektronik 2212 60-MHz Digital Storage Oscilloscope was used to monitor online the EGG and impact stress signals during the experiment. Results revealed that when threshold and saturation effects were excluded, contact quotient and impact stress had a strong correlation. It was found that there was linear relationship between contact quotient and impact stress i.e. an increase of 0.15 in contact quotient (CQ) leads to an increase of 1kPa in terms of impact stress. Thus when the vocal folds collide strongly during vibration they remain in contact with each other for a longer duration thus leading to a rise in contact quotient and impact stress (Verdolini et al, 1998). The study tried to throw some light on the importance of contact quotient as an indicator to the extent of impact stress on the vocal folds. Contact Quotient has also been reported to reflect phonation type, tending to be higher in a more hyper functional phonation (Verdolini et al, 1998).

McCoy & Scott (2007) opined that Contact Quotient (CQ) specifically related to the ratio of time the glottis is closed versus open during each cycle of oscillation, a reading of 0.50 would indicate the glottis is closed for 50% of each cycle. High CQ requires increased glottal adduction, which might correspond to stronger contraction of the interarytenoid and lateral cricoarytenoid muscles, as well as increased medial compression from activity in the thyroarytenoids.

Berry (2001) presented an 'output-cost ratio' (OCR), where the acoustic output (in SPL, dB) is expressed relative to Impact stress:

$$\text{OCR} = 20\ \log_{10}\left(\frac{P_A}{P_0}\right) - 20\ \log_{10}\left(\frac{\sigma_P}{\sigma_0}\right)$$

where σ_p is the impact stress and σ_0 is some nominal value of stress. With this definition, OCR can be computed as the SPL (sound pressure level) minus ISL (impact stress level).

This equation was applied in experiments with excised larynges and in studies with computer models of voice production. It is more problematic to apply to humans, since Impact Stress (IS) is very difficult to measure directly in humans, even though some attempts have been made.

In this study, five canine larynges were excised and it was mounted on a micrometer. The experimental set up was similar to the one carried by (Verdolini et al, 1998). Parameters such as fundamental frequency were kept constant at 150 Hz and the sub glottal pressure was varied from 1.0 to 1.6kPa. Glottal width and vocal processes was varied from a pressed condition to a 2-mm gap. The output cost ratio (OCR) was measured as a function of glottal width. A maximum value in the output cost ratio (OCR) was obtained with no vocal tract, across all pressure conditions, at about 0.6mm. It was suggested that through computer simulations, sharper maxima may be seen when the effect of vocal tract comes into picture. The experimental results correlated with the earlier investigations (Verdolini & Titze, 1995). As a result the output cost ratio (OCR) was considered as a value which was potentially of clinical relevance. This experiment was a key to measure impact stress and its application in clinical utility.

Laukkannen et al (2009) modified the equation presented by Berry et al. based on the correlation between Closed Quotient obtained from EGG and Impact stress as reported by Verdolini et al., 1998. The resulting equation will be called the 'quasi-output-cost ratio' (QOCR) or 'economy ratio':

$$QOCR = [SPL\ (dB)/CQ\ EGG] * [T/T0]$$

Here F 0 has been taken into account in the form of T =period length, which is presented as normalized to the average F 0 in males or females. In the former case, T 0 is set at 10 ms (corresponding to 100 Hz), in T0 is set at 10 ms (corresponding to 100 Hz), in the latter it is set at 5 ms (corresponding to 200 Hz).

Vocal economy using QOCR value in different vocally trained groups was also carried out. It is expected that vocally trained individuals to have more vocal economy. One such study was by comparing the vocal economy of vocally trained actresses and untrained non actresses (Master, Guzman & Dowdall, 2013). A total of 30 actresses and 30 non actresses were recruited and participants were required to sustain the vowels /a/, /i/ and /u/, in habitual, moderate and high intensity levels. Acoustic variables such as sound pressure level (SPL), fundamental frequency (F0), and glottal contact quotient (CQ) were obtained. Even though the actresses demonstrated higher QOCR, the differences did not reach statistical significance. In the study it was found that no differences among groups were found for F0, SPL, and CQ in habitual loudness level. In moderate and high intensity, actresses demonstrated higher values of SPL than non actresses. However, QOCR values did not differ among the groups.

Laukkannen et al, (2013) conducted a study based on QOCR values in teachers. The questions raised were whether (1) vocal economy correlates negatively with self-reported symptoms of vocal loading after a loading test, and (2) whether professional voice users (teachers) and students with and without voice training differ from each other in terms of vocal economy.

The results showed that the QOCR value was highest in teachers followed by students who were undergoing vocal training followed by students without vocal training. Teachers differed from students by having a higher QOCR. Various other vocal parameters also differed. To some extent these differences, like lower F0 in teachers, may be related to age differences between the groups (Krook, 1988; Nishio, 2008). However, a higher QOCR may also reflect the effects of voice training and experience in voice use. QOCR did not correlate with symptoms of vocal fatigue after a vocal loading test. Symptoms may be more related to individual tissue endurance or sensitivity to sensations than to vocal economy. Methods for reliable quantification of the true effects of loading ('loadedness') are needed.

In a study by Kankare & Laukkanen (2012), phonation samples of 119 female kindergarten teachers from two large cities in Finland were recorded. Results revealed that there was a low and negative correlation between QOCR values and the perceived firmness of voicing at standard SPL and also at too high pitch for subjects at both SPLs. Moreover the QOCR values did not predict the results of the self report questionnaire on vocal fatigue.

The literature reviewed so far has not investigated the QOCR values in singers. As mentioned, the singers are vulnerable to voice disorders, and most frequent complaint reported by the singers are unable to raise pitch and maintain high pitch, less modulation, vocal fatigue, pain in throat, less register shifting. Singers spend their time in calibrating and smoothening their quality of voice through vocal training (Chapman, 2006).

In a survey conducted by Boominathan et al (2008) on professional singers from Tamil Nadu, 59% of them reported voice related concerns. The common symptoms reported were: change in voice quality, voice fatigue, discomfort in throat, hoarseness of voice, loss of voice, loss of intelligibility/ clarity of speech/ song, dry throat, shortness of breath, frequent throat clearing sensation, itchy throat, voice tightness, loss of voice control and inability to maintain shruthi/range.

In another study by Ravikumar, Boominathan and Mahalingam (2010), they analyzed 30 Carnatic singers and related the similar clinical findings (change in voice quality (53.3%), vocal fatigue (20%), difficulty in reaching higher pitches and discomfort and pain while singing (13.3%), difficulty sustaining voice, throat tightness and strain while singing (10%), difficulty reaching low pitches, dryness of throat and vocal fatigue (6.7%).

In the study to analyse the voice of classical Carnatic singers (Arunachalam, Boominathan & Mahalingam , 2014),attempt was made to obtain the subjective and objective measures .The symptoms reported were difficulty in singing low pitches and high pitches, dryness of throat, vocal fatigue, discomfort and pain while singing and difficulty in sustaining voice for a long duration. Video stroboscopic findings showed that 33% of the singers were diagnosed to have primary Muscle Tension Dysphonia (grades I, II and III),17% with laryngitis and 20% with vocal nodule which was attributed to vocal hyper function. The rating for the speaking voice was carried using GRBAS scale and overall grade rating (G) showed moderate deviation in the speaking voice in most of the singers. Among the aerodynamic measures, Maximum Phonation Time (MPT) was reduced in both male and female Carnatic singers. This finding was supported by the fact that, even though Carnatic singing highlights the importance of breathing for singing and improving breath support and control, no exercises or any formal training are incorporated to achieve the required breath support and control of singing. Singing frequency range was found out to be 2-2.5 octave comfortably when compared with historic expectations of 3 octaves. On the other hand Dysphonia Severity Index (DSI) scores showed normal to severe deviation. Voice disorder outcome profile (V-DOP) (Mahalingam, Boominathan & Balasubramaniyan, 2010) was administered to assess individual's perception of voice problems in different domains like physical, emotional, and functional aspects and the results revealed that functional domain scores were lesser compared to physical and emotional domains. These studies throw light into fact that, singers are the group who are susceptible to impact stress. Vocal training is proved to produce evident changes in improving endurance, control and dynamicity of voice.

Girish & Rajasudhakar, (2011) assessed the Voice Range Profile in different Carnatic singers supported this notion. Singers outperformed non-singers on VRP metrics/profile parameters. The difference in the performance was attributed to the training effect. That is, trained singers (Vidvat level singers) were superior in terms of adjusting their dynamic and pitch ranges with large capacities and were able to expand their phonatory skills in terms of frequency and intensity. These results were in agreement with the findings of Sulter et al., (1995) who reported better and higher VRP values in trained singers. Hence, one can be curious in knowing whether it is the vocal training or the amount of voice use which determines the vocal economy.

Aim of the study

The study tests the vocal economy in QOCR vales in two group of subjects- trained singers and untrained non singers.

Objectives of the study

The present study mainly address

i. to compare the vocal economy using QOCR estimate in trained singers and non singers

ii. Correlations between QOCR and different acoustic variables are also investigated in singers and non singers

CHAPTER III

METHOD

Participants

Subjects included for the study were eighteen formal trained Carnatic singers (Mean Age-24.33 years,SD-3.24) and twenty one untrained non singers(Mean Age-29.56 years, SD-4.54) in the age range of 20-35 years recruited from Mysore, Karnataka. The inclusion criteria for singers were formal training in classical Carnatic vocal music for a minimum of 8 years and with no past history or current issues of communication disorders. Inclusion criteria for non singers were the same age range as the singers with, no past history or current issues of voice disorder, no professional use of the voice and no previous vocal training.

Procedure

Informed consent was taken from the subjects for the study and they were initially briefed about the same. Later the instructions were given to the subjects about the task they have to perform.

The data recordings were carried out in a sound treated room of the institute. The background noise was <50dB as monitored by the Radio Shack Sound Level Meter. The data recordings were done at times convenient to the subjects. All the subjects (singers and non-singers) of the study were counselled about vocal hygiene tips and given pamphlets about the same after the conclusion of data recordings.

Instrumentation

EGG recordings were measured using Real Time EGG Analysis (Kay PENTAX, Lincoln Park, NJ), model 6103 which was connected to a Computerized Speech Lab (CSL), model 4500. Sound levels were measured using Radio Shack Sound Level Meter which was placed on a tripod stand.

Tasks

1. ***Phonation of the three vowels /a, i, u/ individually for 5 seconds thrice at soft loudness level***
2. ***Phonation of the three vowels /a, i, u/ individually for 5 seconds thrice at moderate loudness level***
3. ***Phonation of the three vowels /a, i, u/ individually for 5 seconds thrice at loud level***

The subjects were instructed to produce sustained vowel /a/, /i/, /u/ for at least a minimum of 5 seconds three times at three different loudness levels- soft, habitual and loud. An audio-video recorded demo of the task was also shown to the subjects when they failed to understand instructions. The subject in the audio-video recorded demo was an age matched female subject who was able to project her voice and carry out the task appropriately.

Subjects were instructed to be seated comfortably in an upright position for EEG recording and two surface electrodes were placed on the thyroid cartilage with an elastic neckband. The electrodes were attached to the Velcro strip and wrapped around the subject's neck comfortably. The electrode placement was adjusted in order to obtain clear visual signals of EGG recordings. The quality and morphology of the waveforms obtained during the EGG recordings was constantly monitored. Sound Level Meter was mounted on a tripod stand and placed in front of the subject at a distance of 30 cms. Then the subjects were asked to perform the tasks in a sequence.

SPL recordings along with EGG recordings were carried out simultaneously using Radio Shack Sound Level Meter and Real Time EGG Analysis connected to Computerized Speech Lab, Model 4500 respectively. Based on the EGG and SPL recordings, stable sections of the signal for each subject was considered for the three vowels ***/a, i, u/*** at three different loudness levels (soft, habitual and loud) to obtain the following parameters

1. SPL (dB) was noted from the digital display in the Radio Shack Sound Level Meter
2. EGG values: F_0 (Hertz)-number of cycles of vocal folds vibration per second for obtaining T= period length (inverse of F_0), CQ (contact quotient). The mean F_0 was considered for obtaining the value of T_0= period length which was normalized in female singers and was considered as a constant. Here the mean F_0 will be considered as 223 Hz for female singers and for non singers is 210 Hz (Joy & Yeshoda, 2004) and therefore T_0= 0.005 secs for the present study.
3. Quasi Output Cost Ratio: the quasi-output cost ratio (QOCR) values were calculated according to Laukkanen et al, (2009) using the following equation:

   $$QOCR= [SPL\ (dB)/CQ_{EGG}] \times [T/T_O]$$

   The SPL values and EGG parameters were used to calculate the QOCR.

Statistical Analysis: The obtained data was subjected to statistical analysis using Statistical Package for Social Sciences Version 21.0. All the variables in both the groups were subjected to Mann Whitney U Test, Friedman’s Test, Wilcoxon’ s Sign Rank Test and Spearman’s Correlation were carried out for detailed statistical analysis.

CHAPTER IV

RESULTS

The study aimed to quantify vocal economy [Quasi Output Cost Ratio (QOCR)] and its correlation with different acoustic variables such as Fundamental Frequency (F0), Sound Pressure Level (SPL) and Contact Quotient (CQ) in singers and non singers at three different loudness levels-soft, medium and loud.

Shapiro Willk test was carried out to check the normality in both the groups (singers and non singers). In many parameters normality was not seen ($p<0.05$). Hence, non parametric test was administered.

Mean, Standard Deviation (SD) and median was obtained for all the acoustic variables across both the groups as shown in the Table 1.

Table 1: *Mean, Standard Deviation and median of F0, SPL, CQ and QOCR values across the two groups singer and non singer groups in three loudness levels-soft, medium and loud*

		Singer			**Non singer**		
		Mean	Median	SD	Mean	Median	SD
	soft	53.26	53.11	1.37	55.27	55.33	2.38
SPL	medium	67.24	68.00	1.97	67.56	68.33	2.85
	loud	85.17	84.33	2.89	82.77	83.00	4.27
	soft	46.18	46.59	6.19	46.12	46.22	4.41
CQ	medium	44.47	44.35	2.66	45.16	45.37	3.23
	loud	49.45	48.79	3.40	48.00	49.77	5.25
	soft	188.04	191.60	20.65	197.42	197.77	23.56
F0	medium	231.76	230.13	17.43	230.73	232.02	20.21
	loud	307.95	312.31	38.81	287.88	280.59	35.64
	soft	1.25	1.24	.12	1.23	1.25	.13
QOCR	medium	1.31	1.31	.14	1.31	1.35	.13
	loud	1.44	1.11	.16	1.22	1.18	.18

From Table 1, it is observed that SPL values are higher for non singers in soft and loud phonation. While for medium phonation both groups had similar values as depicted Figure 1. The values for CQ does not indicate comparable differences for soft, medium and loud phonation across the groups as depicted in Figure 2.F0 values are higher for singers in loud phonation while lower for soft phonation and no comparable differences for medium phonation as shown in Figure 3. QOCR values are higher for singer group in soft and loud phonation while no comparable differences in medium phonation as depicted in Figure 4.

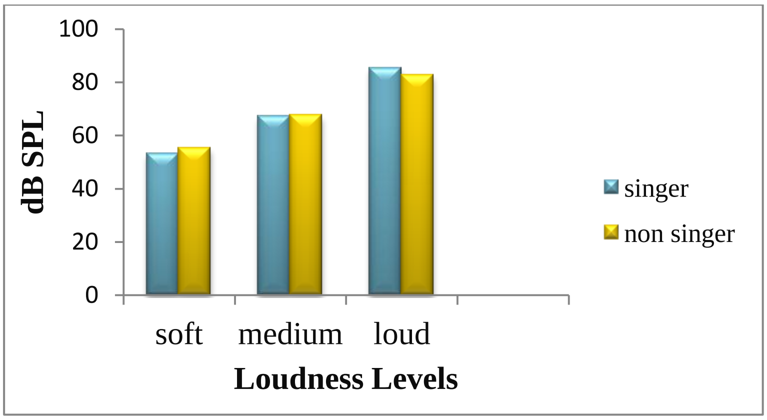

Figure 1: Mean values of sound pressure level across three loudness levels-soft, medium and loud

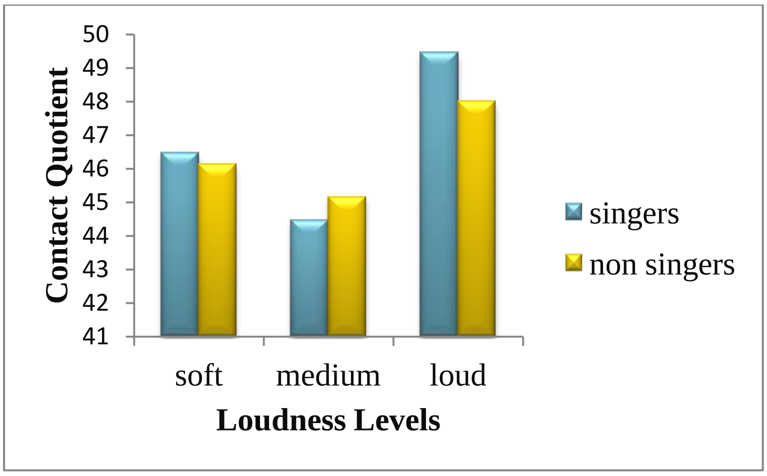

Figure 2: Mean values of Contact Quotient across three loudness levels-soft, medium and loud

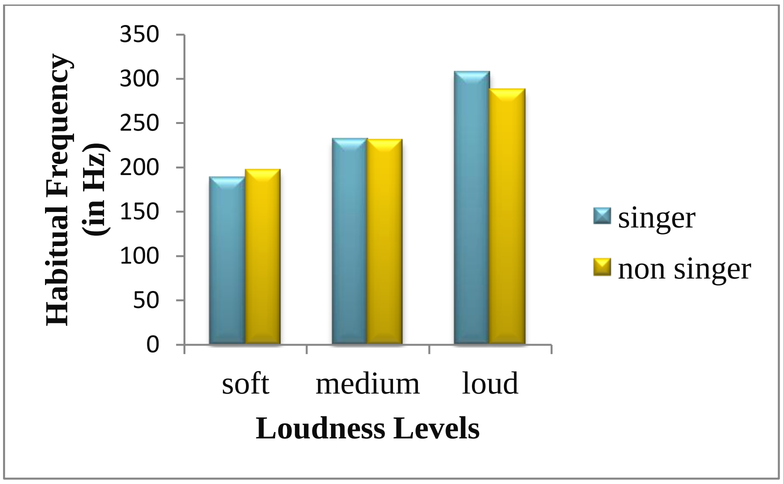

Figure3. Mean values of Habitual pitch across three loudness levels-soft, medium and loud

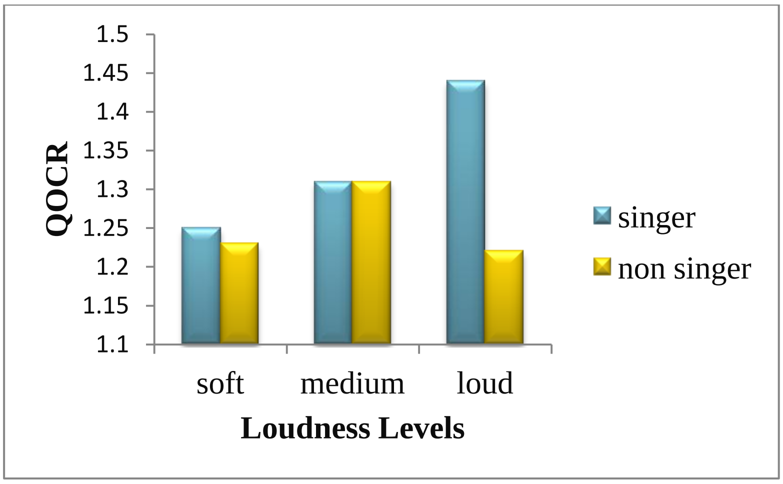

Figure 4. Mean values QOCR values across three loudness levels-soft, medium and loud.

The results of Mann Whitney U Test for QOCR values and other acoustic variables did not show significant difference (Z< 0.05) except for SPL soft across singers and non singers.

Table 2: *Results of Mann Whitney U test for QOCR values and different acoustic variables across the singer and non singer groups*

		Z value	Asymp.sig(2 tailed)
SPL	Soft	-2.496	.013
	medium	-.748	.455
	loud	-1.747	.081
CQ	Soft	-.028	.978
	Medium	-.944	.345
	loud	-.535	.592
F0	Soft	-1.338	.181
	Medium	-.296	.767
	Loud	-1.817	.069
QOCR	Soft	-.282	.778
	Medium	-.549	.583
	loud	-1.718	.086

Comparison of QOCR values within the groups (singers and non singers) across the three loudness levels were carried out using Friedman's test and significant difference ($\alpha < 0.05$) was seen in both the groups. In singers, α=0.002 and in non singers, α =0.013.

Wilcoxon Sign Rank Test was carried out for the pair wise comparison of QOCR values at different loudness levels (soft, medium and loud) within the group for singers and non singers.

Table 3: *Results of Wilcoxon's sign rank test of QOCR values of soft , medium and loud within the groups*

	Z value		Asymp. Sig. (2-tailed)	
	Singers	Non singers	Singers	Non singers
soft –medium	-2.417	-2.346	.016	.019
Medium-loud	-3.419	-2.381	.001	.017
Soft-loud	-2.504	-.122	.012	.903

It was found that singers had statistical significance in the pair wise comparison of QOCR values across all the three loudness levels as shown in Table 3. While in non singers, statistical significance was found for QOCR values of soft-medium and medium–loud.

Table 4: *Results of Spearman's Correlation among the acoustic variables (F0, SPL and CQ) for soft phonation*

		SPL –soft		**CQ-soft**		**F0-soft**		**QOCR-soft**	
		singers	Non singers	singers	Non singers	singers	Non singers	Singers	Non singers
SPL-soft	Correlation coefficient	1.00	1.000	.46	-.30	.17	.47*	-.37	.23
	Sig.(2 tailed)	.	.	.055	.19	.46	.03	.14	.32
CQ-soft	Correlation coefficient	.46	-.30	1.00	1.00	-.27	-.56**	-.53	-.33
	Sig.(2 tailed)	.055	.19	.	.	.28	.01	.025	.14
F0-soft	Correlation coefficient	.19	.47*	-.27	-.56**	1.00	1.00	-.52	-.35*
	Sig.(2 tailed)	.46	.03	.28	.01	.	.	.03	.12
QOCR-soft	Correlation coefficient	-.37	.23	-.53*	-.33	-.52*	-.35	1.00	1.00
	Sig.(2 tailed)	.14	.32	.03	.14	.03	.12	.	.

**. Correlation is significant at the 0.05 level (2-tailed).*

Table 5: *Results of Spearman's Correlation among the acoustic variables (F0, SPL and CQ) for medium phonation*

		SPL –med		CQ-med		F0-med		QOCR-med	
		singers	Non singers	singers	Non singers	singers	Non singers	Singers	Non singers
SPL-med	Correlation coefficient	1.000	1.000	.17	-.07	.24	.12	.17	.106
	Sig.(2 tailed)	.	.	.50	.76	.34	.39	.68	.677
CQ-med	Correlation coefficient	.17	-.07	1.00	1.00	.44	-.07	-.77	-.765
	Sig.(2 tailed)	.50	.76	.	.	.07	.91	.00	.000
F0-med	Correlation Coefficient	.24	.19	.44	-.03	1.00	1.00	-.79	-.789
	Sig.(2 tailed)	.34	.39	.07	.91	.	.	.00	.000
QOCR-med	Correlation coefficient	.11	.20	-.77**	-.66**	-.79**	-.59**	1.00	1.000
	Sig.(2 tailed)	.68	.37	.000	.00	.00	.005	.	.

**. Correlation is significant at the 0.05 level (2-tailed).*

***. Correlation is significant at the 0.01 level (2-tailed).*

Table 6: *Results of Spearman's Correlation among the acoustic variables (F0,SPL and CQ) for loud phonation*

		SPL –loud		CQ-loud		F0-loud		QOCR-loud	
		singers	Non singers	singers	Non singers	singers	Non singers	singers	Non singers
SPL-loud	Correlation coefficient	1.00	1.00	.06	.20	.56*	.24	-.32	-.06
	Sig.(2 tailed)	.	.	.81	.39	.02	.29	.19	.79
CQ-loud	Correlation coefficient	.06	.19	1.00	1.00	.01	-.11	-.35	-.55
	Sig.(2 tailed)	.81	.39	.	.	.96	.63	.15	.009
F0-loud	Correlation coefficient	.56*	.24	.01	-.11	1.00	1.00	-.84*	-.64
	Sig.(2 tailed)	.015	.29	.96	.63	.	.	.000	.002
QOCR-loud	Correlation coefficient	-.318	-.062	-.354	-.55**	-.84**	-.63**	1.00	1.00
	Sig.(2 tailed)	.19	.79	.15	.009	.000	.002	.	.

***. Correlation is significant at the 0.01 level (2-tailed).*

It is observed that from Table 4, for soft phonation, singers had a low positive correlation for SPL, moderate negative correlation for CQ and F0 with QOCR and for non singers, there was low positive correlation for all the acoustic variables with QOCR. For medium phonation, for singers, there was low positive correlation for SPL, high negative correlation for CQ and F0 with QOCR and for non singers, there was low positive correlation for SPL, moderate negative correlation for CQ and F0 with QOCR as depicted in Table 5. For loud phonation, for singers, there was low positive correlation for SPL and low negative correlation for CQ and high negative correlation for F0 with QOCR and for non singers there was low negative correlation for SPL, moderate negative correlation for CQ and F0 as shown in Table6.

CHAPTER V

DISCUSSION

Vocal economy, is defined as “the ratio between voice output (decibel) and intraglottal impact stress (kilopascal)”, one can expect vocally trained subjects to have higher QOCR values owing to low CQ and high SPL. Carnatic singing focuses on powerful voice with more emphasis on the low-pitched and a loud singing, execution of long musical phrases/notes across different octaves and tempos, and with clear articulation of vowels and consonants. So, it can be assumed that, this type of vocal training will get reflected in a measure of vocal economy, QOCR.

Singers demonstrated higher QOCR values in loud and soft phonation but differences were not statistically significant. It can be attributed to the fact that vocal training might contribute to individual sensitivity to sensations and tissue endurance than vocal economy. This is likely to help subjects to avoid vocal overloading -related voice problems. With time and training, the singers may adopt their own physiological strategies to perceptually sensitize subtle changes in their voice which would help them in attaining better vocal health rather than the vocal economy. The results also revealed statistical significance for SPL values at soft phonation across the groups in which singers having lower values. This can be attributed to the vocal training

Jiang and Titze (1994) reported that degree of SPL, F0, and glottal adduction increases with the impact stress. Thus, if there is low F0, CQ and SPL, the impact stress should be low. Findings by the research carried out by Laukkanen et al, (2009) are in accordance with the previous statement. Authors found lower F0, SPL, and CQ values in trained speakers when compared with untrained speakers. In the present study, no differences were found for mean values of F0, SPL, and CQ in medium loudness level across singers and non singers. Similar findings were also found for QOCR values across groups. This may be attributed to subject related factors. The inclusion criteria considered for the singers is based on the number of training years and not based on number of practising time a day.

Studies have found out a positive linear relationship between CQ and glottal impact stress (Verdolini et al, 1998; Laukkanen & Kankare, 2009). Glottal impact stress is also related to modes of phonation, for example, pressed phonation should show a high degree of impact stress, while breathy phonation a low impact stress (Jiang and Titze, 1994). So there should be negative correlation between glottal adduction and vocal economy. The present study are in concordance with earlier studies performed with the vocal economy measure QOCR (Verdolini et al, 1998; Laukkanen & Kankare, 2009). Consequently, the present study also obtained significant, moderate, and negative correlations between CQ and QOCR in all loudness levels for both singers and non singers.

In the present study a negative correlation was found between F0 and QOCR which supports the results of the previous studies (Laukkanen et al., 2009). Researchers have found that high F0 values can be associated with high glottal impact stress which can be linked to less economic voice production. On similar lines, Horacek et al, (2009) reported greater vocal fold tissue acceleration and deceleration at high values of F0. Tissue acceleration is considered to have greater effect on vocal loading leading higher impact stress (Jiang et al, 2000; Horacek et al, 2009. The present study also showed that F0 increased significantly as the intensity level was greater. Subjects produced the lowest F0 for soft phonation, higher F0 for medium intensity, and the highest F0 for loud phonation. This relation is in line with the earlier studies. Vocal intensity and voice F0 are normally interdependent.

The present study showed a low positive correlation for SPL verses QOCR. Among the studies, the relationship between these two parameters is the least consistent. Few studies have demonstrated negative (Verdolini et al,1998); and no correlation (Laukkanen & Kankare,2009). Considering the formula of the QOCR, the SPL is in the numerator; when it increases, the quotient SPL/CQ also increases and this would affect the final QOCR value. Increase in the SPL implies more impact stress (Jiang & Titze,1994; Horacek et al,2004) which would result in less vocal economy. This can be attributed from the physiological point that greater SPL is the resultant of increased subglottic pressure which increases tissue acceleration and thereby impact stress (Jiang et al, 2000)

In the present study, the mean QOCR values for singers showed an increase from soft to medium and from medium to loud intensity levels. An incremental change was demonstrated in SPL and F0. But, CQ did not show any significant differences in both the groups throughout the intensity levels. These are interesting changes from the physiologic point because, QOCR did not show a reduction when SPL and F0 increased together, when there was reduced changes in the glottal CQ throughout the loudness levels. This can be attributed to the fact that vocally trained speakers can produce more SPL (more vocal projection) without any increase of impact stress, but it is not necessarily for untrained participants. Therefore, in medium and loud intensity voice productions, more vocal economy was observed than in soft intensity.

To conclude, the results revealed that QOCR seems to be not able to reflect the effect of voice training in the voice use when comparing trained and untrained subjects in the present study. Additionally, F0 and CQ showed negative correlation with QOCR values which can be attributed to the higher impact stress. Considering the increase in SPL from soft to medium and from medium to loud intensity levels, singers demonstrated high vocal economy in medium and high intensity levels than in soft intensity owing to better voice output without increase in glottal adduction.

Future Directions

1. Questionnaires related to vocal fatigue symptoms can be used and its correlation with QOCR values can be studied .
2. Research can also be done to compare and see whether QOCR values varies across the levels of Carnatic vocal music training (junior, senior and vidwat)
3. Vocal economy cannot be concluded only by taking into account of phonation tasks. It would be a useful tool if new methods are devised in which speech tasks or reading tasks are incorporated to quantify vocal economy.
4. The similar studies can be replicated by considering the amount of practice .

CHAPTER VI

SUMMARY AND CONCLUSIONS

Voice conveys a kaleidoscope of emotional undercurrents such as joy, excitement, tranquillity, irritation, suspicion, true sympathy or lack of it, humour which softens the sly thrust, and the venom of hate. The human voice is a carrier of personality and identity (Greene,1972). A professional voice user can be defined as “an individual who depends on a consistent and appealing voice quality as a main tool in their employment. (Hazlett, Duffy & Moorhead, 2009) Professional singers are one such group of individuals who spend years in vocal training to improve their voice quality.

“Vocal economy” is relatively a new term, is defined as the ratio between voice output (decibels) and intraglottal impact stress (kilopascal) under constant subglottic pressure and frequency conditions. Many studies attempted to quantify vocal economy, as this would be helpful for intensive voice users like professional voice users, especially singers. One such attempt was to introduce a term “Quasi Output Cost Ratio” (Laukkannen & Kankare, 2012; Berry, Montequin, Verdolini, Hess, Chan & Titze, 2001; Master, Guzman & Dowdall, 2013)

$$QOCR = [SPL (dB)/CQ\ EGG] * [T/T\ 0]$$

The present study was one such step where the vocal economy was compared between trained singers and non singers. Subjects included were eighteen female trained Carnatic singers and twenty one untrained non singers in the age range of 20-35 years. EGG recordings and SPL values measured for phonation task (a,i,u) at three different loudness levels- soft, medium and loud. QOCR values were obtained using the formula. Statistical analysis were carried out using Statistical Package for Social Sciences Version 21.0. All the variables in both the groups were subjected to Mann Whitney U Test, Friedman’s Test, Wilcoxon' s Sign Rank Test and Spearman's Correlation were carried out for detailed statistical analysis.

The results in general revealed QOCR values and other acoustic variables did not show significant difference except SPL at "soft" production. The findings were attributed to the fact that vocal training might contribute to individual sensitivity to tissue endurance and susceptibility than vocal economy. In the present study, no differences were found for mean values of F0, SPL, and CQ in medium loudness level across singers and non singers. Similar findings were also found for QOCR values across groups. This may be attributed to subject related factors. The inclusion criteria considered for the singers is based on the number of training years and not based on number of practising time a day.

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