VOCAL REGISTERS IN CLASSICAL CARNATIC SINGERS: AN INQUIRY USING ELECTROGLOTTOGRAPHY

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May – 2009

Dedicated to:
My Lord
Jesus Christ

CERTIFICATE

This is to certify that this master's dissertation entitled "***Vocal Registers in Classical Carnatic Singers: An Inquiry using Electroglottography***" is the bonafide work done in part fulfillment of the degree of master of science (Speech Language Pathology) of the student with Reg.No.07SLP020. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other Diploma or Degree.

Place: Mysore
May 2009

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CERTIFICATE

This is to certify that this master's dissertation entitled "***Vocal Registers in Classical Carnatic Singers: An Inquiry using Electroglottography***" has been prepared under my supervision and guidance. It is also certified that this has not been submitted in any other university for the award of any Diploma or Degree.

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DECLARATION

This is to certify that this master's dissertation entitled "***Vocal Registers in Classical Carnatic Singers: An Inquiry using Electroglottography***" is the result of my own study and has not been submitted in any other university for the award of any Diploma or Degree.

Place: Mysore
May 2009

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Chapter 1

INTRODUCTION

The primary vehicle of human communication is language. Language may be defined as a socially shared code or conventional system for representing concepts through the use of arbitrary symbols and rule governed combinations of those symbols. Speech is a verbal means of communication for conveying meaning. It is the result of planning and executing of specific motor sequences. As such speech is a process that requires very precise neuromuscular coordination (Owens, 1996).

Speech can be further subdivided into voice, articulation, fluency and prosody. Voice has basic and important role in speech production. The production of voice is believed to be a complex process depending on the synchrony between respiratory, phonatory, resonatory and articulatory systems. "Human beings are highly vocal species and it is our ability to communicate via spoken word that makes us unique in the animal kingdom", (Hauser, 1996; Chomsky, 1965; & Fitch, 2002). The act of speaking is a very specialized way of using the vocal mechanism. The act of singing is even more so. Speaking and singing demand a combination and interaction of the mechanism of respiration, phonation, resonance and speech articulation. Boone, (1971) stated, "the best speakers and singers are often those persons, who by natural gift or by training or by a studied blend of both have mastered the acts of optimally using the voice mechanism". Singing requires all that speaking does but far greater skills in all spheres (Greene, 1972).

The vocal folds vibrate differently at low and high pitches. The different modes of vibration at these pitch levels contribute to distinct vocal qualities which singers and teachers of singing call registers. While scientists tend to approach the study of vocal registers as mechanical problem, and the voice scientists as an acoustical study, singers are concerned whether the sound is of equal quality and intensity throughout the entire range of pitches. One of the finest descriptions of registers is an early one by Nadoleqzny (1923).

The concept of register is understood to be a series of consecutive similar vocal tones which the musically trained can differentiate at specific places from another adjoining series of likewise internally similar tones. Its homogenous sounds depend on a definite, invariable behaviour of the harmonics. These rows of tones correspond to definite objectively and subjectively perceptible vibratory regions in the head, neck and chest. The position of the larynx changes more in natural singer during the transition from one series of tones to another than in a well trained singer. The registers are caused by a definite mechanism (belonging to that register) of tone production (vocal fold vibration, glottal shape, air consumption), which allows for a gradual transition however from one to an adjoining register. A number of these tones can actually be produced in two overlapping registers but not always with the same intensity. (Nair, 1999)

The registers have been named by singers according to the subjective sensations they produce. The low register is referred to as “chest”, because singing in that register produces a feeling of vibration in the upper chest and lower neck. The upper register is called “head” (female) or “falsetto”(male) because vibration are sensed high in head. The middle register is often called “mixed”/modal because it has the high and low qualities in it.

It is of interest to objectively quantify the frequency variations, frequency transitions that occur during register production. Electroglottography a tool to understand the vocal fold closure can be of great utility in such instances.

Electroglottography is a non invasive method for the examination of the vocal fold vibration (Baken, 1992). EGG was reported first by Fabre (1957) and since then several studies have been attempted to validate the laryngograph method. Fourcin (1974) is one of the pioneers to the study the larynx waveform extensively and he has described the method of obtaining the glottograms. EGG uses electrical current passing through the neck to measure vocal fold contact across time. Equipment contains two electrodes placed on either side of the thyroid alae, with a weak high frequency electrical current passing through the vocal folds as they vibrate. Tissue conducts the air better than the air, so the resistance will increase when the vocal folds are opening and decrease during the closing phase. Opening and closing of the vocal folds varies the transverse electric impedance producing variation in the electric voltage in phase with vocal fold vibration. The resultant voltage tracing is called an electroglottogram. It traces the opening and closing of the glottis and can be correlated with stroboscopic images. EGG allows objective determination of the presence or absence of the glottal vibrations, easy determination of the fundamental period of vibration, and is reproducible. It reflects the glottal condition more accurately during its closed phase and quantitative interpretation of the glottal condition is possible. The EGG gives information primarily about the closed glottis or vocal fold contact area.

The basic configuration of the device is depicted in the Figure 1 below. The electrodes are made of copper, silver or gold. They have the form of rings or rectangles covering an area ranging from 3 cm^2 to 9 cm^2. A third electrode is often used as a reference for impedance measurements. It may be designed as a separate electrode or as a ring electrode encircling each of the two other electrodes. The electrodes are usually mounted on a flexible band whose length may be adjusted to hold the electrodes in a steady position and to still allow the subject to comfortably speak and breathe naturally. A signal generator supplies the electrodes with an AC sinusoidal current of an alternating frequency usually ranging from 300 kHz to 5 MHz.

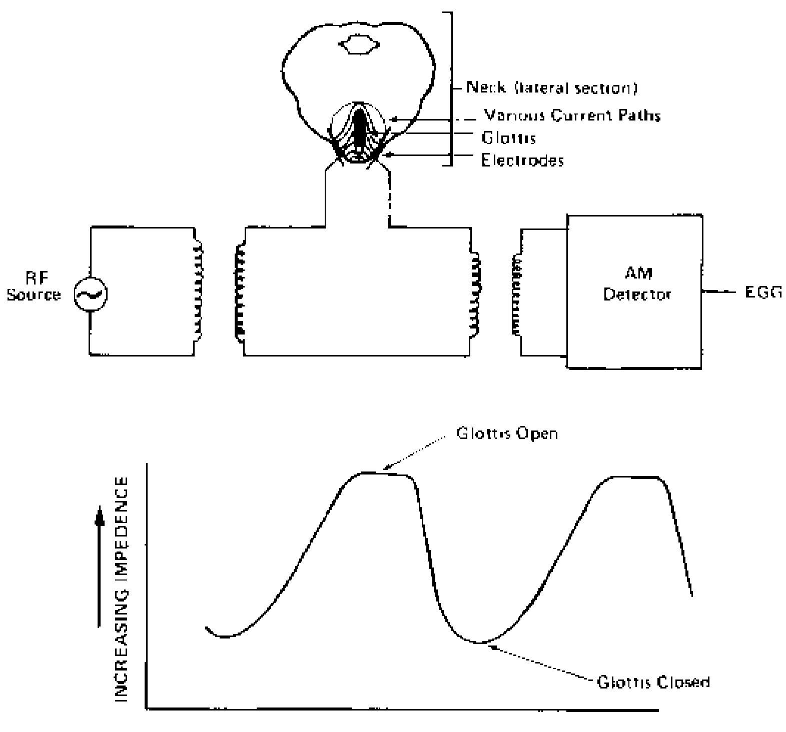


Figure 1: The principle of the EGG device (from Childers & Krishnamurthy, 1985).

The sensing electrode detects the current as it passes through the skin and the throat. The percentage of amplitude modulation of the received signal reflects the percentage change in tissue impedance in the current's path. The received signal is then demodulated by a signal detector circuit. The typical signal-to-noise ratio of the demodulator is about 40 dB. The demodulated waveform is then A/D converted and stored in a computer. Suitable additions to the standard configuration of the device consists of instruments for measuring the signal strength (e.g. a light-emitting diode) or for the measuring of signal symmetricity, showing the relation between the signals emitted by the two electrodes (Synchrovoice and F-J Electronics devices). This is very convenient for the proper placing of the electrodes.

The rapid variation in the conductance is caused mainly by the movement of the vocal folds. As they are separated, the transversal electrical impedance is high due to the fact that air impedance is much higher than tissue impedance. As they approximate, the contact between them increases and the impedance decreases, which results in a relatively higher current flow through the larynx structures. At the maximum contact the decrease is about 1% (up to 2%) of the total larynx conductance (Baken, 1992). According to Childers and Krishnamurthy (1985) the reason for the current modulation effect is a longer tissue passage for the radio frequency current when the glottis is open, since the total impedance of the tissue is a function of the length of the tissue passage.

Four major phases can be identified during a single vibratory cycle: the opening time, the closing time, the open time, the closed time, (Michel & Wendhal,1971). Various kinds of indices can be calculated by measuring the duration of different phases of vibratory cycle such as, open quotient, speed quotient, contact quotient, speed index, ‘s’ ratio, etc.

EGG has been extensively used to understand the vocal fold closure in different register production in singers and non singers. It has reported that the falsetto vibrational pattern in both male and female voices typically lacks the knee exhibiting a downward slope the typical pattern one is likely to encounter from EGG pattern is that one resembling a sinus curve lacking the abrupt changes of slope. Such a signal typically indicates the absence of a closed phase of the glottal cycle. (Nair, 1999)

The production of voice pitch range of any individual is the voice register it appears that and a particular register characterized a certain pattern of Vocal fold vibrations with the vocal cord approximated in a similar way throughout the pitch range. But as the pitch range reaches its maximum limit the folds adjust to new approximation contour which produces an abrupt change in vocal quality. (Boone, 1971)

The studies in the past have focused on various aspects of normal process of voice production, but there are very few studies which explain the physiological aspects of singing. The precise information about vocal fold behaviors in vocal registers is not well understood. Therefore the present study was planned to investigate the vocal registers and their physiological correlates in Indian classical singers following the Carnatic style using electroglottography.

Chapter: 2

REVIEW OF LITERATURE

Singing is a sensory motor phenomenon that requires particular balanced physical skill. A sensitive performer achieves singing as an art when these skills are developed. ‘Singing’ is such a human and moving act, both for those who sing and for those who listen. Hence singers are considered artists in the truest sense, as they combine concepts, melody, text and stage movement, making it all seem effortless and yet capable of winning audience appreciation (Bunch, 1982).

The term ‘*Registe’* was borrowed from the terminology of keyboard organs and has been used in vocal terminology since about the 13th century (Duey, 1951). But a few authors in the early 20th century maintained that a “natural voice” had no registers, so that voices were only in one register.

Timberlake, (1990) opined that singers when singing in their middle pitch range noticed sensations predominantly in the neck region and sound qualities that were different from those who sang in their uppermost or lower pitch ranges. So the terms chest (as sensations were predominantly in chest region), mixed and head or falsetto (as sensations were predominantly in the head region) were used.

It has been reported in literature that there are different registers for singing and speech. In speech, registers are recognized in ascending scale of pitch and they are: pulse (vocal fry), chest/modal, falsetto and whistle. In singing: they are denoted as the chest, head and falsetto for males; and chest, middle and head for females, (Thurman, Welch, Theimer, & Klitzke, 2004). Typical speaking registers are pulse, modal and falsetto; typical singing registers are chest, head and falsetto (Hollien, 1974).

Currently, the terms head register and falsetto register are used by various vocal pedagogues and voice scientists as labels for the different sound qualities produced in middle and higher pitch ranges. For some singing teachers, however, head register is immediately above chest, and falsetto is above head. To others, falsetto refers to all sound qualities above chest in both males and females, and sometimes the traditional high-range male falsetto is termed pure falsetto. Among speakers of English, the common, colloquial use of the term falsetto refers only to the female-like voice quality that males can make, Hollien (1974).

Hollien, (1974) reported and explained the production of four new registers: the pulse, the modal, the loft and flute registers.

Pulse register: a pulsated quality that can be produced in a very low pitch range below modal, a sound quality that also is called vocal fry. It is a form of phonation that occurs briefly in almost every utterance in some speakers. It can occur to a greater or lesser extent in individuals according to mood, level of fatigue or even degree of misuse of the laryngeal system. It occurs at lower frequencies than the modal voice and is characterized by a relatively random rate of vibration in comparison with the high degree of consistency evident in normal modal phonation. The frequency of phonation ranges from about 30 to

80 per second, with a mean of approximately 60 per second. F0 range is usually at the low end of the frequency scale: 25 to 80 Hz in men, 20 to 45 Hz in women. The term is broadly synonymous with “vocal fry”, “glottal fry”, or the musical term “strohbass”.

Modal register: a heavier or thicker voice quality that is produced in a lower pitch range. The label was a reference to the most common "mode" of voice function and the speech equivalent of chest register in singing pedagogy. The range of the fundamental frequencies most commonly used by speakers are from about 75 to about 450 HZ in men; 130 to 520 Hz in women. The vocal cord closure is achieved by mass of vocal folds brought together with sufficient stiffness to interrupt the pulmonary airflow briefly.

Loft register: a voice quality that is higher in pitch and lighter or thinner in quality, compared to modal register. It was the speech equivalent of head or falsetto register in singing pedagogy. It is employed at the upper end of the vocal continuum (275 to 620 Hz) in men: 490 to 1,130 Hz in women). The name is intended to convey to the older term “falsetto”.

Flute register: an even thinner quality that can be produced in a very high pitch range above loft. In singing it is called falsetto in males and in females it is sometimes referred to as whistle register.

PULSE

LOFT

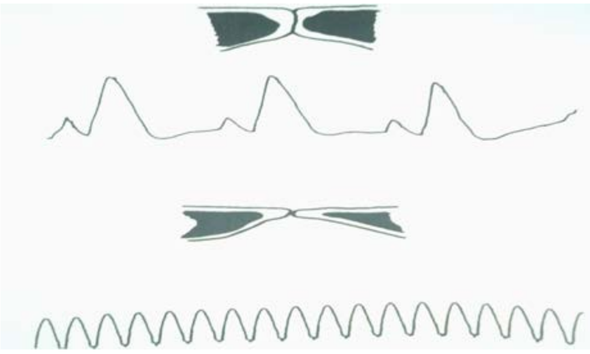


Fig 2: Cross section views of vocal fold configuration and resulting waves in pulse and loft registers.

Different registers sound different, but variant acoustic impression derived from changes in the way the vocal source signal is moulded by the vocal tract as well as from differences in the vocal source signal itself. A laryngeal register reflects a specific and distinct mode of the laryngeal action. Vocal tract contributions are irrelevant. A laryngeal registers is produced across a contiguous range of fundamental frequencies. The F0 range of any given laryngeal registers has little overlap with the F0 range of any other register.

Register changes may occur voluntarily or involuntarily. A voice occasionally breaks or cracks, a phenomenon attributed to a sudden register change. Registration is observed in both singing and speaking. Pitch factors have to be considered in terms of variations within the vibrating medium, supplemented by external mechanism that makes changes possible.

Transition between registers

Production and perception of different vocal registers are most pronounced when changing the voice quality in vocal register breaks. This change could be sudden, abrupt, or smooth. Smooth change is characteristic of classical educated singers, who use mixing of adjacent registers. The change is difficult to be perceived in such case. Abrupt change occurs in non-singers, or modern style singers. Well-know examples of register breaks are vocal jumps in young men suffering from voice mutation.

Transition from pulse to modal register

Acoustical sign of this transition is perception of continuity of the neighbouring pulses. Fundamental frequency for pulse register is very low and glottal pulses are perceived separately. There is broad band noise in the spectrogram. Modal register is normal, which is mainly used in spontaneous speech.

Transition from modal to falsetto register

This transition is generally the best known. Perceptually there is a marked change of voice timber. Falsetto, unlike modal register is characterized by thinner, softer voice quality (false voice) like female quality for men. Spectral differentiation of registers is spectral slope: smaller for modal (-12 dB/octave) and steeper for falsetto (- 18 dB/octave).

Transition from falsetto to whistle register

This event is not so common and its characterization is difficult. In whistle usually only the front parts of vocal folds vibrate, therefore produce quite high frequencies, and may be described as a tiny voice quality.

Nair (1999) opined that production of voice registers could be described from acoustical or physiological point of view. In particular there are three main factors influencing the voice register production: (a) Configuration of larynx – phonatory settings (mechanism of oscillation of the vocal folds), (b) Vocal tract resonance (formants setting influence resultant spectrum) and (c) Interaction of the sub glottal and supra glottal resonances with the vocal fold oscillations.

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. Correlations between CQ and registration: heavy mechanism (chest voice) is produced with a CQ generally in excess of 50%, light mechanism (head voice and falsetto) is produced with a CQ below 40% (the zone between 40 and 50% can be ambiguous and might be either a heavy or light source). 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.

In falsetto the vocal ligaments are pressed together so firmly by the strong contraction of the lateral cricoarytenoid (LCA) muscle, as well as the other muscles of approximation, that their edges are in contact for a short distance in front of the vocal processes, leaving only a shortened length of the ligament free to vibrate. Changes in vocal register may lead to differences in control of frequency. The description of laryngeal control of frequency relate most closely to modal register, in which a rise in vocal pitch is principally achieved by contractions of both the cricothroid and vocalis/thyroarytenoid. The most noticeable difference in muscle control between the modal and falsetto register is in the activity of the vocalis/ thyroarytenoid, Aikin (1902). Closed quotient varies in falsetto as well as in chest register (Nair, 1999).

Sawashima, Gay, Harris (1969) observed that in falsetto compared with modal register there is a marked decrease in electromyography activity for the vocalis /thyroarytenoid that is accompanied by a slight decrease in cricothyroid activity. The difference in the muscle control for the two registers results in a difference in the physical conditions of the cover and body of the vocal folds. The difference is reflected in the mode of the vocal fold vibration.

Aronson (1973) has explained the physiological mechanism of falsetto in term of both intrinsic and extrinsic muscles of larynx as follows: a) through the action of the thyrohyoid and the supra hyoid musculature the larynx would be elevated high in to the neck, b) through action of the stlyohyoid muscles the larynx would be tilted downwards, maintaining the vocal folds in a state of laxity, c) although the vocal folds would be in a flabby state, the contraction of the cricothyroid muscles will causes the vocal folds to be stretched, d) as a result the vocal fold mass reduces owing to loss resistance to sub glottal air pressure, e) and hence only the medical edges of the folds vibrate will vibrate because of reduced sub glottal air pressure.

Measurement of Vocal registers

Different techniques have been employed to study vocal registers. The technique employed varies with the subjects selected and the tasks involved. Electroglottography has been used in various studies to study the normal and abnormal anatomical and physiological correlates of voice production. It has been used extensively in understanding vocal fold closure patterns in singers, especially, during production of different registers.

Vilkman, Alku, Laukkanen (1995) studied the shifts in registers from chest to falsetto registers in trained and untrained male and female subjects. The shift from breathy "falsetto" phonation to normal chest voice phonation was studied in normal female (pitch range 170–180 Hz) and male (pitch range 94–110 Hz) subjects. The phonations gliding from falsetto to chest register were analyzed using adaptive inverse filtering and electroglottography. The results revealed that differences noticed in the trained and untrained subjects during the register shift were not significant and register shift were interpreted in terms of critical mass concept.

Blomgren (1998) did a study on 20 normal speakers' characterization of modal and vocal fry production. The results showed that considerable difference across voice parameters for modal and vocal fry registers. Fundamental frequency was lower in vocal fry than in modal for both males and females. In modal register difference was observed. Pitch and fundamental frequency were inter changeable as it means the rate of vibration of vocal cord during phonation. Mass, length and tension of vocal cords determines the fundamental frequency of voice, (Ohla, 1978).

EGG and vocal registers

Chen, Robb & Gilbert (2002) studied the vocal fry register men and women using EGG. EGG parameters noted were vocal F0, duration of opening and closing phase and SQ. Results revealed significantly higher F0, further, it also reveal that female speakers demonstrate greater increase in SQ in fry register, indicating longer opening-phase duration per glottal cycle. The results confirmed that the general notion that the gender difference exist even in vocal fry register.

Henrich, (2003) measured EGG vocal quotient in 18 classically trained male and female singers in different registers and results revealed that open quotient values are usually lowest in modal and chest when compared to falsetto and head. It was concluded that OQ depended on the functioning of laryngeal mechanism and the laryngeal mechanize were similar for males and females.

Henrich (2005) explores the relationship between open quotient and laryngeal mechanisms, vocal intensity, and fundamental frequency using EGG in 18 classically trained male and female singers in different vocal registers. It was found that open quotient (OQ) ranged from 0.3 to 0.8 in chest voice and from 0.5 to 0.95 in head and falsetto voices. The OQ was strongly related to vocal intensity in chest voice and to fundamental frequency in head and falsetto voices.

Henrich, d'Alessandro, Doval and Castellengo (2005) conducted a study and measured open quotient using EGG during speech and singing in three singers. EGG signals were analyzed, under various speech and singing conditions: sustained vowels, spoken and sung sentences, crescendos and decrescendos, glissandos. They reported that open quotient was different in male and female voices and depended on underlying laryngeal mechanism. The dynamic variations produced were much pronounced during speaking when compared to singing. And they also observed correlation between OQ and vocal intensity in vocal register.

Howard (1995) studied the upper registers in trained singers using EGG. The results revealed increased open phase duration and increased open quotient. It was reported that EGG wave morphology revealed sharp peaks during upper register production reflecting, the fact that only the superior area of the VF mucosa was in contact.

Archana (1987) in her study on five trained female singers investigated the efficacy of EGG parameters and LTAS to differentiate the musical notes within and across the registers in carnatic vocal music: Mandhra (low) sthayi, Madhya sthayi (mid), tara sthayi (high). And the results revealed that all EGG parameters: the open time, closed time, opening time, closing time, open phase, closed phase, open quotient, speed quotient, speed index and total period were significantly different across notes and registers.

Review suggest that the EGG findings are not uniform across studies due to the various factors like the subjects selected, the type of singing, the task employed and the instrumentation used. Hence the present study was planned to understand the vocal fold closure or laryngeal behaviour in singers during different register. The aims of the study were as follows:

1. To compare the EGG parameters across vocal registers in classical Carnatic singers.
2. To compare the EGG parameters between Carnatic singers and non singers across registers.

Chapter III

METHOD

Subjects: 40 females in the age range of 18-50 years with a mean age of 34 years participated in the study. Subjects had no complaints of vocal, speech or hearing problems at the time of recording. The subjects were divided into control group and experimental group. *Experimental group* consisted of 20 professional Carnatic singers with a minimum of 3 years of formal training in Carnatic classical musical form. *Control group* consisted of 20 female non-singers who had no formal training in any form of singing.

Recording Environment: Recording was carried out in department laboratory and data was recorded individually.

Procedure

Instrumentation: Kay Pentax Electroglottograph Model 6103 was used for acquisition of the EGG data. The acquired data was represented as (a) selected parameter, (b) F0 in Hz and (c) a glottal wave. The glottal wave was represented as time (in seconds) on X axis and amplitude of the signal (in volts) on Y axis. One glottal cycle at any given point could be measured by moving the cursor horizontally.

Instruction: All the subjects were explained about the purpose of the study. Familiarization was done for all subjects.

Singers: Singers were asked to sing song or a particular 'Raaga' wherein, transitions across the three registers occurred for the familiarization. Then they were asked to sing vowel /a/

in ascending scale in a single breath reaching the three sthayis (registers).

Non singers: were familiarized with suitable examples wherein the investigator sung the required task. They were asked to model the task and practice. Then they were instructed to sing vowel /a/ in the lowest pitch, habitual pitch and the highest pitch possible simultaneously in continuous manner and sustain the pitch for at least three seconds. They were asked to maintain a comfortable loudness level while singing.

Recording: The recordings were done individually. Subjects were seated comfortably in front of the instrument neckbands with the electrodes were tied to the neck and securely positioned on either sides of the thyroid prominence. They were asked to sit quiet without moving head and the positions of the electrodes were adjusted until clear EGG sine waveforms appeared on the screen when the subjects phonated. The gain of the instrument was also manually adjusted and the task was captured directly on to the instrument. Subjects were asked to sustain the pitch for at least 3 seconds. Each subject was asked to sing the vowel /a/ thrice and all the data were saved on to the computer memory. The recording that yielded best EGG waveform morphology was retained for extraction of the parameters. The cursor was positioned at the steady state of F0 and the following EGG parameters were extracted CQ, OQ, SQ, and F0.

Open quotient (OQ): is the proportion of the period during which the glottis is open to the total period and represented in percentage.

$$OQ = \frac{\text{Duration of Open phase}}{\text{Total period}} \times 100$$

Speed quotient (SQ): measures the ratio of opening and closing durations and represented in percentage.

$$SQ = \frac{\text{Duration of Opening phase}}{\text{Duration of Closing phase}} \times 100$$

Closed quotient (CQ): measures the degree of vocal fold approximation during phonation and is represented in percentage.

$$CQ = \frac{\text{Duration of Contact phase (Closed time)}}{\text{Total period}} \times 100$$

Fundamental frequency (F0): from the displayed data, the extracted mean F0 in Hertz was noted.

The measured EGG parameters were tabulated for further statistical analysis. The data was then subjected to suitable statistical analysis using SPSS software (version 15). Mean and standard deviation were extracted. Repeated measures ANOVA was done to analyze the variation of glottal parameters across registers within singers and independent t test was done for pair wise comparison of Carnatic singers and non singers for each parameter.

Chapter IV

RESULTS AND DISCUSSION

The study aimed to investigate the vocal fold closure during singing at different registers in Carnatic singers and non singers. The EGG parameters used in the current study were fundamental frequency (F0), contact quotient (CQ), open quotient (OQ), and speed quotient (SQ). Results are discussed under the following headings.

- Mean and standard deviations for the Carnatic singers and non singers across registers
- Comparison of Carnatic singers across registers.
- Comparison of non singers across registers.
- Comparison of Carnatic singers and non singers across registers

Mean and standard deviations for the Carnatic singers and non singers across registers

Mean and standard deviations for all the EGG parameters in the Carnatic singers in three different register (Chest, head and falsetto) are tabulated in Table 1. EGG values across registers showed no much difference except in fundamental frequency. Mean CQ and SQ values were higher in falsetto register and mean OQ scores were higher for head register.

Parameters	*Chest*		*Head*		*Falsetto*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
F0	169	31.40	223	31.72	351	39.58
CQ	46	4.29	45	5.16	47	3.54
OQ	53	4.29	54	5.15	52	3.54
SQ	116	91.20	102	81.19	127	95.40

Table 1: Mean and SD of EGG parameters across registers for Carnatic singers

Similarly, Mean and standard deviations were tabulated for non singers in three different registers in Table 2. The mean values EGG parameters for the non singers across registers do not show much difference except in fundamental frequency. Mean CQ and SQ values were higher in head register and mean OQ values were lower for head register.

Parameter	*Chest*		*Head*		*Falsetto*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
F0	193	12.43	210	21.74	341	47.14
CQ	41	7.55	43	3.45	41.21	6.71
OQ	58	7.56	56	3.44	58.78	6.71
SQ	233	115.96	258	84.50	210.91	122.51

Table 2: Mean and SD of EGG parameters across registers for non singers

Comparison of tables 1 and 2 gives an impression that non singers were not able to match the F0 of Carnatic singers across the registers. Especially in chest register, non singer obtained higher mean F0 values. Also the standard deviations of non singers were more compared to Carnatic singers in chest and falsetto registers. This indicates that non singers could not control their F0 production in chest and falsetto registers.

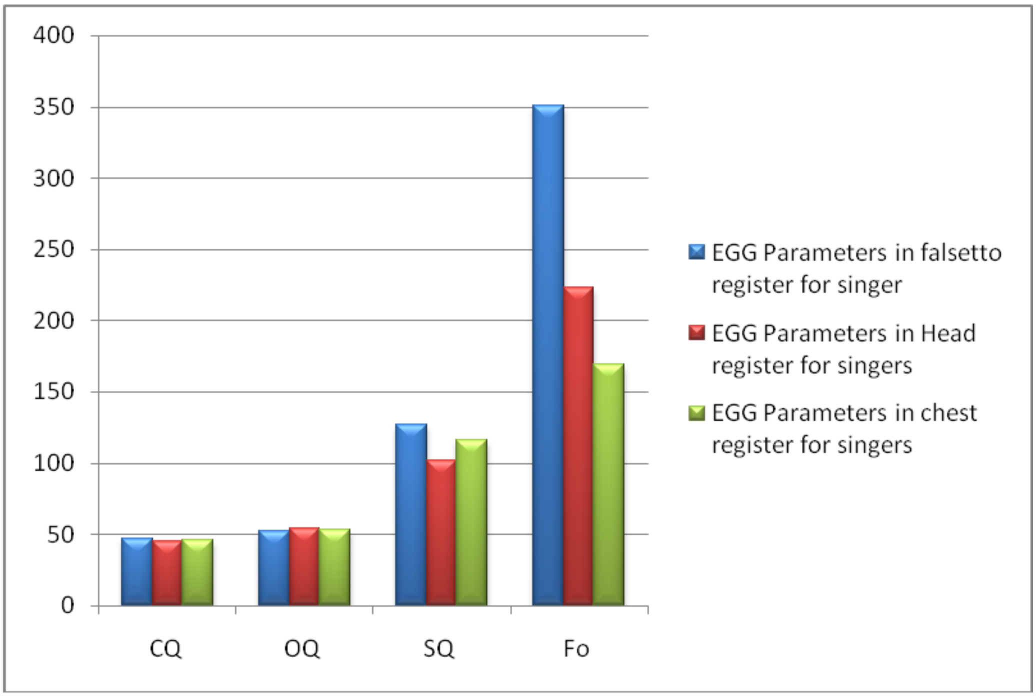
Comparison of Carnatic singers across registers

For the comparison of EGG parameters across three register, repeated measures ANOVA were used as shown in Table 3. It shows there is no significant difference across registers in any of the EGG parameters, except fundamental frequency which increased with the registers and was highest for falsetto and lowest for chest registers. Pair wise comparison for F0 showed significant difference across the three conditions.

Parameter	*Number of Subjects*	*f*	*Significance*
F0	20	227.36	0.000**
CQ	20	0.721	0.493
OQ	20	0.737	0.485
SQ	20	0.490	0.616

Table 3: f value across registers in Carnatic singers. **p<0.001

The findings of the current study results are in contrast with Archana (1987) and Henrich, et. Al., (2005). Archana (1987) reported significane at difference in EGG parameters across registers. Henrich et al (2005) found that OQ was higher in falsetto register. The glottal closure decreases as the rate of vocal fold vibration increases. This could explain the significant increase in F0 as register changes. The Graph 1 shows comparison for F0, OQ, SQ and SQ in singers across three registers. Although from the graph it is clear that only F0 had greater difference between the registers, even SQ was different between the registers but was not statistically significant.



Graph 1: Comparison of Carnatic singers across 3 registers

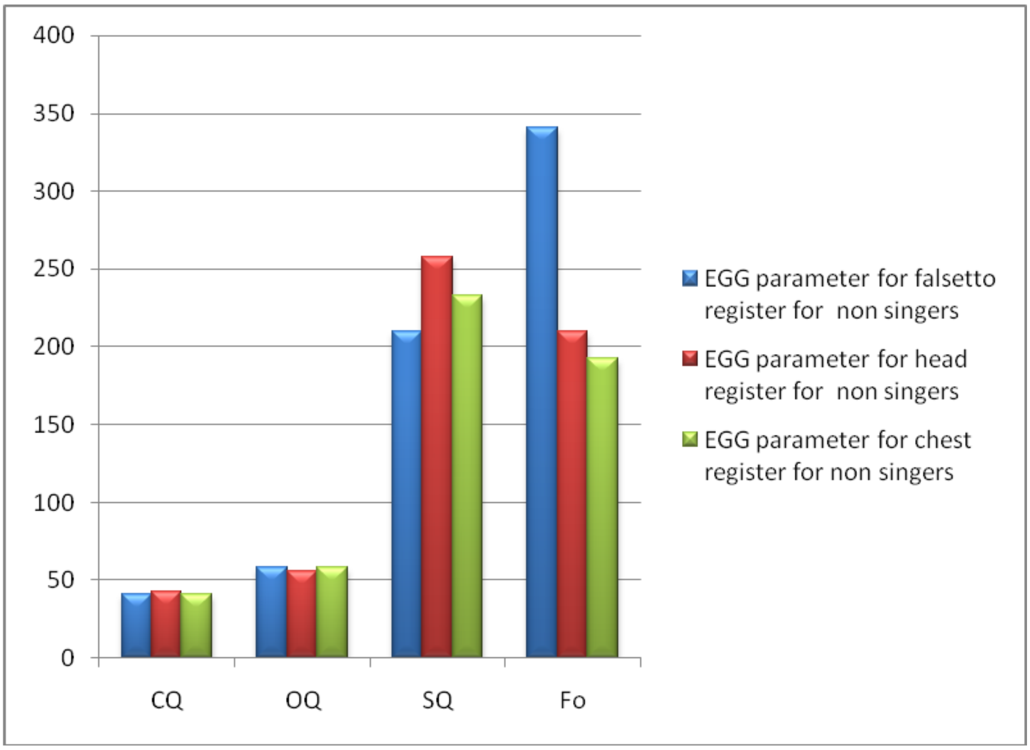
Comparison of EGG parameters across three registers in non singers

For the comparison of EGG parameters across three register in non singer (chest, head and falsetto) repeated measures ANOVA was used. Table 4 shows the results of repeated measure ANOVA across registers. It shows there is no significant difference across registers in any of the EGG parameters, except fundamental frequency which shows statistically high significant difference across register. Pair wise comparison for F0 showed significant difference across the three conditions.

Parameter	*Number of subjects*	*f*	*Significance*
F0	20	184.07	0.000**
CQ	20	1.114	0.389
OQ	20	1.087	0.348
SQ	20	1.038	0.364

Table 4: f value across registers in non singers. **p<0.001

Graph 2 shows the comparison F0, CQ, OQ and SQ for all the three register. It can be noticed that only F0 had greater difference between the registers, SQ was different across the registers but not basically significant.



Graph 2: Comparison of non singers across 3 registers

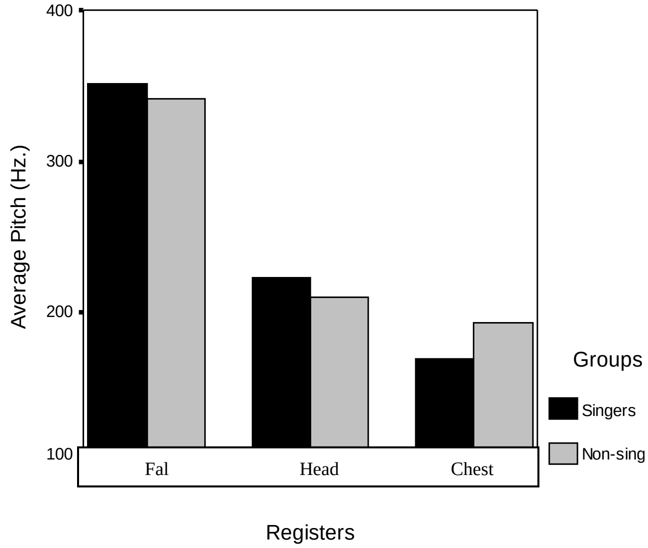
Comparison of non singers across registers.

The results are pooled for the two groups in Table 5 and it reveals that singers had a wider pitch range compared to the non singers.

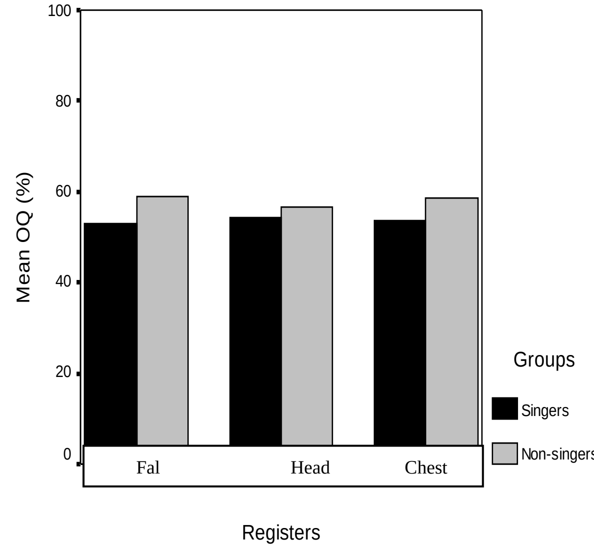
	Parameter	*Groups*	*Mean*	*SD*	*t*
F0	*Falsetto*	Singers	351	39.58	0.488
		Non-singers	341	47.14	
	Chest	Singers	169	31.40	0.003**
		Non-singers	193	12.43	
	Head	Singers	223	31.72	0.148
		Non-singers	210	21.74	
CQ	*Falsetto*	Singers	47	3.54	0.001**
		Non-singers	41	6.71	
	Chest	Singers	46	4.29	0.012*
		Non-singers	41	7.55	
	Head	Singers	45	5.15	0.117
		Non-singers	43	3.45	
OQ	*Falsetto*	Singers	52	3.54	0.001**
		Non-singers	58	6.71	
	Chest	Singers	53	4.29	0.012*
		Non-singers	58	7.56	
	Head	Singers	54	5.15	0.117
		Non-singers	56	3.44	
SQ	*Falsetto*	Singers	127	146.40	0.058*
		Non-singers	210	122.51	
	Chest	Singers	116	91.20	0.001**
		Non-singers	233	115.96	
	Head	Singers	102	81.19	0.000**
		Non-singers	258	84.50	

Table 5: Mean, SD, t values for Carnatic singers and non singers. * $p < 0.05$, ** $p < 0.01$

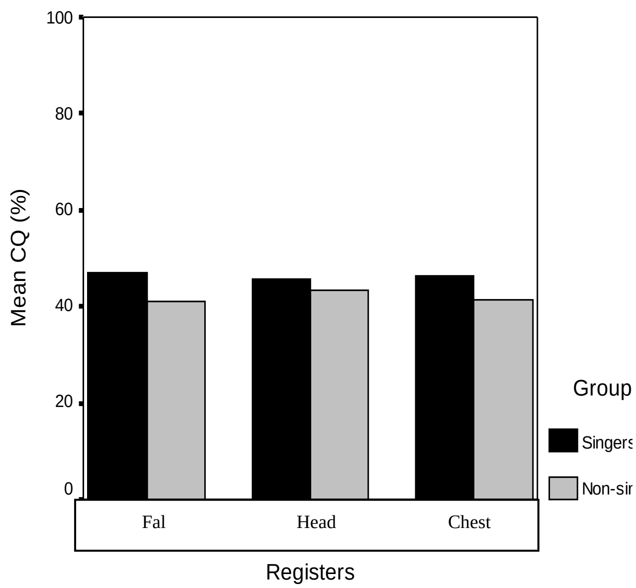
The mean F0 and CQ values were higher for Carnatic singers when compared to the non singers in falsetto register. These verdicts are in consonance with the findings of Howard (1995) and Nair (2002). Trained singers are able to produce upper register with a CQ that is slightly above 50% (Howard, et. al., 1995), presumably because they have the ability to strongly adduct their vocal folds. Mc Coy & Scott, (2007) opined that CQ values are higher in heavy mechanism like chest voice; it's more than 50%. And CQ is less in light mechanism like head and falsetto. In this present study CQ values are less in head or modal register compared to falsetto register. Increased CQ values shows increased glottal adduction and stronger contraction of inter arytenoids and lateral cricoarytenoid (LCA) increased medial compression from activity of the thyroaryteniod muscles. Graph 3 shows comparison of EGG parameters between the Carnatic singers and non singers. Results also shows that mean OQ values are higher in head register for singers when compared to the other two registers. And for non singers OQ scores are higher in falsetto register which is in consonance with Henrich (2005). But according to Henrich (2005) the open quotient depends on the laryngeal mechanisms in singers. The open quotient is strongly related to vocal intensity in chest, modal, and male head register. And OQ related to fundamental frequency in falsetto for male and head register for female singers. SQ values were significantly different for falsetto register in singers and mean SQ values were higher in non singers in falsetto register. SQ reflects the asymmetry of the glottal pulse; since the F0 is higher in falsetto, it suggests more asymmetrical vibrations in falsetto register both in Carnatic singers and non singers and especially in non singers as they have not mastered production of those registers.



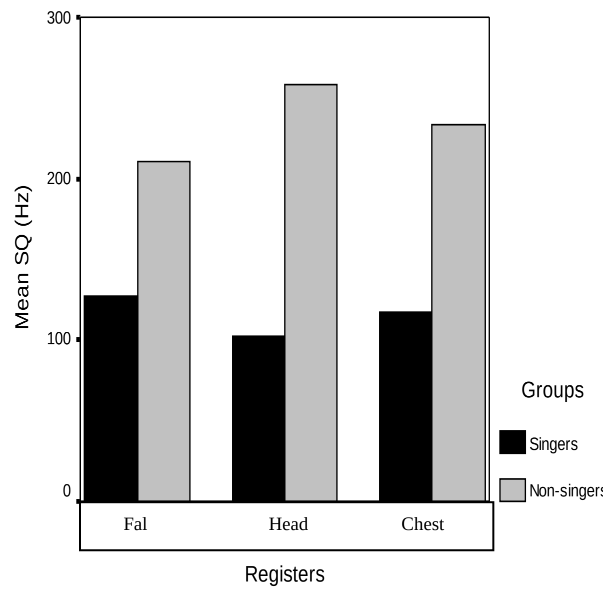
a) F0: Carnatic singers vs non- Singers.



b) OQ: Carnatic singers vs non Singers.



c) CQ: Carnatic singers vs non Singers.



d) SQ: Carnatic singers vs non- Singer.

Graph 3: Comparison of EGG parameters between the Carnatic singers and non singers.

Chapter V

SUMMARY AND CONCLUSION

Current study is an attempt to investigate some of the EGG parameters of Carnatic vocal singers in different vocal registers. Purpose of the study was to analyze EGG waveforms and compare the EGG parameters within and across registers for both Carnatic vocal singers and non singers.

The subjects participated in the study consisted of 40 females in the age range of 18-50 years with a mean age of 34 years. They were divided into 2 groups: experimental group and control group. Experimental group consisted of 20 professional Carnatic singers with the 3 years of formal training of in Carnatic classical musical form. Control group consisted of 20 non singers who did not have any formal voice training. All the ssubjects had no complaints of vocal or hearing problems at the time of recording.

Subjects were instructed to sing vowel /a/ in ascending scale in a single breath reaching the three sthayis (register). And the non singers were instructed to sing vowel /a/ in the lowest pitch, habitual pitch and the highest pitch simultaneously in continuous manner and sustain the pitch for at least three seconds. EGG was used to measure the behavior ie vocal fold closure. Each subject was asked to sing thrice, recording were done individually and all the data were saved on the computer memory. The recording that yielded best EGG waveform morphology was retained for extraction of the parameters. The cursor was positioned at the position where the F0 was steady and the following EGG parameters were extracted CQ, OQ, SQ, F0.

The extracted parameters were tabulated and data was subjected to statistics. Mean and standard deviation was done. Repeated measures ANOVA was done to analyze the variation of glottal parameters across registers within singers and independent t test was done for pair wise comparison singers and non singers for each parameter.

The results are summarized as follows a) F0: The mean F0 and CQ were higher for Carnatic singers when compared to the non singers in falsetto register. b) CQ: CQ values are less in head or modal register compared to falsetto register in singers. C) OQ: values were higher in head register for singers when compared to the other two registers. And for non singers OQ scores are higher in falsetto register d) SQ: SQ values are significantly different for falsetto register in singers and mean SQ values are higher in non singers in head and falsetto register.

Conclusion

In general the results revealed that except for F0, the OQ, SQ, CQ were not significantly different though they varied across registers. On comparison, singers though they had minimum of 3 years of experience, EGG parameters were significant by different measures especially in chest and falsetto register. This difference is because of the training in voice use.

Limitations

- Numbers of subjects were limited.
- Most of the singers were still under formal training ie they had a minimum of 3 years of formal practice.

Future direction

- Comparison of classical Carnatic singers and Hindustani classical singers to know more about their laryngeal mechanism.
- Comparison between male and female classical singers.

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