EFFECT OF VOCAL TRAINING ON NASAL AIRFLOW WITH VARYING FUNDAMENTAL FREQUENCY AND INTENSITY

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CERTIFICATE

This is to certify that this dissertation entitled ***"Effect of Vocal Training on Nasal Airflow with Varying Fundamental Frequency and Intensity"*** is a bonafide work submitted in part fulfillment for the degree of Masters of Science (Speech-Language Pathology) of the student (Register No.11SLP032). This has been carried out under the guidance of a faculty of the institute and not has been submitted earlier to any other university for the award of any other Diploma or Degree.

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May, 2013

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DECLARATION

I hereby declare that this dissertation entitled ***"Effect of Vocal Training on Nasal Airflow with Varying Fundamental Frequency and Intensity"*** is the result of my own study under the guidance of Dr. T. Jayakumar, Lecturer in Speech-Language Sciences, Department of Speech-Language Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted to any other university for the award of Diploma or Degree.

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Dedicated to my
lovely PAPA,
AMMA, CHETTAN,
n' to my
KRISHNA....

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CHAPTER I

INTRODUCTION

"Speech is the way of life for human is the chief medium of social adaptation. What we are, what we do and what we decide to do are accomplished majorly through speech. Through speech or indirectly through written language which records speech, we gain and give meaning to our existence" (Punt, 1979). Human beings able to speak because of having a set of organs that are capable of being modified and adapted for the function of speech and accompanied by highly developed nervous system.

Vibration of the vocal cords in the human larynx results in the production of voice. Voice is considered to be the vehicle for communication and nation in speech. Power produced from the lungs, tightening of the crico-arytenoids & inter-arytenoid muscle, tension and thickness of the vocal folds are the important physiological factors for the production of voice. The pitch of the voice is determined by the frequency with which the vocal folds vibrate. Singers required well developed, coordinated and flexible laryngeal system compared to others.

Singing is defined as the act of producing musical sounds using the voice, and augments regular speech with tone and rhythm. The person who sings is called a singer or vocalist. Singing can be produced either with or without the use of by musical instruments. It is done with a group of other musicians, such as in a choir of singers with different voice ranges, or with instrumentalists, such as a rock group. Singing is a form of sustained speech and mostly anyone who is able to speak can sing. Singing can be in different form, formal or informal, arranged or improvised. Usually singing may be done for pleasure, comfort, ritual, education, or profit. Regular practice will make the singer excellent. Professional singers usually focus their career in one specific music, such as classical, rock etc. They take voice training from the voice teachers or vocal coaches throughout their careers. Therefore, proper practicing and training is essential for the professional singers.

Professional singing and speaking depend on person's ability to establish optimum conditions of vocal resonance. The resonator for increasing resonance in the voice is the vocal tract. It consists of seven areas are the possible vocal resonators. As a sequence from the lowest to the highest in the body, these areas include the chest, the tracheal tree, the larynx itself, the pharynx, the oral cavity, the nasal cavity, and the sinuses. Vocal resonance is defined as "the process by which the basic product of phonation is enhanced in timbre and/or intensity by the air-filled cavities through which it passes on its way to the outside air" (McKinney, 1994). In general, there are two types of resonation, oral and nasal. The expression of 'nasal resonance' is widely used to represent a desirable property in singing (Vennard, 1964). In normal speakers, no conscious effort is needed to produce the nasal resonance and it generally occurs without their effort. However, the long-standing controversies regarding nasal resonance during singing reveals that velar adjustments are more refined and/or controlled during singing. It is considered as a "sensory motor phenomenon that requires balanced skills" (Bunch, 1982).

Vocal resonance affects various factors such as size, shape, thickness of the walls and surface of the resonators. Optimal vocal resonance, which is considered as the positive sympathetic and conductive vibration of the resonant cavities of the head and throat, is the main goal of the classical singer. The singer tries to encourage the best possible open throat to most beautifully enhance and amplify the fundamental pitch or frequency. “Singers, generally operatic singers enrich and enhance their voice by developing the singer’s formant” (Stone, Cleveland & Sundberg, 1999). Sundberg (2001) defined “singer’s formant is a prominent spectrum envelope peak near 3 KHz that appears in voiced sounds sung by classically trained bass, baritone, tenor, and alto singers’ voices”. It helps singer’s voice to be heard easier in the presence of loud back ground noise or orchestra. The professional singers and the trained classical and Carnatic singers use their nasal resonance to enrich their voice. The high vocal demands among the group of singers make them use their nasal resonance to a greater extend making their voice more effortless and melodious.

Indian classical music tradition has a history spanning millennia and it was developed over many eras. Mainly there are two traditions of Indian classical music Carnatic and Hindustani. Indian classical singing origins can be found in the Vedas, which are the oldest scriptures in the Hindu tradition. As described in Samaveda, one of the four Vedas, music at length. In 14th century Indian classical music is divided into Hindustani and Carnatic music. Indian classical music is elaborate and expressive. Hindustani music is the music of North India and Carnatic music is the music of South India. Like Western classical music, Indian classical music divides the octave into 12 semitones. In this 7 basic notes are in ascending pitch order, *Sa Re Ga Ma Pa Dha Ni Sa* for Hindustani music and *Sa Re Ga Ma Pa Dha Ni Sa* for Carnatic music, which is similar to Western music's *Do Re Mi Fa Sol La Ti Do*. Indian classical music is monophonic in nature. Melodically singing performance is based on particular ragas and rhythmically on talas. Singing is both, a talent and a skill. Regardless of your voice range, learning to control the velum is important in singing. There are certain singing styles that sound better when utilizing the nasal cavity; such a style is used by many country singers.

Trained singers are perceived to sing better than non-singers because trained singers are able to perform a variety of phonatory and articulatory/resonatory adjustments during singing whereas non-singers not able to do this. Also these articulatory and phonatory differences during singing help the listeners to perceptually distinguish the two groups during singing. The acoustic cues that help listeners to perceptually distinguish trained singers from non-singers have not been clearly identified. Trained singers are able to use vocal resonance more efficiently than non-singers.

The long standing question exist in the field of vocal pedagogy is whether nasal resonance is used during the production of non-nasal phonemes by classically trained singers. Monahan (1978) reported that regarding resonance characteristics of the singing voice are related to the nasal cavities. In normal speakers, generally nasal resonance occurs without any conscious effort, however, controversies on nasal resonance during singing reveals that velar adjustments are more refined and/or controlled in singers. If this is true, what is the manner and extent of velar adjustments required to produce good vocal qualities. Also whether depending up on the style of music being sung, these adjustments are changed, and whether there are improper patterns of velar adjustments which could result increased risk of vocal injury in singers. So what is the effect being seen in singer, who consciously elevate the velum during the production of a vowel that is often produced with a small velopharyngeal opening during speech?

Brown & Behnke (1883) proponed that, “the soft palate rises with the ascending scale, the arch between the pillars of the fauces becomes narrower and higher, and the uvula diminishes in size”. Different instrumental measurement have done in singers and in a very few of studies investigating how singers use VP valving. To investigate whether the soft palate gradually elevated when singers sing from their lower to higher registers, Scotto di Carlo & Autesserre (1987) examined six professional singers using sound-synchronized endoscopy and xeroradiography. The authors reported that the transverse tension of velum and the stretching of the posterior faucial pillers is being accompanied by the hyper retraction of uvula.

Majority of the studies concluded that as the pitch increases, the velum is also opened (House and Stevens, 1956; Gramming, Nord, Sundberg, & Elliot, 1993; Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg, 2002). If the nasalance is not controlled while singing it will be distracted to the listeners. There is little information which gives the evidence that the vocal training will helps to control the nasality. Even though singing consists of both oral and nasal sound; it wouldn’t be heard as noisy. Then the question arise is how the singers are able to project their voice when the velum is opened or are they able to control their velum movement while singing?

Need of the study

Evidence from various studies suggests that trained singers have the ability of to make skillful phonatory, resonatory, and articulatory adjustments is different from non singers (Brown, Rothman, & Williams, 1978; Gauffin & Sundberg, 1989; McGlone, 1976; 1977; Shipp & Izdebski, 1975; Sundberg & Rothenberg, 1986). Majority of the researchers suggested that there is velopharyngeal opening with increasing pitch or in the upper registers and it is negatively correlated (House and Stevens, 1956; Gramming, Nord, Sundberg, & Elliot, 1993; Birch et al, 2002; Fowler, 2004; Carlo and Autesserre, 1987) with the perceived nasality in the singers when they sing in upper registers. But only a very few number of studies focused on the effect of training and perceived nasality in singing. The initial murmur of /ma/, /mi/ and /mu/ as a part of warm up before singing, suggesting velopharyngeal opening is helpful in singing, on the other hand if nasality is perceived, it is considered as noisy or unacceptable. Very few studies are persisting about the question 'Do vocal training helps reducing nasality with an open velopharynx? Carnatic singing is a wide musical system which is commonly associated with the southern part of Indian subcontinent. It is believed to be a divine and the tradition of singing and practicing classical music is established throughout India. Even though Carnatic music consists of a wide range of oral and nasal consonants; still the music has never been heard as unacceptable or nasal and noisy. So, how experienced singer should sing to color and enrich their voice when the velum is open or whether professional singer can better able to control the degree of velum movement?. Many studies evaluated velum behavior and movement while singing, but not so much research were conducted to find the correlation between the open velum and the perceived quality of the voice. Also a very few of the studies described the effect of training and the experience in controlling the nasalance with an open or lowered velum. Considerably less number of research have been done on Indian classical singers (Carnatic or Hindustan) on Nasalance. The present study compares the nasal airflow between vocally trained and untrained using frequency and intensity.

Aim of the study

- To find the effect of vocal training on controlling nasal airflow with variation in F0 and Intensity.
- To find the effect of vocal training on controlling perceived nasality with variation in F0 and Intensity.
- To find the correlation between perceptual and objective measurements of nasality.

CHAPTER II

REVIEW OF LITERATURE

Voice is a marvelous tool of communication for our daily life. In the modern life people are even more dependent on their voice due to specialized options in the modern computer systems. Voice is multidimensional in nature. Voice is one of the aspects which make human beings as different from other organisms and also the universality of human voice as an instrument is its greatest joy and major advantage. Human voice is a wonderful instrument capable of conveying ideas, thoughts, and emotions. Bunch (2009) reported that "the voice is considered to be as much as thirty-eight percent of a person's communication, accompanying with visible or non verbal aspects (55%) and the words (7%)". Sundberg (1994) reported that "the singer must control over all perceptually relevant voice parameters, so that they do not change by accident and signal an unintended boundary". Control of all voice parameters is pre-requisite for singing.

The term professional voice user refers to the group of population for whom the voice is mainly used as a tool as their occupation. Professional singers are highly specialized subset of individuals in the group of professional voice users. Singers have significant functional demands that place on laryngeal mechanism in account of frequency range, amplitude control, acoustic variation, and overall vocal stamina and which is unique for only singers. These specific demands are varied between singers having various singing styles and capabilities. Well trained singers will have a high level of neuromuscular laryngeal control which may eliminate or even lessen their laryngeal pathologies and other symptoms. Performance demands will depend up on the size of the orchestra with which the classical singer is singing. Some of the demands are common among all professional singers of all styles, however, the duration of singing, travelling before the performance, warm up exercises and practice will also affect their voice quality.

Singers have high vocal demands and they are more systemic in their voice use than non-singers. “Bharata (Durga, 1997) in his famous work “Natya Shastra” proposes six essential qualities that a good singer requires.

- ‘Sraavaka’ is explained as loudness or carrier of the voice, which can be heard from a long distance.
- The voice that is loud and pleasing without any wobble is called ‘ghana’.
- The voice which does not sound harsh though loud, is described as ‘snigdha’. This also refers to the ‘fluency’ of producing the notes of high octaves.
- The voice that is pleasant at high notes is called ‘madhura’.
- ‘Avadhanavan’ is explained as a voice that is neither too loud nor too soft.
- ‘Tristhanashobha’ is that voice which is pleasant in producing the notes of all the three ‘sthanaas’ (equivalent of registers)”.

Singers must increase subglottal pressure (Ps) to increase pitch and/or loudness (Griffin, Woo, Colton, Casper, & Brewer, 1995). Classically trained singers have considerable formant frequency differences during speech and singing because the speech like formant frequencies cannot produce a singer's formant, which male singers and altos need in order to be heard against a loud orchestral accompaniment. The singer’s formant refers to a prominent spectrum envelope peak near 3 KHz that appears in voiced sounds sung by classically trained singers mainly, bass, baritone, tenor, and alto singers' voices. This makes the voice easier to hear in the presence of a loud orchestral support. It can be described as mainly resonatory phenomenon arising from a clustering of formants 3, 4, and 5. In the case of country singing, no need for a country singer to use special formant frequencies producing a singer's formant in singing (Stone, Cleveland & Sundberg, 1999) as the singers need not concern about the audibility of their voice since it is a technical problem handled by the sound engineer rather than by the singer himself.

Sundberg, Cleveland, Stone & Iwarsson (1999) studied the voice source characteristics from inverse filtering. They analyzed 6 country singer's speech and singing. He reported that the closed quotient varied systematically with vocal loudness, and that glottal compliance decreased with increases in fundamental frequency but remained unaffected by vocal loudness. No significant differences were found in source characteristics between speech and singing within subjects. An increase in phonatory press reduces the sound pressure level (SPL). The subject's voices often tended to sound more pressed at high than at low pitches. The result indicates that these singers tended to use more phonatory press when singing in a high rather than in a low pitch range.

Lawrence (1979) reported that those singers who exhibited the least vocal pathology had the greatest amount of vocal training. Brown, Hunt, & Williams (1988) said that better performance by trained singers was due to the benefits of better vocal training rather than their superior physiologic characteristics. Thus, the skills acquired through vocal training appear to have a modifying effect on the extent of laryngeal incompetence resulting from vocal abuse or misuse.

Breathing is the subconscious process that happening everyday life is also important for singing. The three main stages in natural breathing consist of: breathing-in period, a breathing out period, and a resting or recovery period. These stages are not usually consciously controlled. According to Titze (1994) there are four stages of breathing during singing which must be under conscious control by the singer until they become conditioned reflexes. These stages include breathing-in period (inhalation); a setting up controls period (suspension); a controlled exhalation period (phonation); and a recovery period. Many of the singers increase conscious controls before their reflexes are fully conditioned which will finally leads to chronic vocal pathologies. (http://en.wikipedia.org/wiki/Vocal_resonation)

Most of the researchers reported that trained singers have more capability than others. Devadas, Rajashekhar & Aithal (2009) used a standard group comparison study design and the fundamental frequency [F0], speaking fundamental frequency [SFF], jitter percent [JITT], shimmer dB [SH dB], noise to harmonic ratio/NHR, maximum phonation duration(MPD) and S/Z ratio of Bhagavata's voice were compared with age matched nonsingers. Their results revealed, significantly higher fundamental frequency, speaking fundamental frequency and reduced MPD in Bhagavatas as compared to their non-singing counterparts.

Indian music tradition

Indian music is the great wealth of Indian culture and it is considered as a gift of God. India is considered as a "Sangitha Bhumi" (musical land). *'Naadam'* is the word used to represent the musical sound which is the basis of *'shruthi'* which is the musical tone, ‘*shruthi’* gives rise to ‘*swaram’* which is the musical notes and *‘swaram’* gives rise to *‘raagam’* which is the musical scale (http://*shodhganga.inflibnet.ac.in/bitstream/10603/4551/.../07_chapter%202.pdf*). History of Indian music is not only about the cultural value, but also enables us to understand about the concepts of “raga” and “tala” systems. The concept of “raga” is India’s gift to the musical world. The ragas are artistic facts and it can be perceived by anyone who has little training in music. Indian music is distinguished from other music. Carnatic and Hindustani music are bifurcation in Indian music. ‘Carnatic system’ is usually a South Indian art where as ‘Hindstani system’ is a North Indian art. In Carnatic music, there are mainly seventy two ‘melakarta raagas’.

The Indian musical scale is evolved from a set of seven primary notes or ‘swaras’ (‘sapta swaras’). A scale is divided in to 22 shruthi or intervals that constitute the basis of musical notes or swaras. The ‘sapta swaras’ are “sa, ri, ga, ma, pa, da, ni”. The entire singing range in Carnatic music is classified in the three ‘sthaayis – mandra, madhya and taara’ i.e., low, mid and high respectively. Sthaayi is the octave of music. The three sthaayi’s are also known as ‘mandra saptak’ ‘madhya saptak’ and ‘taara saptak’. A ‘saptak’ consists of seven notes. According to the Indian conception, the fundamental note is called the ‘aadhara shadja’ and this will always belong to ‘madhya sthaayi shadja’ and is known as ‘madhya shadja’. The notes, which are sung below this ‘madhya shadja’, belong to ‘mandra sthaayi’. The notes, which are sung above the ‘madhya sthaayi nishaada’, belong to ‘tara sthaayi’ (http://*shodhganga.inflibnet.ac.in/bitstream/10603/4551/.../07_chapter%202.pdf*)

Resonance in singers

Like all acoustic instruments such as the guitar, trumpet, piano, or violin, voice has its own special chambers for resonating the tone. When the sound is produced by the vocal cords, it vibrates in and through the open resonating chambers, producing four primary resonances such as chest, mouth, nasal (or mask) and head. In the lower pitch range, the chest resonance is dominant; in the middle range, the mouth-nasal resonance predominates and in the higher range, the head-nasal resonance (bright color) predominates. The resonance also depends on the emotional content of the lyric or phrase suggests and also the personal choice of the artist. Head resonance is used primarily for softer singing in either register throughout the range. Mouth resonance is used for a conversational vocal color in singing and, in combination with nasal resonance. Chest resonance adds richer, darker, deeper tone coloring and it creates a feeling of depth and drama in the voice. Nasal or mask resonance is present at all times in a well-produced tone, except, perhaps, in the instance of the pure head tone or at very soft volume. Nasal resonance is bright and is used in combination with mouth resonance. In an over-all nasal resonance gives clarity and projection to the voice. There are some singers who are recognized by their pronounced nasal quality such as a deep, dark and *chesty* sound or their breathy or heady sound. Such individuality depends on the structure of the singer's vocal instrument, that is, the inherent shape and size of the vocal cords and resonating chambers. The quality the voice also depends on the ability to develop and use various resonances by controlling the shape and size of the chambers through which the sound flows. According to Sundberg (2004) "occasional oral–nasal coupling might tune the resonating system and strengthen the singer's formant during classical singing".

As we know nasal resonance occurs during the production of nasal phonemes during speech. The unresolved question exists is whether classically trained singers use nasal resonance during the production of non-nasal phonemes. Monahan (1978) proposed two questions about nasal resonance as “whether singers consciously use nasal resonance to achieve a beautiful tone and how is nasal resonance incorporated into the vocal tone by conscious or natural means”. Generally nasal resonance occurs without any conscious effort in normal speakers but controversies regarding nasal resonance during singing imply that velar adjustments during singing are more controlled and/ or refined.

Perception of nasality in singers

Perception of nasality during singing is researched by various authors. House and Stevens (1956) found that smaller velopharyngeal port (VP) openings were needed to produce a perception of nasality in the vowels /i/ and /u/ compared to /a/ to produce a perception of nasality**.** Also three times the amount of oral/nasal coupling was needed to nasalize /a/ than was needed to nasalize /u/. The evidence proved that the perception of nasality is closely associated with different sizes of velopharyngeal port (VP) and different sounds. Several authors reported in literature that the velopharynx must reach a critical degree of closure for perception of good speech. The investigation of House and Stevens (1956) showed that when vowels produced with a port area of 25mm^2, listeners did not perceive vowels as being more nasal than vowels produced with complete velopharyngeal port closure. It was noted that complete VP closure depends on target phonemes and speech is perceived as being hypernasal when critical minimum closure of 20-30mm^2 is not reached.

Singers use large oral opening while singing. So on perception to judge whether a singer uses open VP postures is problematic. Yanagisawa, Estill, Mambrino, & Talkin (1991) examined the role of the soft palate in singers with increase in pitch. The study included nine professional singers and two untrained subjects. Audio and video recordings were taken as the subjects produced a continuous glide from one pitch to another on the nasal sound /N/ (glissando). Also the three subjects recorded vocal productions in speech, falsetto, sob, and operatic qualities at 10%, 50% and 90% of their frequency ranges using the same sound. The authors reported that under all vocal conditions laryngeal height, soft palate height, and the medial movement of the lateral pharyngeal walls all increased as the pitch increased and velopharyngeal port closure was also greater during sob and falsetto qualities as compared to speech and operatic qualities. The authors also reported the pattern of velopharyngeal closure to be more sphincteric during falsetto and sob qualities, whereas during speech and opera, the closure pattern appeared to be of the trap-door type. These results suggest that, independent of the velopharyngeal morphology and depending on the musical style and their intended result singers are able to vary their VP closure patterns. These results would have been beneficial if information were provided as to whether changes in the shape of the velopharyngeal opening in singers were frequency or vowel dependent.

Aerodynamic measures

Singers may show a wide variety of tendencies regarding velopharyngeal opening during singing. Gramming, Nord, Sundberg, & Elliot (1993) investigated the use of the velopharyngeal port during singing. They used three different analysis techniques, flexible nasofiberoscope, recordings of oral and nasal flow and experiments on a vocal tract model. Four professional singers were included in the study, two sopranos (F1 and F2), one bass (Ml), and one baritone (M2). In these, F1 was an internationally renowned opera singer, F2 an advanced student, also with considerable experience of solo singing, MI an experienced professional opera singer, and M2 a highly experienced singing teacher. A number of speaking and singing tasks which included stops, nasals, and vowels were included in the protocol. Speech samples involving velar activity using the word [punta], singing tasks consisted of ascending/ descending fifth-wide scales. For soprano F1, there was no evidence of velar opening during the production of scales was observed. Soprano F2 showed a nasal DC (constant) airflow in all tasks indicating a constant velopharyngeal opening. The bass singer M1 also revealed nasal leakage in most of the tasks. No evidence of nasal DC airflow was shown by baritone M2 for any of the tasks. Nasofiberoscopic data reveals a small opening in the velopharyngeal port only at the higher pitch. For the other subjects, the two results correlated. The vertical position of the velum found to change with pitch suggesting velum plays a role of articulator in singing to shape their vocal tract to arrive at the target formant frequencies. Inter individual variability using velopharynx in singing is evident in the study. Even though soprano F1 was the teacher of Soprano F2, still they exhibited velopharyngeal opening, which reveals an improper vocal technique used in singing.

Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) analysed velopharyngeal opening in 17 professional operatic singers, 3 high sopranos, 3 sopranos, 2 mezzo-sopranos, 3 tenors, 2 baritones, 2 bass-baritones, and 2 basses singing the vowels [a, i, u] as in the stimulus /panta/, /pinti/, and /puntu/ at middle degree of vocal loudness in an ascending scale of seven pitches throughout their pitch range. Three methods were used in the study, naso fiberoscopy for the visualisation of the naso pharynx. A divided oral-nasal pneumotach flow mask was used to measure the oral and nasal airflow. Both flow signals were recorded together with an audio signal on separate tracks of a multichannel data recorder and after that all three signals were then digitized. Average DC components of the oral and nasal airflows during each word for each pitch were measured. The results suggested that oral flow varied between vowels, with pitch, and across singers. Nasal flow for the vowels /a/ and /u/ varied according to the pitch sung where as nasal flow was detected on the vowel /i/ for only one tenor. These findings suggest that the singers use VPO during singing.

The authors also proposed that the poor contact between the face and mask may render the presence of airflow and thereby the presence of velopharyngeal opening (VPO). To avoid this possibility, the difference between the level of the fundamental in the nasal (LO_n) and oral (LO_o) airflows was calculated as an alternative measure ((LO_n-LO_o). The researchers opined in the case of VPO, the LO_n should be above -15 dB below the level of the fundamental in the oral airflow. Therefore they calculated the used narrow band spectrograms of the nasal and oral AC (alternating current) signals for all /a/ productions and the difference (LO_n – $LO_{o)}$ was calculated. In cases where the nasal DC airflow was greater than zero, the difference between LO_n – LO_o was above -15 dB. There were also cases where no detected nasal DC flows were also associated with LO_n – LO_o differences above -15 dB. These singers were also considered to sing with a VPO. Visual and perceptual data were also obtained in addition to the airflow measurements. To record visual images of VPO, a nasofiberscope was used. Four phoniatricians rated the degree of VPO using a 100-mm-long visual analogue scale (VAS) for the production of the second vowel in the word *panta* as it was sung in mezzo forte only. Nine of the 17 singers were rated as utilizing a VPO. Observed VP openings were divided into different types such as coronal, sagittal and constricted categories. A high correlation was reported between VPO and the production of the vowel /a/. Alternately, low intrarater reliability and correlation between airflow and perceived nasality were reported. These findings are not surprising as the subjects were highly skilled classical singers who, in typical fashion, probably sang with large oral openings, thereby reducing the perception of nasality due to the interplay of oral and nasal impedances.

The authors pointed that the acquisition of DC flow data was dependent on a proper placement of the mask without any leakage. Therefore they concluded that a zero nasal DC airflow and the inability to visually document VPO was not sufficient evidence to rule out its presence. Even though, they believed that the presence of VPO could only be proven by the presence of airflow and/or visible observation. These criteria were demonstrated in nine of the singers. In six additional singers a difference of less than 15 dB between LO_n – LO_o was found, suggesting the presence of a VPO. Taking the 15 dB differential into account, there was evidence of VPO in 15 of the 17 subjects. The authors concluded that the different patterns of VPO observed in different singers suggested "that singers carefully tune the degree of opening, perhaps in order to color the timbre".

The third method was to compare the level of fundamental in the nasal and oral airflow signals. In airflow measures, in some singers, oral airflow decreased with increasing pitch and they could not find significant nasality probably due to the leakage of the airflow through the mask. Nasofiberoscopic results did not correlated with the airflow measures completely as it showed a velopharyngeal opening. An open velopharynx was observed in high soprano 3, soprano 1, tenor1, while no DC nasal airflow was measured. This study gives us the information that at higher pitches, singers use their velopharyngeal opening to tune their vocal timbre or to color their vocal tone and it is evident they have an opened velum while singing at higher pitches.

Nasalance in singers and non-singers

Fowler (2004) investigated and compared the Nasalance between 36 trained female singers and 36 female non-singers by sustaining phonation of /i/, /ae/, /u/, and /a/ for six seconds across three frequency levels. Oronasal Nasality System 1.5 hardware/software system (Glottal Enterprises, 2000) was used for measuring nasalance and intensity was not controlled in the study. They could see a difference in nasalance between front and back vowels but could not see any statistically significant difference between singers and non-singers, even though singers had a low nasalance scores for the back vowels.

Tanner Roy, Merrill, & David (2005) studied the status of the velopharyngeal (VP) port during classical singing. They investigated nasal airflow (ml/s), oral pressure (cm H_2O), and VP orifice area estimates (cm) in 10 classically trained sopranos during singing and speaking. Nasal cross sectional area measures were taken for all participants and were within normal limits. For evaluating the effects of vowel height on VP valving, three nonsense words were taken- hampa/, /hampi/ and /humpu/. Each of these contains the blend /mp/ and three cardinal vowels. Each subject had to sing and speak these three words /hampa/, /hampi/ and /humpu/ at three loudness levels (loud, comfortable and soft) and in three different pitches also (high, comfortable and low). All the words were produced three times at a rate of one syllable/sec with the help of a metronome. The participants were asked to sing using classical style with vibrato. They were instructed to repeat the nonsense words as speech like and also naturally as possible for the speaking task.

The authors also used aeromechanical instrumentation. Nasal airflow, nasal pressure, and oral pressure values were acquired using the PERCI (Palatal Efficiency Ratings Computed Instantaneously)—Speech Aeromechanics Research System. Flexible polythene tubing which was connected to the pneumotachometer, was used to acquire the nasal airflow values. This was fitted to the nostril of the participant. The participant's opposite nostril was inserted by a foam cork and it was connected to a pressure transducer for measuring the nasal pressure. Nasal airflow (ml/sec), nasal pressure (cm H_2O), oral pressure (cm H_2O) and velopharyngeal orifice area estimates were recorded for each of the three nonsense words.

Anticipatory nasal airflow was seen in 9 of 10 participants for singing and speaking and was significantly greater in the first vowel in /hampa/ compared to /himpi/ and /humpu/. This suggestive of vowel height has a significant effect on nasal airflow. The nasal airflow was significantly greater for loud phonation during /m/ and soft phonation. They concluded that nasal airflow decreased as pitch and intensity reduces from high to low in phonation, more so for singing compared to speaking task. Their results suggested that velopharyngeal area measures, nasal airflow, and oral pressure were significantly greater for the singing task than speech task. It was found that nasal airflow was greater in singing task compared to speaking during the time maximum intraoral pressure i.e. at the point of /p/. These results suggesting the singers allow an amount of nasal flow through the VP port during the production of oral consonant /p/; that means, these singers permit to leave the VP port slightly open followed by the point of maximum nasal airflow i.e., during the production of /m/. The authors reported one possible explanation that the singers might allow a little amount of VP opening that leads to the midfacial vibratory sensations which is associated with forward–focused resonance in classical singing.

Jennings & Kuehn (2008) studied the nasalance in singers. They investigated 21 amateur singers and 25 classically trained singers during singing an ascending five-tone scalar passage in different pitch ranges (low, mid, and high frequency ranges). The Nasometer was used to obtain the nasalance. The amateur singers had significantly higher nasalance scores than classically trained singers in all ranges and on all vowels except /o/. Dynamic loudness level had a significant effect on nasalance for all subject groups except for female majors in the mid- and high frequency ranges. The vowel, /i/, received significantly higher nasalance than all of the other vowels. Although results of the study show that dynamic loudness level, vowel, and level of training in classical singing have a significant effect on nasality, nasalance scores for most subjects were relatively low. Only six of the subjects, all of whom were amateur singers, had average nasalance scores that could be considered hypernasal.

Velum has to be lowered for the production of nasal consonants such as /m/, /n/, /ng/. When producing these nasal consonants, a buzzing or tingling effect is felt in the cheeks on both sides of the nose. This area is known in singing literature as the ‘‘mask.’’ In classically trained singers, efficient singing is produced by sympathetic vibrations in the mask, which are similar to the buzzing sensation of nasal consonants. As a consequence, many teachers of singing advise singing students to use nasal consonants and humming in vocal exercises to simulate the feeling of resonance in the mask. However, some pedagogues believed this use of nasality is a means to an end. That means, a nasalized sound will help the singer in ‘‘placing’’ the tone in the mask. Once a forward placement has been established, the nasal component will be abandoned. For other singing teachers, some nasality in the tone is desirable because it helps in the projection of voice. But how much nasality is actually present in classical singing which is yet to be answered.

Many singing pedagogues argued that there is no nasality in sung vowels because an elevated velum creates more resonating space in the oral cavity and blocks the nasal cavity to avoid an undesirable nasal tone and thereby increased damping inherent in nasal sounds. McIver & Miller (1996) studied 30 trained singers using the Nasometer to obtain nasalance scores by singing non-nasal phonemes. Their results suggest that several singers obtained nasalance scores near zero as evidenced on the nasogram and thus concluded that oral/nasal coupling was not a contributing factor to efficient singing. Here the authors did not indicate a cut-off score for hypernasality or include nasalance scores for individual subjects. Although Miller attributed that velopharyngeal port opening is not harmful to the singing voice, he opined that ‘‘nasality intruded into non-nasals is not aesthetically pleasing.’’

Even though, other singing pedagogues hypothesized that “some nasality or ‘‘nasal resonance’’ as called in the singing literature contributes to the vocal ring of a classically trained voice. Acoustically, this ring is caused by a cluster of energy around 3 KHz typically found in spectrographic analysis of singing by classically trained vocalists.

This is also known as the singer's formant". This envelope of acoustic energy is ‘‘rather independent of vowel and pitch’’ and enables the voice to be heard over an orchestra, which has an average spectrum around 500 Hz. Alderson (1993) suggests that a little nasality contributes a well-produced sound and he recommends ‘‘directing a portion of the sound waves through the nasal cavity to add a more brilliant ring to the tone.’’

Instrumental analyses of velopharyngeal valving in singers

Other researchers proposed that singers show a wide variety of tendencies regarding velopharyngeal opening. Volo, Farnetani, Troup, & Ferrero (1986) suggested that velopharyngeal opening may be dependent up on the style. Using xeroradiographic images of two professionally trained baritone subjects who were instructed to sing all the Italian vowels /a,e,i,o,u/ starting on ‘‘do’’ moving to ‘‘sol’’ and back to ‘‘do’’ in a key of their choosing. Then the singers were asked to sing a two-octave arpeggio on all the Italian vowels. The xeroradiographic images showed that the slower sustained singing had complete closure of the velopharyngeal port for both singers, whereas the more florid arpeggios did not.

Carlo & Autesserre (1987) investigated the movement of velum in six professional singers with the phonation of /a/, /i/, /u/ and /ae/ using endoscopy and xero radiography. The study focused upon two questions, first ‘why the velum was in a specific position in the upper register’ and ‘how singers could think that the velum is raised when it is actually in a relatively low position?’. A physiological and perceptually explanation were given regarding the particular position of the velum. Physiologically, pharyngeal tightening in the upper register occurs due to tension of the muscles. In order to avoid the excessive contraction of velar and pharyngeal muscles, singer will adjust the velum in a particular position without letting the velopharyngeal contact occur through the simultaneous action of levator palate and the palate pharyngeus muscle. Perceptually the same voice was rated and those which was sung with a raised velum was rated as ‘flat’, ‘crushed’, and ‘dull’ while those sung with a lowered velum was rated as ‘beautiful’, ‘round’, and ‘powerful’. The authors answered the second question with the help of exo- and endo-buccal endoscopy where they found that, in the upper register, the transverse tension of the velum and the stretching of the posterior faucial pillars is being accompanied by the hyper retraction of the uvula. This substantial raising of the uvular area makes singers feel as though they are raising their entire velum.

Troup, Welch, Volo, & Tronconi (1989) studied nine professional sopranos singing the following pitches spanning a three-octave range: E3 (165 Hz), E4 (330 Hz), E5 (660 Hz), C6 (1000 Hz), and E6 (1320 Hz) using xeroradiographic images. He reported that two of the nine sopranos had an open velopharyngeal port across all pitches, one singer had a closed velopharyngeal port across all pitches, and the remainder of the singers had a mixture of open and closed positions. Overall, as the pitch increased, the number of subjects with oral-nasal coupling decreased. Results show that seven subjects had an open velopharyngeal port on E3 (165 Hz), six subjects on E4 (330 Hz), four subjects on E5 (660 Hz), and three subjects on C (1000 Hz). Interestingly, five of the nine subjects showed an open port on the highest pitch, E6 (1320 Hz). The authors concluded that ‘‘total velum closure is language dependent, education dependent, style dependent, pitch dependent, and anatomically dependent.’’

Austin (1997) investigated velopharyngeal port activity in four classically trained female singers during speech and operatic singing, using a photodetector system. With the photodetector in place, the subjects had spoken and then sang the sentence ‘‘Connie came to Free Ontario for the firm’s money.’’ The subjects sang the sentence in recitative style (vocal style that reflects natural speech rhythms and inflections) in different vocal ranges such as low, medium, and high. Then subjects sang the vowel series /i,e,a,o,u/ on a repeated pitch at the three different frequencies selected for the singing samples. Each subject had to perform the task five times. The averaged value of five repetitions for each task was taken. During the sentence task, the duration of opening in speech was 39%; for low voice singing, 45%; for medium voice singing, 50%; and 29% for high voice singing. From the results authors concluded that as frequency increased, the duration of velopharyngeal opening decreased.

CHAPTER III

METHOD

Participants

Fifteen professional female singers and 25 female non-singers who were in the age range of 20 to 60 years served as participants. All participants use Kannada as their primary language. Background information regarding medical history and hearing ability was collected. Each participant was evaluated by an experienced speech pathologist to check, oral structure and function. Normal speech and language ability were also evaluated informally before recording. All the participants were normal in GRBAS scale. Participants with any history of upper respiratory tract infection, cold, asthma or allergic diseases at the time of recording were not included in the study. None of the participants reported symptoms of hoarseness, loudness disturbance, and loss of range, vocal abuse, breathiness, choking sensation, phonation break and pitch break. All participants were non smokers.

Professional singers or group I includes fifteen professional singers who are currently practicing Carnatic singing or those who have selected their profession as singing, with ten years of minimum experience in singing. Non-singers or Group II have not received any kind of training on formal singing from church choirs, music bands, singing troops etc.

Stimuli

The two groups, the professional singers and non-singers were evaluated under two different conditions.

- Condition I: The participants have to sustain the phonation of the vowels /a/, /i/ and /u/ with an ascending pitch in three different frequencies (low, middle and high) and with an increase in vocal intensity were recorded for singers and non-singers. The phonation should be minimum of 6 sec. for each vowel.

- Condition II: Non words were given as oral and nasal stimulus for singing task with three ascending pitch in three different scales (low, middle and high) and with an increase in vocal intensity for singers and non singers.

Before the actual recording ten minutes of practice was given. During practice session the model was provided with audio and video. The model pitches for the vowels were 240Hz, 360Hz, and 482Hz for low, mid, and high pitch respectively. For oral non words 245Hz, 373Hz, and 497Hz were used for the respective pitches and for nasal non words 250Hz, 376Hz, and 501.4Hz were used. All the participants were able to match the model pitch and obtained above 90% matching score (APPENDIX I). As the non-singers were not able to vary the pitch and intensity independently, pitch and intensity variation was taken together. It was found that as pitch increases the intensity also increasing. The non-singers who were not able to match the model pitch by 90% were eliminated from the study. All the recordings were done in a quiet room using an Aeroview system, version 1.5.0 and using the digital audio recorder. Table 1 shows the stimuli for two different conditions.

Table 1: *List of stimuli for condition I and II*

Condition I			Condition II					
Vowels			Non words					
Low pitch	Mid pitch	High pitch	Low pitch		Mid pitch		High pitch	
/a/	/a/	/a/	/pava/*	/mava/#	/pava/*	/mava/#	/pava/*	/mava/#
/i/	/i/	/i/	/piva/*	/miva/#	/piva/*	/miva/#	/piva/*	/miva/#
/u/	/u/	/u/	/puva/*	/muva/#	/puva/*	/muva/#	/puva/*	/muva/#

(- oral non-words, # - nasal non-words)*

Instrumentation

Aeroview system, version 1.5.0, developed by Martin Rothenberg and manufactured by Glottal Enterprises was used for the aerodynamic measurements. The Aeroview consists of two transducers, one measures airflow and other measures the intraoral pressure. The Oro-nasal mask is used in the instrument which is connected by the transducers. It is dual chamber mask so that both oral and nasal airflow and pressure can be separately recorded. The average nasal airflow is calculated by placing the two cursors on the two peaks of adjacent waves which gives the measured value in ml/sec.

Procedure

Aerodynamic measurements

Aeroview was setup in a suitable quiet recording room. The instrument was calibrated prior to the recording based on the instructions provided in the manual. The subjects were recorded individually. They were seated comfortably, and practiced the singing task before recording by providing appropriate video models. They were practiced to place the mask correctly and asked not to breathe through the mask while recording. The subjects were instructed to phonate the vowels /a/, /i/, and /u/ in three different pitches such as low, middle and high with an increase in intensity as provided in the model. The subjects were asked to follow the same pitch as in the recorded video sample. Each vowel were recorded individually like low /a/, mid /a/ and high /a/ in one breath and then low /i/, mid /i/, and high /i/. After completing the recording of vowels singing task of non words (oral and nasal) were recorded in similar way.

The nasal airflow trace was monitored continuously throughout each recording to ensure that the data were being captured. In conditions where the subjects made an error during the singing task and phonation, retrial was taken. The correct version was included for data collection. After the completion of data collection of singing task, the nasal airflow trace was stored in a computer file for further data analysis.

Perceptual measurement:

Phonation and singing task was evaluated by 5 qualified Speech Language Pathologists for the perceptual measurement of nasality in different conditions (Increasing F0 and Intensity). Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) used to rate the nasality. Only nasality parameter has been rated in 100 point scale. The SLPs were asked to rate the nasality only for the vowel /a/, the oral non-word /pava/, and the nasal non-words /mava/ for all three pitches.

Statistical analysis

Aerodynamic measurements:

SPSS, 17.0 software was used for statistical analysis. Wilcoxon Signed Rank test was done in order to obtain the pair wise significant difference in the parameters for the two groups. Mann-Whitney U test was done to compare the aerodynamic analysis between singers and non-singers for vowels, oral non-words and nasal non-words.

Perceptual measurement:

For analysis of perceptual measurement the average perceptual nasality is calculated from the ratings of five SLPs for the vowel /a/, the oral non-word /pava/ and the nasal non-word /mava/ at three different pitches such as low, mid and high. Then the mean of the perceptual nasality was taken for singers and non-singers for each stimulus in different pitches. Using Wilcoxon Signed Rank test, the perceptual nasality within the groups were analyzed across pitch for vowel /a/, oral non-word /pava/ and nasal non-word /mava/. Spearman's coefficient of correlation was used to obtain the correlation between aerodynamic and perceptual measurements.

CHAPTER IV

RESULTS

In the present study, there were two groups of participants, group I with professional singers having 15 participants and group II with the non-singers having 25 participants. The study was aimed to find out the effect of vocal training on nasal airflow and perceived nasality with variation in F0 and intensity and also to find correlation between perceptual and objective measurements of nasality. Descriptive statistical analysis was done to observe the mean and standard deviation for both the groups in each parameter. Since the standard deviation of nasal airflow was high for the vowels, the oral non words and for the nasal non words, non parametric statistical tests were used to compare the parameters within the groups and between the groups. The results of the study sub grouped under three main headings.

I. Aerodynamic analysis
II. Perceptual measures
III. Comparison of aerodynamic & perceptual measures

I. Aerodynamic analysis

Wilcoxon signed Rank test was done in order to find the pair wise significant difference in the parameters for the two groups, professional singers and non-singers and Mann-Whitney U test was used to compare the aerodynamic analysis between singers and non-singers for vowels, oral non-words and nasal non-words.

a. Comparison of aerodynamic analysis between singers and non-singers

Mann-Whitney U test was done to compare the aerodynamic analysis between singers and non-singers for vowels.

i. Vowels

Table 2 shows the mean, standard deviation (SD), 'Z' and *p-value* for all the vowels between singers and non-singers.

Table 2: *Mean, SD, Z, and p-value of vowels in singers and non-singers*

	Stimuli	Nasal airflow		Z	*p-value*
		Mean & SD of singers	Mean & SD of non-singers		
Vowel /a/	Low pitch /a/	61.63(69.09)	30.89(31.10)	-1.467	0.142
	Mid pitch /a/	52.05(58.37)	50.20(49.07)	-0.237	0.812
	High pitch /a/	80.81(84.41)	64.94(67.28)	-0.014	0.989
Vowel /i/	Low pitch /i/	92.05(123.88)	37.82(42.01)	-0.894	0.371
	Mid pitch /i/	108.55(115.34)	57.30(84.09)	-1.076	0.282
	High pitch /i/	124.21(129.68)	80.86(87.67)	-0.433	0.665
Vowel	Low pitch /u/	51.25(97.52)	18.31(24.09)	-0.852	0.394

/u/	Mid pitch /u/	37.11(70.22)	18.36(17.54)	-0.321	0.748
	High pitch /u/	81.35(90.16)	43.18(58.38)	-0.740	0.459

There is no statistically significant difference found between singers and non-singers across pitch and vowel. Results also showed that over all nasal airflow of singers is high compared to non-singers in all the vowels as well as in different pitches. The vowel /i/ showed more nasal airflow compare to other vowels in both the groups. For majority of the stimuli it showed that the nasal airflow is increasing as the pitch increases in both the groups. But in the vowels /a/ and /u/ nasal airflow is lower in mid pitch compares to low and high pitches in singers whereas in non-singers, nasal airflow is increasing as the pitch increases in these vowel.

ii. Oral non words

Table 3 shows the mean, SD, Z and *p-value* of nasal airflow for singers and non-singers in oral non words at three different pitches.

Table 3: *Mean, SD, Z, and p-value of the oral non words in singers and non-singers*

	Parameter (Nasal airflow)	Nasal airflow		Z	*p-value*
		Mean & SD of singers	Mean & SD of non-singers		
Oral non word /pava/	Low pitch /pava/	45.84(62.34)	17.03(18.33)	-1.523	0.128

	Mid pitch /pava/	79.72(93.22)	27.63(27.77)	-1.383	0.167
	High pitch /pava/	104.42(115.19)	39.81(38.18)	-1.020	0.308
Oral non word /piva/	Low pitch /piva/	79.62(121.53)	39.33(55.43)	-0.265	0.791
	Mid pitch /piva/	65.78(85.05)	46.35(64.56)	-0.265	0.791
	High pitch /piva/	65.06(93.45)	64.98(85.06)	-0.545	0.586
Oral non word /puva/	Low pitch /puva/	30.98(47.52)	14.78(18.94)	-0.629	0.530
	Mid pitch /puva/	31.96(88.45)	22.68(27.73)	-1.131	0.258
	High pitch /puva/	54.21(100.23)	27.28(35.25)	-0.349	0.727

Result shows that no statistically significant difference found between singers and non-singers in oral non words across different pitches. However, the mean value of nasal airflow shows that singer had more airflow than non singer in all the vowels across three different pitches. Nasal airflow was seen more in the stimulus /piva/ across the three pitches for both the groups. Also increase in nasal airflow was seen for majority of the stimuli as the pitch increases for both the groups.

iii. Nasal non words

Table 4 shows the mean, SD, Z and *p-value* of nasal airflow in singers and non-singers in the nasal non words.

Table 4: *Mean, SD, Z, and p-value of the nasal non-words in singers and non-singers*

	Stimuli	Nasal airflow		Z	*p-value*
		Mean & SD of singer	Mean & SD of non singer		
Nasal non word /mava/	Low pitch /mava/	152.88(129.13)	92.90(61.48)	-1.020	0.308
	Mid pitch /mava/	157.58(200.40)	127.75(80.79)	-0.489	0.625
	High pitch /mava/	170.35(146.65)	165.86(103.83)	-0.377	0.706
Nasal non word /miva/	Low pitch /miva/	223.74(142.71)	160.39(97.40)	-1.299	0.194
	Mid pitch /miva/	222.44(126.88)	161.78(94.66)	-1.662	0.096
	High pitch /miva/	179.06(123.91)	185.36(102.57)	-0.168	0.867
Nasal non word /muva/	Low pitch /muva/	193.49(81.22)	114.83(105.47)	-3.031	0.002
	Mid pitch /muva/	135.05(94.82)	138.71(115.22)	-0.279	0.780

High pitch /muva/	117.43(109.18)	147.34(121.49)	-0.545	0.586

The results revealed that only for low pitch /muva/ there is a significant difference shown between singers and non-singers ($p<0.01$). Even though there is no statistically significant difference between singers and non-singers, there is a high nasal airflow in singers than the non-singers in other parameters. In singers as the pitch increases from low to high there is a decrease in nasal airflow is seen /miva/ and /muva/ whereas it is not seen in non-singers i.e., as the pitch increases the nasal airflow also increases in non-singers for these stimuli. In both the groups /miva/ is having higher nasal airflow compared to other nasal non words.

b. Aerodynamic analysis of group I (Professional singers)

Using Wilcoxon Signed Rank test the nasal airflow within both the groups were analyzed for across vowels, oral non words and nasal non word stimuli.

i. Vowels

Results showed that majority of comparison across vowel and pitch did not show significant difference. This showed that singer maintained the nasal airflow across pitch and vowel without much of variation. Only mid pitch /i/ Vs mid pitch /a/ and high pitch /u/ Vs mid pitch /u/ showed significant difference in nasal airflow of singers. Table 5 shows the mean, SD, Z and *p-value* of nasal airflow of vowels in singers and table 6 shows the comparison of three vowels across pitch in singers.

Table 5: *Mean, SD, Z, and p-value of vowels for the singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Mid pitch /i/	108.55(115.34)	-2.158	0.031
	Mid pitch /a/	52.05(58.37)		
2	High pitch /u/	81.35(90.16)	-2.669	0.008
	Mid pitch /u/	37.11(70.22)		

Table 6 shows that there is no much variation in nasal flow occurred in singers.

Table 6: *Comparison report of three vowels across pitch in singers*

		Low			Mid			High		
		/a/	/i/	/u/	/a/	/i/	/u/	/a/	/i/	/u/
Low	/a/									
	/i/									
	/u/									
Mid	/a/					+				
	/i/				+					

	/u/									+
High	/a/									
	/i/									
	/u/						+			

(+ = *p*< *0.05*)

ii. Oral non words

Results showed that majority of comparison across oral non word and pitch did not show significant difference. This showed that singer maintained the nasal airflow across pitch and oral non word without much of variation. Only low pitch /puva/ Vs low pitch /piva/, mid pitch /puva/ Vs mid pitch /pava/, high pitch /puva/ Vs high pitch /pava/ and high pitch /puva/ Vs mid pitch /puva/ showed significant difference in nasal airflow of singers. Table 7 shows the mean, SD, Z and *p-value* of nasal airflow of oral non words in singers and table 8 shows the comparison of three oral non words across pitch in singers.

Table 7: *Mean, SD, Z, and p-value of oral non words for the singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /puva/	30.98(47.52)	-2.726	0.006
	Low pitch /piva/	79.62(121.53)		
2	Mid pitch /puva/	31.96(88.45)	-2.385	0.017
	Mid pitch /pava/	79.72(93.22)		
3	High pitch /puva/	54.21(100.23)	-2.442	0.015
	High pitch /pava/	104.42(115.19)		
4	High pitch /puva/	54.21(100.23)	-2.215	0.027
	Mid pitch /puva/	31.96(88.45)		

Table 8 shows that there is no much variation in nasal airflow occurred I in singers

Table 8: *Comparison report of three oral non words across pitch in singers*

		Low			Mid			High		
		/pava/	/piva/	/puva/	/pava/	/piva/	/puva/	/pava/	/piva/	/puva/
Low	/pava/									
	/piva/			+						
	/puva/		+							
Mid	/pava/						+			
	/piva/									
	/puva/				+					+
High	/pava/									+
	/piva/									
	/puva/						+	+		

(+ = $p < 0.05$)

iii. Nasal non words

Results showed that majority of comparison across nasal non word and pitch did not show significant difference. This showed that singer maintained the nasal airflow across pitch and nasal non words without much of variation. Only low pitch /miva/ Vs low pitch /mava/, mid pitch /mava/ Vs mid pitch /muva/, mid pitch /miva/ Vs high pitch

/muva/ and high pitch /muva/ Vs low pitch /muva/ showed significant difference in nasal airflow of singers. Table 9 shows the mean, SD, Z and *p-value* of nasal airflow of nasal non words in singers and table 10 shows the comparison of three nasal non words across pitch in singers.

Table 9: *Mean, SD, Z, and p-value of oral non words for the singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /miva/	223.74(142.71)	-2.101	0.036
	Low pitch /mava/	152.88(129.13)		
2	Mid pitch /miva/	222.44(142.71)	-2.329	0.020
	Mid pitch /mava/	157.58(200.40)		
3	Mid pitch /muva/	135.05(94.82)	-2.499	0.012
	Mid pitch /miva/	222.44(126.88)		
4	High pitch /muva/	117.43(109.18)	-2.442	0.015
	High pitch /miva/	179.06(123.91)		
5	High pitch /muva/	117.43(109.18)	-2.385	0.017
	Low pitch /muva/	193.49(81.22)		

Table 10 shows that there is no much variation in nasal airflow occurred in singers for nasal non words.

Table 10: *Comparison report of three nasal non words across pitch in singers*

		Low			Mid			High		
		mava	miva	muva	mava	miva	muva	mava	miva	muva
Low	Mava		+							
	miva	+								
	muva									+
Mid	mava					+				
	miva				+		+			
	muva					+				

High	mava									
	miva									+
	muva			+					+	

(+ = *p< 0.05*)

c. Aerodynamic analysis of group II

Similar to group I, the Wilcoxon Signed Rank Test was used to analyze the nasal airflow within group II across vowels, oral non words and nasal non words.

i. Vowel

Results showed that majority of the comparison across vowel and pitch showed significant difference in nasal airflow. This shows that non-singers not able to maintain the airflow constantly across the vowel and pitch. Table 11 shows the mean, SD, ‘Z’ and *p-value* of vowels across pitch and table 12 shows comparison of three vowels across pitch in non singer.

Table 11: *Mean, SD, Z, and p-value of vowels for the non-singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /u/	18.31(24.09)	-3.350	.001
	Low pitch /i/	37.82(42.01)		

2	Mid pitch /u/	18.36(17.54)	-3.996	.000
	Mid pitch /i/	57.30(84.09)		
3	Mid pitch /u/	18.36(17.54)	-3.646	.000
	Mid pitch /a/	50.20(49.07)		
4	High pitch /u/	43.18(58.38)	-2.812	0.005
	High pitch /i/	80.86(87.67)		
5	High pitch /u/	43.18(58.38)	-2.650	0.008
	High pitch /a/	64.94(67.28)		
6	Mid pitch /a/	50.20(49.07)	-3.431	0.001
	Low pitch /a/	30.89(31.10)		
7	High pitch /a/	64.94(67.28)	-2.301	0.021
	Mid pitch /a/	50.20(49.07)		
8	High pitch /a/	64.94(67.28)	-3.592	0.000
	Low pitch /a/	30.89(31.10)		
9	High pitch /i/	80.86(87.67)	-3.269	0.001
	Mid pitch /i/	57.30(84.09)		
10	High pitch /i/	80.86(87.67)	-3.431	0.001

	Low pitch /i/	37.82(42.01)		
11	High pitch /u/ Mid pitch /u/	43.18(58.38) 18.36(17.54)	-3.646	0.000
12	High pitch /u/ Low pitch /u/	43.18(58.38) 18.31(24.09)	-3.511	0.000

Table 12: *Comparison report of vowels across pitch in non-singers*

		Low			Mid			High		
		/a/	/i/	/u/	/a/	/i/	/u/	/a/	/i/	/u/
Low	/a/				+			+		
	/i/			+					+	
	/u/		+							+
Mid	/a/	+					+	+		
	/i/						+		+	
	/u/				+	+				+
High	/a/	+			+					+
	/i/		+			+				+
	/u/			+			+	+	+	

(+ = *p< 0.05*)

Table 12 shows that variation in nasal airflow across and vowel is more in non-singers.

ii. Oral non words

Results showed that majority of the comparison across oral non words and pitch showed significant difference in nasal airflow. This shows that non-singers not able to maintain the airflow constantly across the oral non-words and pitch. Table 13 shows the mean, SD, 'Z' and *p-value* of nasal non-words across pitch and table 14 shows comparison of three nasal non-words across pitch in non singer

Table 13: *Mean, SD, Z, and p-value of oral non words for the non-singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /piva/ Low pitch /pava/	39.33(55.43) 17.03(18.33)	-3.108	0.002
2	Low pitch /puva/ Low pitch /piva/	14.78(18.94) 39.33(55.43)	-3.565	0.000
3	Mid pitch /puva/ Mid pitch /piva/	22.68(27.73) 46.35(64.56)	-2.301	0.021
4	High pitch /puva	27.28(35.25)	-3.108	0.002

	High pitch /piva/	64.98(85.06)		
5	High pitch /puva/	27.28(35.25)	-2.166	0.030
	High pitch /pava	39.81(38.18)		
6	Mid pitch /pava/	27.63(27.77)	-3.027	0.002
	Low pitch /pava/	17.03(18.33)		
7	High pitch /pava/	39.81(38.18)	-2.422	0.015
	Mid pitch /pava/	27.63(27.77)		
8	High pitch /pava/	39.81(38.18)	-3.700	0.000
	Low pitch /pava/	17.03(18.33)		
9	High pitch /piva/	64.98(85.06)	-3.108	0.002
	Mid pitch /piva/	46.35(64.56)		
10	High pitch /piva/	64.98(85.06)	-2.139	0.032
	Low pitch /piva/	39.33(55.43)		
11	Mid pitch /puva/	22.68(27.73)	-2.906	0.004
	Low pitch /puva/	14.78(35.25)		
12	High pitch /puva/	27.28(35.25)	-2.180	0.029
	Mid pitch /puva/	22.68(27.73)		
13	High pitch /puva/	27.28(35.25)	-3.484	0.000
	Low pitch /puva/	14.78(18.94)		

Table 14 shows that more variation is seen in nasal airflow of oral non words in non-singers

Table 14: *Comparison report of the oral non-words across pitch in non-singers*

		Low			Mid			High		
		/pava/	/piva/	/puva/	/pava/	/piva/	/puva/	/pava/	/piva/	/puva/
Low	/pava/		+		+			+		
	/piva/	+		+					+	
	/puva/		+				+			+
Mid	/pava/	+						+		
	/piva/						+		+	
	/puva/			+		+				+
High	/pava/	+			+					+
	/piva/		+			+				+
	/puva/			+			+	+	+	

(+ = $p < 0.05$)

iii. Nasal non words

Results showed that majority of the comparison across nasal non words and pitch showed significant difference in nasal airflow. This shows that non-singers not able to maintain the airflow constantly across the nasal non-words and pitch. Table 15 shows mean, SD, 'Z' and *p-value* of nasal non-words across pitch and table 16 shows comparison of three nasal non-words across pitch in non singer.

Table 15: *Mean, SD, Z, and p-value of nasal non words for the non-singers*

Sl No.	Stimuli	Mean & SD of Nasal air flow	Z	p-value
1	Low pitch /miva/	160.39(97.40)	-3.767	0.000
	Low pitch /mava/	92.90(61.48)		
2	Low pitch /muva/	114.83(105.47)	-2.785	0.005
	Low pitch /miva/	160.39(97.40)		
3	Mid pitch /miva/	161.78(94.66)	-2.543	0.011
	Mid pitch /mava/	127.75(80.79)		
4	Mid pitch /muva/	138.71(115.22)	-2.112	0.035
	Mid pitch /miva/	161.78(94.66)		
5	High pitch /miva/	185.36(102.57)	-2.166	0.030
	High pitch /mava/	165.86(103.83)		
6	High pitch /muva/	147.34(121.49)	-2.112	0.035
	High pitch /miva/	185.36(102.57)		

7	Mid pitch /mava/	127.75(80.79)	-2.892	0.004
	Low pitch /mava/	92.90(61.48)		
8	High pitch /mava/	165.86(103.83)	-2.274	0.023
	Mid pitch /mava/	127.75(80.79)		
9	High pitch /mava/	165.86(103.83)	-3.162	0.002
	Low pitch /mava/	92.90(61.48)		

Table 16: *Comparison report of three nasal non words across pitch in non-singers*

		Low			Mid			High		
		/mava/	/miva/	/muva/	/mava/	/miva/	/muva/	/mava/	/miva/	/muva/
Low	/mava/		+		+			+		
	/miva/	+		+						
	/muva		+							

	/									
Mid	/mava/	+				+		+		
	/miva/				+		+			
	/muva/					+				
High	/mava/	+			+				+	
	/miva/							+		+
	/muva/								+	

(+ = $p < 0.05$)

Table 16 shows that the more variation is seen in the nasal airflow of nasal non words in non-singers.

II. Perceptual analysis

For analysis of perceptual measurement the average perceptual nasality is calculated from the ratings of five SLPs for the vowel /a/, the oral non word /pava/ and the nasal non word /mava/ at three different pitches such as low, mid and high. Then the mean of the perceptual nasality was taken for singers and non-singers. Table 17 shows the mean and SD of perceptual nasality in singers and non-singers.

Table 17: *Mean & SD of perceptual analysis of singers and non-singers*

	Stimuli	Perceptual nasality	
		Mean & SD of singers	Mean & SD of non-singers
Vowel /a/	Low /a/	9.97(3.40)	10.42(3.16)
	Mid /a/	12.51(4.19)	13.01(3.15)
	High /a/	15.22(5.03)	15.34(3.18)
Oral non word /pava/	Low/pava/	11.82(2.30)	12.53(3.12)
	Mid /pava/	13.68(2.66)	15.69(2.66)
	High /pava/	16.62(3.29)	19.06(3.14)
Nasal non word /mava/	Low /mava/	19.26(2.47)	21.63(3.83)
	Mid /mava/	22.97(3.98)	24.73(4.27)
	High /mava/	25.62(3.32)	29.46(3.83)

The findings show that perceptually the nasality is more in non-singers than singers. As pitch increases from low to high the nasality is also increasing perceptually in both the groups.

Using Wilcoxon Signed Rank test the perceptual nasality within the groups were analyzed across pitch for vowel /a/, oral non word /pava/ and nasal non word /mava/.

Table 18 and table 19 show the pair wise comparison of perceptual analysis of singers and non-singers respectively.

Table 18: *Pair wise comparison of perceptual analysis in singers*

	Low Vs Mid	Mid Vs High	Low Vs High
/a/	+	+	+
/pava/	+	+	+
/mava/	+	+	+

(+ = $p < 0.05$)

Table 19: *Pair wise comparison of perceptual analysis in non-singers*

	Low Vs Mid	Mid Vs High	Low Vs High
/a/	+	+	+
/pava/	+	+	+
/mava/	+	+	+

(+ = $p < 0.05$)

Results showed that variation in perceived nasality present for all the stimuli across pitch in singers and non-singers.

III. Comparison of aerodynamic and perceptual measures

Spearman's coefficient of correlation was used to obtain the correlation between aerodynamic and perceptual measurements of singers and non-singers. Table 20 shows the correlation coefficient between perceptual and aerodynamic analysis in singers and non singers for the vowel /a/, oral non-word /pava/ and nasal non-word /mava/ in three pitches.

Table 20: *Correlation between perceptual and aerodynamic analysis of singers and non-singers*

Stimuli	Correlation coefficient for singers	Correlation coefficient for non-singers
Low /a/	0.066	-0.075
Mid /a/	0.292	0.130
High /a/	-0.200	0. 098
Low /pava/	-0.428	-0.109
Mid /pava/	-0.165	0.154
High /pava/	-0.002	-0. 231
Low /mava/	0.354	0. 205
Mid /mava/	0.014	0. 317
High /mava/	-0.174	0.260

The results revealed that there is poor correlation present between aerodynamic and perceptual measures either in singers or non-singers. However, singers showed more negative correlation between nasal airflow and perceived nasality in comparison with non singers.

CHAPTER V

DISCUSSION

Many researchers are of the view that velum opens greatly when singing in higher pitches and which is negatively correlated to the perceived nasality. Few research evidence shows that trained singers have more capability than non-singers and the researchers reported that singers uses specific velar adjustments while singing in upper registers. Since there are very few studies focused on the effect of vocal training and perceived nasality in singing especially in Indian music. The present study compared the nasal airflow between vocally trained (professional singers) and untrained (non-singers) with increasing frequency and intensity. The current study investigated 40 female participants which consisted of 15 professional singers and 25 non-singers. Nasal airflow was compared between singers and non-singers in vowels, oral non-words, and nasal non-words with three different pitches and with the assumption that intensity will also increase with increase in pitch. Later aerodynamic and perceptual measurements were compared between group I and group II.

I. Aerodynamic analysis

a. Comparison of aerodynamic analysis between singers and non-singers

The comparison of aerodynamic analysis of vowels, oral non-words and nasal non-words between singers and non-singers suggested that overall nasal airflow of singers is higher compared to non-singers. One of the possible explanations is that singers uses velopharyngeal opening (VPO) more compared to non-singers during singing. Since VPO is more beneficial in singing, singers use the nasal murmer such as /ma/, /mi/, and /mu/ as classical exercises to initiate phonation, is an evidence to that. Presence of VPO in classical singers is found by various methods such as x-ray imaging, nasometer, airflow measurements photodetector and by nasofiberscopy. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) reported that a narrow VPO can be regarded as a slit and acoustic impedance of VPO increases as frequency increases. Hence the lowest force in the VPO will lead to squeeze even through narrow opening. They also reported that VPO may exist even in the absence of nasal DC flow. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) suggested that singers use VPO during singing and also found different pattern of VPO in different singers and suggested that "singers carefully tune the degree of opening, in order to color the timbre". They suggested that singers are capable of using even a wide VPO without producing high degree of nasal quality. The present study also supports this finding that singers are able to use the VPO to color their timbre thereby the nasal airflow was increased in singers than non-singers and without producing much nasality.

Even though nasal airflow shows higher value, the perceived nasality in singers has no significant difference compared to non-singers as the study by Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002). This also suggests that trained singers have ability to control their velum movement to project their voice and make it better. Contradicting to this view, using photodetector Austin (1997) found that small or no VPO present in singers. He concluded that as frequency increased, the duration of VPO is decreased. The present study is not supporting his view that VP is closed during classical singing. According to Miller (1996) VPO is not harmful to the singing voice, and he also postulated that "nasality intruded into non-nasals is not aesthetically pleasing." The above discussion is based on the assumption that there is positive correlation between VPO and nasal airflow and in turn with perceived nasality also. However, literature shows that there may be no correlation between VPO and the nasal airflow. Hence, the reader has to interpret with caution.

i. Vowels

Findings of vowels in the present study suggest that there is no statistically significant difference found between singers and non-singers. Also the nasal airflow of vowels showed that vowel /i/ has more nasal airflow compared to other vowels in both the singers and non-singers. Jennings & Kuehn (2008) reported the similar results in singers using nasometer. In accordance with this, Fowler (2004) reported that singers had a low nasalance score for the back vowels. These findings suggested that since /i/ is a high front vowel, greater nasal airflow in /i/ is due to the anterior constriction and which is correlated with more oral impedance. This information is consistent with literature. Lewis, Watterson & Quint (2000) and Von Berg (2002) revealed that vowel /i/ had greatest mean nasalance score compared to the other four vowels /a,u, ae/. Similar trends were seen in this study compared to the other to vowels /a/ and /u/.

The present finding is also supporting by Carlo & Autesserre (1987). They used x-rays to obtain the velum behavior during singing and reported that a total occlusion was found in the velum when the vowel /i/ was spoken whereas 1mm opening was observed during /i/ was sung in the lower vocal register and about 2 mm opening found when it was sung in the higher register. In upper register pharyngeal tightening occurs because of the tension of the muscle. Singers will adjust their velum in a specific position to avoid the excessive contraction of pharyngeal and velar muscles. Their result shows that perceptually the voice was rated as beautiful and powerful for those who sung with a lowered velum whereas 'dull' was rated for those who sing with raised velum. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) found that the nasal flow varied with increasing pitch in singers. They found that nasal airflow was present for the vowels /a/ and /u/, while nasal airflow was observed for the vowel /i/ only in one tenor singer. Several studies have shown that nasal resonance is still accepted and is used in singing. Singing teachers and voice clinicians should suggest the students to produce the vocal quality as forward rather than backward.

ii. Oral non-words

Findings of oral non-words in the present study suggest that there is no statistically significant difference found between singers and non-singers, same as the findings of vowels. However, it was observed that nasal airflow was seen more in the stimulus /piva/ across pitch for both the groups. Similar as vowel /i/ during singing, the oral non-word with the high vowel /i/ also shows the findings in consensus with the findings of Jennings & Kuehn (2008) and Fowler (2004). Their results suggest that the anterior constriction and more oral impedance in the vowel /i/ cause more nasal airflow.

This suggestion can also be attributed to the production of /piva/. Due to the higher intra oral pressure of /p/ and the oral impedance and tongue constriction of /i/ would give a combined effect in the production of /piva/ which results in increased nasal airflow. The production of stop consonants is considered as the point of maximum VP closure and also has maximum intra oral pressure.

iii. Nasal non-words

Similar as in vowels and oral non-words, the nasal non-word with /i/, i.e., /miva/ has more nasal airflow in both the groups. Compared to the findings of vowels and oral non-words, the results of nasal non-words revealed that there is a significant effect present for the low pitch /muva/ between singers and non singers. Also it was observed that as the pitch increases from low to high there is a decrease in nasal airflow is seen in /miva/ and /muva/. This finding suggests that in nasal context singers are able to control their nasality as pitch increases. According to Carlo & Autesserre (1987) velum is lowered for the nasal vowel and lateral pharyngeal walls were apart than oral vowel. Present study also supports the view of these authors that in the findings, only non-words with nasal vowels showing a variation between singers and non singers. They concluded that "VPO is increased as singers going from lower to the upper registers." However, Tanner, Roy, Merrill & David (2005) reported that the nasal airflow was higher in singing compared to speaking in the production of /p/ in the /mp/ blend. It is discussed that this is due to the carryover effect of the preceding nasal consonant /m/ in the blend. In the view of this study, the findings in nasal airflow of /miva/ also can be attributed to the anticipatory effect of /m/ and oral impedance and tongue constriction of /i/ would result in combined effect of increased nasal airflow.

The comparison across vowels, oral non-words and nasal non-words across pitch did not show significant difference in singers in many of the comparison, in contrast to the non-singers. This suggests that singers are able to maintain the nasal airflow across pitch and vowel without much of variation. The singers are controlled to use velar adjustments with varying pitch. Whereas non-singers are not able to maintain the airflow constantly which suggests that non-singers are not able to control their velum during singing with increasing pitch and intensity.

II. Perceptual analysis

The comparison of perceptual nasality between singers and non singers revealed that nasality is more seen in non singers than singers. However, it was not statistically significant. As pitch increases perceived nasality was also increasing in both the groups. Pair wise perceptual nasality findings shows that there is a variation in nasality present with varying pitch in both singers and non singers. This suggests that even though the nasal airflow was varied between singers and non-singers, the perceived nasality was same. This is correlated with effect of vocal training on nasality i.e., the singers use their VPO during singing to color their voice without much change in the perceptual nasality.

III. Comparison of aerodynamic and perceptual measure

The results revealed that there is poor correlation present between aerodynamic and perceptual measures, both in singers and non singers. It was also found that singers showed more negative correlation between nasal airflow and perceptual nasality compared to non-singers. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) also found a lack of correlation between perceived nasality and nasal DC (constant) airflow. The correlation would have been better if the airflow data and audio recording were done at the same session. The finding suggests that singers produce more nasal airflow during singing but it is not sensing as much nasality to the listeners. That is the singers are trained to use specific velar adjustments in singing which will not affect perceived nasality and it is some extent same in the present study.

Results of the present study suggest that majority of the singers had a higher nasal airflow during upper registers in most of the stimuli. Only those who got sufficient vocal training and have been judged to be proficient in singing shows less nasal airflow than non singers. This leads to two different conclusions, i.e., either the singers are taught to reduce or avoid nasality in their singing or they have tendency towards nasal airflow. This suggests that vocal training has an effect on nasal airflow while increasing pitch. In this study, even though the singer's perceived nasality was lower than the non singers which did not give a significant difference because only few of the singers were effectively trained.

Habitual pitch was not measured in the study. Nasal airflow measure on habitual pitch would have given some insight for the study. Also rate of singing was not controlled in this study. Participants were given the model to sing in the same rate but some of them sing at different rate. Most of the singers start with a classical style in the initial part of singing. This will leads to more nasal airflow than the steady state. But when they reached the steady vowel position it may reduced. Hence, the classical style also contributed to increased nasal airflow during singing. Also as singers demonstrated more energy during singing for singer's formant, would also result in increased airflow.

Another observation seen was that the participants are controlling their singing when sung in the upper register through the mask. Some of the participants are not comfortable to sing through the mask. They had to be trained to sing through mask for some time. Also the inadequate seal between the mask and the face will render the acquisition of nasal airflow. Mask also prevented the normal auditory feedback to the singers. So VPO could only be proved by the presence of nasal airflow and also observation of it through nasofiberscopy, x-rays and photodetector which was not used in the study. If it was used this would give a better result regarding the VPO and nasal airflow during singing. According to Sundberg (2004) "occasional oral–nasal coupling might tune the resonating system and strengthen the singer's formant during classical singing". Thus it was revealed that VPO is not harmful to the singers. Singers use this to color their voice. If proper vocal training is not achieved, this would result in increased perceptual nasality. Present study also supports the same findings that VPO leads to an increase in nasal airflow however, it is not perceived as high nasality to the listeners. If the singers were not trained properly they would not achieve the velar adjustments during singing and will result in inadequate nasal airflow. Authors reported that in most efficient singers, the presence of VPO would not result in presence of nasal airflow. This is not occurring in non-singers or untrained singers.

Most of the singers use specific technique in their singing style. One of that is wide oral opening. This was not much achieved when using oral-nasal mask. Oral opening would color their voice and result in singer's formant. Also wrong techniques in singing adversely affect their voice. Any conscious attempt to maintain lowered or elevated velopharynx during singing would result hyperfunctional in some cases and which will also increase the risk of developing different vocal and velar pathologies.

Only few of the singers showed a pattern of nasal airflow when increasing pitch which was not significant difference. Pattern of nasal airflow is found in some studies which mean that there is a trend in singers with decreased nasalance when they sing from low to high pitch. However, the variation in nasal airflow was more shown in non-singers compared to singers which suggest that singers have the ability to control the VPO when sung at different pitches whereas non-singers not have this capability. Their velum is not tuned to that.

The variation in nasal airflow between participants (singers and non-singers) was more in the study. This variability is occurred for reasons other than independent variable and it also affects the overall results of the study. In future it can be studied the factors that contribute wide range of nasal airflow observed in the study. Literature shows significant difference in nasal airflow would be seen when comparing the various styles of singing, different language, gender and experience level. Troup, Welch, Volo & Tronconi (1989) also concluded as "total velum closure is language dependant, education dependant, style dependant, pitch dependant and anatomically dependant."

Limitations of the study

- Rate of singing was not controlled in the study.
- The oro-nasal mask used in the airflow measurements was not comfortable to some participants.

- The nasal habitual pitch and nasal airflow of habitual pitch was not measured in the study.
- The perceptual rating scale used in the study felt inappropriate for the listeners.
- Nasal airflow measurement and the recordings for perceptual measurements were not done simultaneously

Implications

- The results of the present study add the knowledge in the field of physiology behind singing, especially in Indian music. Also give some insight in the relation between nasal airflow and perceived nasality in singers.
- Since the individual variation in the nasal airflow is more the single subject design will give more information than group design.

Future directions

- The study can be compared between gender, age, music style, language and duration of experience in vocal training.
- The study can be done with aerodynamic and acoustic measurements and also using various methods such as x-ray imaging, nasometer, airflow measurements photodetector and by nasofiberscopy.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Vocal resonance is most important in singing. Out of the four primary resonances such as chest, mouth, nasal and head, nasal resonance gives clarity and projection to the singing voice. These resonances are used depending on the style of singing. This nasal resonance occurs due to the oro-nasal coupling mainly during the production of nasal phonemes during speech. In normal individuals, it occurs without any control or conscious effort. But authors have reported that trained singers use nasal resonance during singing. Various studies have been done to find whether singers use nasal resonance during singing.

Several researchers investigated the velopharyngeal opening (VPO) during singing and suggest that there is VPO present with increasing pitch and it is negatively correlated with the perceived nasality. If nasality is not controlled while singing it will be distracted to the listeners. Even though singing consists of both oral and nasal consonants like speech, it is not heard as noisy or dull. So how the singers are able to project their voice when there is an opened velum, is worth of investigation. There are only few number of studies focused on the effect of vocal training and perceived nasality in singing. So the present was aimed to find out the effect of vocal training on nasal airflow and perceived nasality with variation in F0 and intensity and also to find correlation between perceptual and objective measurements of nasality, in Indian Carnatic singers.

Two groups of participants were included in this study. Group I included 15 female professional singers and group II included 25 non-singers with an age range of 20-60 years. Professional singers had minimum ten years of experience in Carnatic singing and non singers have not received any kind of training on formal singing. The participants were evaluated under aerodynamic and perceptual measurements. The first condition in aerodynamic measurements was to phonate the vowels /a/, /i/ and /u/ with an ascending pitch in three different frequencies (low, mid, and high) and with an increase in vocal intensity. In the second condition the participants were instructed to sing oral (/pava/, /piva/, and /puva/) and nasal (/mava/, /miva/, and /muva/) non-words with ascending pitch in three different scales and increase in intensity.

Ten minutes practice session was given before actual recording and provided with an audio and video model and they were instructed to match the pitch as the model. Aerodynamic measurements (nasal airflow) were recorded using Aeroview syste, version 1.5.0. Perceptual nasality for the two conditions was rated by five SLPs using CAPE-V. Only nasality parameter has been rated in 100 point scale. All the participants were able to match the pitch and scored more than 90 % of matching.

The current study compared the aerodynamic and perceptual measurements between singers and non-singers. Mann-Whitney U test used to compare the aerodynamic analysis between singers and non-singers and Wilcoxon Signed Rank test used to find the pair wise significant difference within the groups and parameters in aerodynamic and perceptual analysis. In aerodynamic analysis, the study results found a significant difference between singers and non-singers only in the low pitch /muva/. However, the mean value of nasal airflow shows that singers had more airflow than non-singers in all the vowels, oral non-word and nasal non-words across pitch. The vowel /i/ showed more nasal airflow compare to other vowels in both the groups. Also in the vowels /a/ and /u/ nasal airflow is lower in the mid pitch compare to low and high pitches in singers whereas in non-singers, nasal airflow is increasing as the pitch increase in these vowels. In oral non-words, nasal airflow was seen more in the stimulus /piva/ and in nasal non-words /miva/ showed more nasal airflow in both the groups. For majority of the stimuli it showed that the nasal airflow is increasing as the pitch increases in both the groups.

The results of aerodynamic analysis in singers showed that majority of comparison across vowel Vs pitch, oral non-words Vs pitch and nasal non-words Vs pitch did not show significant difference. This suggested that singer maintained the nasal airflow across pitch and stimuli without much of variation. Whereas the results of non-singers showed that majority of comparison across the stimuli and pitch showed a significant difference in nasal airflow. This shows that non-singers are not able to maintain the airflow constantly across the pitch and different stimuli.

The results of mean value of perceptual nasality between singers and non-singers show that the nasality is more in non-singers than singers. Also as pitch increasing from low to high the nasality is also increasing in both the groups. Variation in perceived nasality present for all the stimuli across pitch in both the groups. The results of comparison of aerodynamic and perceptual measures in singers and non-singers revealed that there is poor correlation present between the two measures in both the groups. However, singers showed more negative correlation between nasal airflow and perceived nasality in comparison with non-singers. However, the correlation values were poor.

The results of the study are in consonance with some of the previous literature. The present study revealed several points of interest. ***First,*** the nasal airflow was higher in majority of the stimuli in singers in comparison with non singers. ***Second,*** the analysis of perceptual measurements shows that the mean value of perceived nasality is higher in non-singers compared to non-singers. These findings suggest that singers use the VPO to project and color their voice but it is not perceived as much while singing. ***Third,*** majority of the comparison across the stimuli and pitch did not show significant difference in singers whereas non-singers showed a significant difference for majority of the comparison across pitch and stimuli. These findings suggest that singers are able to maintain the airflow constantly across pitch and the different stimuli whereas non-singers are not able to maintain it. This showed the effect of vocal training in singers with ascending pitch. ***Fourth,*** there is more negative correlation found between aerodynamic and perceptual measurements in singers.

REFERENCES

Alderson, A. (1993). Positioning the velum. *The Journal of Research in Singing and Applied Vocal Pedagogy*, 16, 25-32.

Aronson, A. E., & Bless, D. M. (2009). Clinical Voice Disorders**.** *Thieme Medical Publishers, Inc. New York.*

Austin, S. F. (1997). Movement of the Velum during Speech and Classically Trained Singers. *Journal of Voice*, 2(2), 212-221.

Birch, P., Gumoes., Stavad, H., Prytz, S., Bjokner & Sundberg, J. (2002). Velum behavior in professional classic operatic singing. *Journal of Voice,* 16, 61-71.

Brown, L. & Behnke, E. (1883). Voice, Song, and Speech, A practical guide for singers and speakers, London, Sampson Low

Brown, W. S., Hunt, E., & Williams, W. N., (1988). Physiological differences between the trained and untrained speaking and singing voice. *Journal of Voice*, 2(2), 102-10.

Brown, W.S., Jr., Rothman, H., & Williams, W. (1978). Physiological differences between singers and non-singers. In V. Lawrence (Ed.). *Transcripts of the Seventh Symposium on Care of the Professional Voice*. New York, NY: Voice Foundation, 11-18.

Bunch , M. (1982). Dynamics of Singing Voice. *Springer Verlag, New York* .

Bunch, M. (1995). Dynamics of Singing Voice (*III* edition). *Disorders of Human Communication Disorders, Springer Verlag, New York* .

Bunch, M. (2009). Dynamics of the Singing Voice, *5th edition, Springer Wein, New York.*

Carlo, D., S. & Autesserre, D. (1987). Movement of Velum in Singing. *Journal of Research in Singing,* 10, 3-13.

Chakraborty, S., & Debashis. (2012). Pattern Classification of Indian Classical Ragas based on Object Oriented Concepts. *International Journal of Advanced Computer Engineering & Architecture, 2(2),* 285-294

Devadas, U., Rajashekhar, B., & Aithal, U. V. (2009). Analysis of Voice in Yakshagana Singers. *Journal of AIISH*, 28, 59-64.

Fowler, P. L. (2004). Comparison of Nasalance between Trained Singers and Non-singers, A Dissertation submitted to the Department of Communication Disorders

In partial fulfillment of the requirements for the degree of Doctor of Philosophy, *Florida State University.*

Gauffin, J., & Sundberg, J. (1989). Spectral correlates of glottal voice source waveform characteristics. *Journal of Speech and Hearing Research, 32,* 556-565.

Gramming, P., Nord, L., Sundberg, J., & Elliot, N. (1993). Does the nose resonate during singing?, *STL-QPSR*, 34 (4), 35-42

Griffin, B., Woo, P., Colton, R., Casper, J., & Brewer, D. (1995). Physiological Characteristics of the Supported Singing Voice. A Preliminary Study. *Journal of Voice,* 9(1), 45-56.

Hamdan, A. L., Deeb, R., Tohme, R. A., Rifai, H., Husseini, S., & Fuleihan, N. (2008). Vocal Technique in a Group of Middle Eastern Singers. *Folia Phoniatrica Logopedics,* 60, 217–221

Hoit, J. D., Jenks, C. L., Watson, P. J., & Cleveland, T. F. (1996). Respiratory Function During Speaking and Singing in Professional Country Singers. *Journal of Voice,* 10(1) 39-49

House, S., & Stevens, K. N. (1956). Analog Studies of the Nasalization of Vowels. *The journal of Speech and Hearing Disorders,* 21 (2), 218-232

http://en.wikipedia.org/wiki/Vocal_pedagogy

http://en.wikipedia.org/wiki/Vocal_resonation http://*shodhganga.inflibnet.ac.in/bitstream/10603/4551/.../07_chapter%202.pdf*

Jennings, J. J., & Kuehn, P. D. (2008). The Effects of Frequency Range, Vowel, Dynamic Loudness Level, and Gender on Nasalance in Amateur and Classically Trained Singers. *Journal of Voice*, 22(1), 75-89.

Lawrence, V. L. (1979). Laryngological observations on belting. *Journal of Research Singing,* 2(1), 26-8.

Lewis, K. E., Watterson, T. L., & Quint, T. (2000). The effect of vowels on nasalance scores. *Cleft Palate Craniofacial Journal*, 37, 584-589.

McIver, W., & Miller, R. (1996). A brief study of nasality in singing. *Journal of Singing,* 52, 21-25.

McCrea, C. R., & Morris, R. J. (2001). Effects of Vocal Training and Phonatory Task on Voice Onset Time. *Journal of Voice,* 21(1), 54-63.

McGlone, R. (1976). Lingual pressure variation during singing by trained and untrained individuals. Paper presented at the Fifth Symposium on Care of the Professional Voice, New York.

McGlone, R. (1977). Supraglottal air pressure variation from trained singers while speaking and singing. In: Lawrence, V. (ed.) *Transcripts of the Sixth Symposium on Care of the Professional Voice*. New York: The Voice Foundation, 48-49.

McKinney, & James (1994). The Diagnosis and Correction of Vocal Faults, Nashville, TN: Genovex Music Group.

Monahan, B. J. (1978). The art of singing; a compendium of thoughts on singing published between 1777 and 1927. New Jersey, The Scarecrow Press

Punt, N. A. (1979). The way to sing. Boston: Birchard.

Shipp. T., & Izdebski, K. (1975). Vocal frequency and vertical larynx positioning by singers and non-singers. *Journal of the Acoustical Society of America, 58*, 1104-1106.

Stone, E. R., Cleveland, F.T., & Sundbergt, J. (1999). Formant Frequencies in Country Singers' Speech and Singing. *Journal of Voice*, 13(2), 161-167.

Sundberg, J., & Rothenberg, M. (1986), Some phonatory characteristics of singers and nonsingers. *STL-QPSR*, 27(4), 065-077

Sundberg, J., Cleveland, E. T., Stone, E. R., & Iwarsson, J.S. (1999). Voice Source Characteristics in Six Premier Country Singers. *Journal of Voice*, 13(2), 168-183.

Sundberg, J. (2001). Level and Center Frequency of the Singer's Formant. *Journal of Voice*, 15(2), 176–186

Tanner Roy, K. N., Merrill, R. M., & David, P. (2005). Velo pharyngeal port status during classical singing. *Journal of Speech, Language, and Hearing Research,* 48, 1311-1324.

Titze, Ingo. (1994). Acoustics of the Tenor High Voice. Journal of the Acoustic Society of America, 95(3), 1133-1142

Troup, G. J., Welch, G. F., Volo, M., Tronconi, A., Ferrero, F., & Farnetani, E., (1989). On velum opening in singing. *The Journal of Research in Singing and Applied Vocal Pedagogy*, 13, 35–39.

Von Berg, S., (2002). The effect of vowels on nasalance measures and nasality judgments [dissertation]. Reno, Nevada, University of Nevada.

Vennard, W. (1964). An experiment to evaluate the importance of nasal resonance in singing. *Folia Phoniatrica Logopedics,* 16, 146-153.

Volo, M., Farnetani, E., Troup, G. J., Ferrero, F. E., (1986) A pilot study of nasal aerodynamic flow in singing. Quaderni del Centro di Studio per le Ricerche di Fonetica del C.N.R, 5, 395-404.

Yanagisawa, E., Estill, J., Mambrino, L., & Talkin, D. (1991). Supraglottic contributions to pitch raising videoendoscopic study with spectroanalysis. *Annals of Otology, Rhinology and Laryngology,* 100, 19-30.

APPENDIX I

Percentage of Matching the Model Pitch in Participants Pitch (Singers & Non-Singers)

(1-15 = singers, 16-40 = non-singers)

Vowels

Participants	Low /a/	Mid /a/	High /a/
1	98.33	99.81	96.62
2	98.63	98.53	98.07
3	100.00	99.64	98.55
4	98.20	98.81	100.00
5	99.38	99.31	98.82
6	98.13	98.31	98.18
7	94.42	94.95	96.69
8	95.67	96.29	95.55
9	98.92	98.28	97.76
10	98.13	97.48	96.58
11	98.88	99.11	97.35
12	94.92	96.70	95.05
13	99.00	99.14	97.91
14	96.33	98.86	95.92
15	97.83	97.92	97.89
16	96.54	99.28	97.31
17	99.92	98.92	96.19
18	98.92	98.03	99.44
19	99.04	98.59	99.59
20	96.25	96.15	95.19
21	98.08	96.20	98.74
22	98.22	98.53	99.46
23	99.25	97.73	99.25
24	97.12	98.46	100.00
25	99.13	100.00	98.82
26	99.21	98.06	97.39
27	95.63	98.23	97.72
28	98.25	98.59	96.83
29	96.33	96.34	94.82
30	89.25	91.20	88.48
31	91.79	98.31	92.34
32	96.75	92.87	80.13
33	98.29	95.65	96.71
34	90.74	97.87	99.73
35	100.00	97.62	100.00
36	99.63	98.06	99.21
37	99.75	98.53	98.84
38	98.63	97.75	97.33
39	97.54	99.42	98.84
40	98.29	98.13	97.24

Participants	Low /i/	Mid /i/	High /i/
1	96.21	100.00	96.87
2	100.00	100.00	98.74
3	97.04	100.00	99.46
4	100.00	98.64	100.00
5	98.42	99.42	99.32
6	100.00	99.75	99.42
7	97.71	98.72	97.43
8	95.38	96.42	96.21
9	100.00	98.75	100.00
10	98.42	97.98	97.62
11	99.58	97.81	97.80
12	97.75	97.92	97.45
13	98.58	98.84	99.11
14	97.08	96.37	95.69
15	100.00	99.22	98.51
16	96.54	98.97	99.19
17	99.92	97.98	93.99
18	98.91	100.00	100.00
19	99.04	97.45	96.66
20	96.25	94.51	96.79
21	98.08	97.50	95.63
22	96.21	99.14	90.70
23	99.54	98.31	98.94
24	94.46	94.76	98.11
25	96.75	98.17	100.00
26	99.46	98.59	99.09
27	99.38	98.02	98.20
28	96.92	98.86	91.94
29	99.46	96.59	98.22
30	91.54	94.87	92.77
31	90.29	97.17	90.56
32	96.67	99.14	90.11
33	97.33	89.71	97.51
34	90.33	91.24	97.61
35	95.67	100.00	98.94
36	99.42	98.72	98.78
37	98.83	97.39	97.33
38	98.21	97.98	96.19
39	96.92	97.62	96.08
40	90.42	98.34	95.12

Participants	Low /u/	Mid /u/	High /u/
1	95.38	99.42	97.95
2	98.75	99.22	98.11
3	96.04	99.36	96.89
4	100.00	98.50	100.00
5	99.42	96.51	96.46
6	98.58	99.45	99.11
7	98.29	99.83	99.94
8	95.46	96.62	96.37
9	98.46	99.36	98.57
10	94.17	97.78	97.53
11	99.79	97.89	97.85
12	91.75	91.99	90.41
13	100.00	98.39	98.74
14	96.08	97.12	95.88
15	100.00	99.03	98.82
16	100.00	100.00	99.46
17	99.00	97.42	95.46
18	99.04	97.42	98.53
19	100.00	100.00	99.54
20	97.50	97.48	96.42
21	99.67	97.50	92.44
22	99.25	98.36	94.78
23	98.54	96.84	99.50
24	93.96	97.84	95.03
25	99.38	99.56	100.00
26	98.58	100.00	98.74
27	98.13	98.17	97.64
28	100.00	98.28	97.45
29	99.75	95.79	96.15
30	92.92	98.81	94.63
31	90.42	93.18	97.24
32	100.00	94.65	90.95
33	97.96	93.79	98.40
34	92.58	92.13	95.73
35	94.20	90.34	94.28
36	98.04	98.25	98.26
37	99.71	97.26	97.74
38	99.08	96.65	94.70
39	97.21	99.64	95.19
40	96.92	93.74	94.56

Oral non-words

Participants	Low /pava/	Mid /pava/	High /pava/
1	95.56	97.11	95.40
2	95.52	95.83	96.18
3	92.55	94.78	93.53
4	98.41	98.77	98.73
5	98.49	96.12	97.51
6	97.48	96.44	96.67
7	97.84	96.98	98.25
8	95.93	98.23	96.26
9	97.80	98.58	95.98
10	97.64	97.89	95.94
11	98.66	98.47	96.77
12	95.32	95.34	94.21
13	97.56	94.67	94.23
14	91.98	93.77	93.45
15	99.10	95.29	95.32
16	95.56	97.56	95.00
17	95.89	96.31	92.71
18	96.09	96.25	96.50
19	98.05	97.78	96.50
20	98.70	97.08	97.51
21	96.46	98.13	91.57
22	95.32	98.88	93.59
23	98.24	98.66	98.94
24	97.72	95.32	94.60
25	96.38	96.04	95.38
26	95.20	97.35	98.45
27	96.50	96.04	95.60
28	98.86	98.53	98.11
29	95.81	93.18	95.12
30	90.90	90.78	91.34
31	90.00	100.00	93.81
32	98.29	96.66	92.67
33	96.29	97.86	98.53
34	98.94	99.06	97.93
35	92.14	94.19	96.89
36	99.02	99.09	97.99
37	99.51	97.46	98.29
38	96.34	96.79	96.26
39	98.70	97.08	97.65
40	98.94	98.25	93.45

Participants	Low /piva/	Mid / piva /	High /piva /
1	96.82	99.25	95.78
2	97.35	96.84	96.00
3	97.76	94.43	94.21
4	97.11	98.94	99.30
5	98.62	98.58	97.99
6	97.92	99.36	98.47
7	100.00	99.41	98.17
8	95.52	98.93	98.03
9	96.38	95.77	95.86
10	97.80	96.31	99.24
11	98.53	96.52	96.30
12	97.23	95.83	95.62
13	96.05	94.94	94.90
14	93.57	93.15	90.82
15	97.11	96.17	95.82
16	93.69	95.48	93.69
17	95.85	93.90	93.73
18	100.00	97.97	98.71
19	100.00	97.51	97.33
20	97.43	94.65	95.32
21	97.03	98.88	92.41
22	93.61	99.12	96.20
23	98.98	99.06	98.29
24	100.00	99.25	98.27
25	98.25	96.04	95.70
26	97.43	99.84	99.46
27	93.53	92.61	95.20
28	96.70	93.82	92.29
29	90.68	96.23	94.56
30	90.57	86.89	90.99
31	90.01	98.64	90.78
32	92.59	96.63	93.45
33	94.91	95.75	98.43
34	95.24	98.88	98.53
35	95.77	98.34	100.00
36	98.57	98.85	97.51
37	99.76	93.63	96.93
38	96.66	95.16	95.70
39	98.25	95.93	98.27
40	98.58	96.81	98.20

Participants	Low /puva/	Mid /puva /	High /puva /
1	97.84	99.14	97.85
2	98.09	95.34	94.70
3	94.34	92.99	94.13
4	96.70	98.64	99.42
5	98.57	98.42	98.33
6	100.00	100.00	99.22
7	100.00	100.00	99.74
8	97.35	99.20	98.92
9	97.64	100.00	98.13
10	98.94	97.14	99.02
11	99.23	98.98	97.17
12	97.76	97.97	96.63
13	94.83	95.85	95.70
14	92.39	92.94	92.73
15	96.95	96.17	94.96
16	96.13	97.89	94.31
17	94.42	94.35	91.86
18	100.00	99.12	99.06
19	93.40	91.89	92.71
20	99.43	96.36	96.28
21	96.38	95.56	92.27
22	95.85	99.36	97.75
23	99.10	98.50	98.61
24	97.96	98.47	97.89
25	96.86	96.60	96.10
26	96.17	97.75	100.00
27	100.00	99.84	99.50
28	98.57	99.20	93.93
29	99.63	96.55	94.09
30	85.91	82.95	90.78
31	90.66	93.74	91.67
32	97.80	98.31	92.00
33	98.21	97.19	100.00
34	92.47	95.16	100.00
35	98.98	93.68	95.58
36	99.47	98.72	97.69
37	99.71	98.26	97.79
38	98.33	96.28	96.52
39	99.67	99.52	96.32
40	97.76	97.74	94.78

Nasal non-words

Participants	Low /mava/	Mid /mava/	High /mava/
1	98.04	97.64	95.57
2	94.64	94.95	94.26
3	91.44	91.66	93.74
4	98.60	98.75	98.70
5	96.56	97.82	97.33
6	99.60	98.38	97.85
7	98.28	99.65	98.34
8	95.56	98.11	97.93
9	97.48	97.08	97.19
10	100.00	97.90	98.98
11	96.92	96.41	95.49
12	89.96	93.23	92.54
13	93.72	94.66	93.72
14	89.04	90.73	90.13
15	94.80	93.92	95.15
16	95.40	95.30	94.99
17	92.48	92.46	91.74
18	97.48	98.51	98.78
19	100.00	97.16	97.61
20	98.88	97.56	97.23
21	90.60	94.85	90.27
22	98.92	99.39	97.83
23	99.24	99.55	99.20
24	98.40	97.34	97.85
25	97.92	98.65	99.12
26	96.36	97.40	98.70
27	91.28	92.03	92.38
28	99.28	99.28	98.98
29	95.52	94.63	96.07
30	91.52	83.00	93.78
31	100.00	97.74	93.56
32	97.76	95.06	91.34
33	97.04	102.39	99.60
34	97.20	95.99	96.11
35	93.76	92.19	92.12
36	93.16	96.81	97.81
37	99.56	98.65	91.72
38	98.88	93.12	97.19
39	98.64	97.69	97.79
40	97.24	95.41	98.11

Participants	Low /miva/	Mid /miva /	High /miva/
1	95.24	99.15	96.17
2	96.16	96.39	94.04
3	91.92	92.40	91.94
4	100.00	99.87	99.02
5	96.52	96.71	95.65
6	98.16	99.26	97.79
7	97.48	100.00	98.98
8	97.00	96.20	96.35
9	97.08	98.09	97.15
10	100.00	96.84	96.89
11	97.48	98.22	97.57
12	95.00	92.91	92.76
13	93.92	93.94	93.64
14	91.24	89.80	89.29
15	96.20	96.47	95.85
16	95.00	95.86	94.10
17	94.44	90.92	91.20
18	99.65	98.99	99.32
19	98.08	98.03	100.00
20	95.16	95.09	95.33
21	96.48	94.53	90.77
22	96.12	99.31	97.75
23	98.64	98.67	98.76
24	96.22	98.34	98.01
25	95.40	99.52	96.07
26	96.64	98.06	99.12
27	95.44	94.56	93.82
28	94.25	98.25	97.51
29	100.00	100.00	99.36
30	89.36	94.34	93.68
31	91.00	94.66	91.18
32	99.72	99.26	90.57
33	99.08	95.41	99.50
34	96.34	95.51	99.48
35	92.80	97.53	97.19
36	96.04	97.24	98.86
37	99.44	97.88	92.78
38	98.72	94.98	92.50
39	98.32	98.41	97.47
40	99.63	98.06	93.82

Participants	Low /muva/	Mid /muva/	High /muva/
1	97.84	97.85	97.11
2	93.96	94.24	94.32
3	91.76	93.04	91.14
4	97.12	99.23	97.77
5	97.48	95.33	94.79
6	97.44	96.79	96.71
7	98.24	73.73	98.92
8	96.48	97.26	97.09
9	93.48	93.81	92.70
10	100.00	98.11	98.34
11	97.92	97.16	97.51
12	90.72	92.78	94.40
13	94.80	95.75	95.35
14	90.88	91.34	90.45
15	95.08	94.42	94.60
16	97.04	97.95	97.89
17	91.16	92.64	91.01
18	99.88	98.38	98.48
19	96.54	97.50	99.76
20	100.00	98.57	97.49
21	100.00	96.10	90.21
22	95.00	98.30	99.32
23	99.52	99.58	99.40
24	99.76	99.47	98.52
25	95.56	95.96	93.90
26	99.04	99.60	99.70
27	96.60	95.83	96.33
28	98.25	98.59	97.03
29	97.64	96.71	95.33
30	90.90	91.23	89.29
31	100.00	95.01	89.03
32	100.00	98.94	90.05
33	97.24	94.18	98.92
34	100.00	97.85	97.11
35	98.52	99.81	100.00
36	96.52	97.10	97.47
37	99.72	96.07	93.08
38	97.48	94.37	95.45
39	97.84	97.18	95.45
40	85.91	94.56	93.90

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CHAPTER I

INTRODUCTION

"Speech is the way of life for human is the chief medium of social adaptation. What we are, what we do and what we decide to do are accomplished majorly through speech. Through speech or indirectly through written language which records speech, we gain and give meaning to our existence" (Punt, 1979). Human beings able to speak because of having a set of organs that are capable of being modified and adapted for the function of speech and accompanied by highly developed nervous system.

Vibration of the vocal cords in the human larynx results in the production of voice. Voice is considered to be the vehicle for communication and nation in speech. Power produced from the lungs, tightening of the crico-arytenoids & inter-arytenoid muscle, tension and thickness of the vocal folds are the important physiological factors for the production of voice. The pitch of the voice is determined by the frequency with which the vocal folds vibrate. Singers required well developed, coordinated and flexible laryngeal system compared to others.

Singing is defined as the act of producing musical sounds using the voice, and augments regular speech with tone and rhythm. The person who sings is called a singer or vocalist. Singing can be produced either with or without the use of by musical instruments. It is done with a group of other musicians, such as in a choir of singers with different voice ranges, or with instrumentalists, such as a rock group. Singing is a form of sustained speech and mostly anyone who is able to speak can sing. Singing can be in different form, formal or informal, arranged or improvised. Usually singing may be done for pleasure, comfort, ritual, education, or profit. Regular practice will make the singer excellent. Professional singers usually focus their career in one specific music, such as classical, rock etc. They take voice training from the voice teachers or vocal coaches throughout their careers. Therefore, proper practicing and training is essential for the professional singers.

Professional singing and speaking depend on person's ability to establish optimum conditions of vocal resonance. The resonator for increasing resonance in the voice is the vocal tract. It consists of seven areas are the possible vocal resonators. As a sequence from the lowest to the highest in the body, these areas include the chest, the tracheal tree, the larynx itself, the pharynx, the oral cavity, the nasal cavity, and the sinuses. Vocal resonance is defined as "the process by which the basic product of phonation is enhanced in timbre and/or intensity by the air-filled cavities through which it passes on its way to the outside air" (McKinney, 1994). In general, there are two types of resonation, oral and nasal. The expression of 'nasal resonance' is widely used to represent a desirable property in singing (Vennard, 1964). In normal speakers, no conscious effort is needed to produce the nasal resonance and it generally occurs without their effort. However, the long-standing controversies regarding nasal resonance during singing reveals that velar adjustments are more refined and/or controlled during singing. It is considered as a "sensory motor phenomenon that requires balanced skills" (Bunch, 1982).

Vocal resonance affects various factors such as size, shape, thickness of the walls and surface of the resonators. Optimal vocal resonance, which is considered as the positive sympathetic and conductive vibration of the resonant cavities of the head and throat, is the main goal of the classical singer. The singer tries to encourage the best possible open throat to most beautifully enhance and amplify the fundamental pitch or frequency. “Singers, generally operatic singers enrich and enhance their voice by developing the singer’s formant” (Stone, Cleveland & Sundberg, 1999). Sundberg (2001) defined “singer’s formant is a prominent spectrum envelope peak near 3 KHz that appears in voiced sounds sung by classically trained bass, baritone, tenor, and alto singers’ voices”. It helps singer’s voice to be heard easier in the presence of loud back ground noise or orchestra. The professional singers and the trained classical and Carnatic singers use their nasal resonance to enrich their voice. The high vocal demands among the group of singers make them use their nasal resonance to a greater extend making their voice more effortless and melodious.

Indian classical music tradition has a history spanning millennia and it was developed over many eras. Mainly there are two traditions of Indian classical music Carnatic and Hindustani. Indian classical singing origins can be found in the Vedas, which are the oldest scriptures in the Hindu tradition. As described in Samaveda, one of the four Vedas, music at length. In 14^{th} century Indian classical music is divided into Hindustani and Carnatic music. Indian classical music is elaborate and expressive. Hindustani music is the music of North India and Carnatic music is the music of South India. Like Western classical music, Indian classical music divides the octave into 12 semitones. In this 7 basic notes are in ascending pitch order, *Sa Re Ga Ma Pa Dha Ni Sa* for Hindustani music and *Sa Re Ga Ma Pa Dha Ni Sa* for Carnatic music, which is similar to Western music's *Do Re Mi Fa Sol La Ti Do*. Indian classical music is monophonic in nature. Melodically singing performance is based on particular ragas and rhythmically on talas. Singing is both, a talent and a skill. Regardless of your voice range, learning to control the velum is important in singing. There are certain singing styles that sound better when utilizing the nasal cavity; such a style is used by many country singers.

Trained singers are perceived to sing better than non-singers because trained singers are able to perform a variety of phonatory and articulatory/resonatory adjustments during singing whereas non-singers not able to do this. Also these articulatory and phonatory differences during singing help the listeners to perceptually distinguish the two groups during singing. The acoustic cues that help listeners to perceptually distinguish trained singers from non-singers have not been clearly identified. Trained singers are able to use vocal resonance more efficiently than non-singers.

The long standing question exist in the field of vocal pedagogy is whether nasal resonance is used during the production of non-nasal phonemes by classically trained singers. Monahan (1978) reported that regarding resonance characteristics of the singing voice are related to the nasal cavities. In normal speakers, generally nasal resonance occurs without any conscious effort, however, controversies on nasal resonance during singing reveals that velar adjustments are more refined and/or controlled in singers. If this is true, what is the manner and extent of velar adjustments required to produce good vocal qualities. Also whether depending up on the style of music being sung, these adjustments are changed, and whether there are improper patterns of velar adjustments which could result increased risk of vocal injury in singers. So what is the effect being seen in singer, who consciously elevate the velum during the production of a vowel that is often produced with a small velopharyngeal opening during speech?

Brown & Behnke (1883) proponed that, “the soft palate rises with the ascending scale, the arch between the pillars of the fauces becomes narrower and higher, and the uvula diminishes in size”. Different instrumental measurement have done in singers and in a very few of studies investigating how singers use VP valving. To investigate whether the soft palate gradually elevated when singers sing from their lower to higher registers, Scotto di Carlo & Autesserre (1987) examined six professional singers using sound-synchronized endoscopy and xeroradiography. The authors reported that the transverse tension of velum and the stretching of the posterior faucial pillers is being accompanied by the hyper retraction of uvula.

Majority of the studies concluded that as the pitch increases, the velum is also opened (House and Stevens, 1956; Gramming, Nord, Sundberg, & Elliot, 1993; Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg, 2002). If the nasalance is not controlled while singing it will be distracted to the listeners. There is little information which gives the evidence that the vocal training will helps to control the nasality. Even though singing consists of both oral and nasal sound; it wouldn’t be heard as noisy. Then the question arise is how the singers are able to project their voice when the velum is opened or are they able to control their velum movement while singing?

Need of the study

Evidence from various studies suggests that trained singers have the ability of to make skillful phonatory, resonatory, and articulatory adjustments is different from non singers (Brown, Rothman, & Williams, 1978; Gauffin & Sundberg, 1989; McGlone, 1976; 1977; Shipp & Izdebski, 1975; Sundberg & Rothenberg, 1986). Majority of the researchers suggested that there is velopharyngeal opening with increasing pitch or in the upper registers and it is negatively correlated (House and Stevens, 1956; Gramming, Nord, Sundberg, & Elliot, 1993; Birch et al, 2002; Fowler, 2004; Carlo and Autesserre, 1987) with the perceived nasality in the singers when they sing in upper registers. But only a very few number of studies focused on the effect of training and perceived nasality in singing. The initial murmur of /ma/, /mi/ and /mu/ as a part of warm up before singing, suggesting velopharyngeal opening is helpful in singing, on the other hand if nasality is perceived, it is considered as noisy or unacceptable. Very few studies are persisting about the question 'Do vocal training helps reducing nasality with an open velopharynx? Carnatic singing is a wide musical system which is commonly associated with the southern part of Indian subcontinent. It is believed to be a divine and the tradition of singing and practicing classical music is established throughout India. Even though Carnatic music consists of a wide range of oral and nasal consonants; still the music has never been heard as unacceptable or nasal and noisy. So, how experienced singer should sing to color and enrich their voice when the velum is open or whether professional singer can better able to control the degree of velum movement?. Many studies evaluated velum behavior and movement while singing, but not so much research were conducted to find the correlation between the open velum and the perceived quality of the voice. Also a very few of the studies described the effect of training and the experience in controlling the nasalance with an open or lowered velum. Considerably less number of research have been done on Indian classical singers (Carnatic or Hindustan) on

Nasalance. The present study compares the nasal airflow between vocally trained and untrained using frequency and intensity.

Aim of the study

- To find the effect of vocal training on controlling nasal airflow with variation in F0 and Intensity.
- To find the effect of vocal training on controlling perceived nasality with variation in F0 and Intensity.
- To find the correlation between perceptual and objective measurements of nasality.

CHAPTER II

REVIEW OF LITERATURE

Voice is a marvelous tool of communication for our daily life. In the modern life people are even more dependent on their voice due to specialized options in the modern computer systems. Voice is multidimensional in nature. Voice is one of the aspects which make human beings as different from other organisms and also the universality of human voice as an instrument is its greatest joy and major advantage. Human voice is a wonderful instrument capable of conveying ideas, thoughts, and emotions. Bunch (2009) reported that “the voice is considered to be as much as thirty-eight percent of a person’s communication, accompanying with visible or non verbal aspects (55%) and the words (7%)”. Sundberg (1994) reported that “the singer must control over all perceptually relevant voice parameters, so that they do not change by accident and signal an unintended boundary”. Control of all voice parameters is pre-requisite for singing.

The term professional voice user refers to the group of population for whom the voice is mainly used as a tool as their occupation. Professional singers are highly specialized subset of individuals in the group of professional voice users. Singers have significant functional demands that place on laryngeal mechanism in account of frequency range, amplitude control, acoustic variation, and overall vocal stamina and which is unique for only singers. These specific demands are varied between singers having various singing styles and capabilities. Well trained singers will have a high level of neuromuscular laryngeal control which may eliminate or even lessen their laryngeal pathologies and other symptoms. Performance demands will depend up on the size of the orchestra with which the classical singer is singing. Some of the demands are common among all professional singers of all styles, however, the duration of singing, travelling before the performance, warm up exercises and practice will also affect their voice quality.

Singers have high vocal demands and they are more systemic in their voice use than non-singers. "Bharata (Durga, 1997) in his famous work "Natya Shastra" proposes six essential qualities that a good singer requires.

- 'Sraavaka' is explained as loudness or carrier of the voice, which can be heard from a long distance.
- The voice that is loud and pleasing without any wobble is called 'ghana'.
- The voice which does not sound harsh though loud, is described as 'snigdha'. This also refers to the 'fluency' of producing the notes of high octaves.
- The voice that is pleasant at high notes is called 'madhura'.
- 'Avadhanavan' is explained as a voice that is neither too loud nor too soft.
- 'Tristhanashobha' is that voice which is pleasant in producing the notes of all the three 'sthanaas' (equivalent of registers)".

Singers must increase subglottal pressure (Ps) to increase pitch and/or loudness (Griffin, Woo, Colton, Casper, & Brewer, 1995). Classically trained singers have considerable formant frequency differences during speech and singing because the speech like formant frequencies cannot produce a singer's formant, which male singers and altos need in order to be heard against a loud orchestral accompaniment. The singer's formant refers to a prominent spectrum envelope peak near 3 KHz that appears in voiced sounds sung by classically trained singers mainly, bass, baritone, tenor, and alto singers' voices. This makes the voice easier to hear in the presence of a loud orchestral support. It can be described as mainly resonatory phenomenon arising from a clustering of formants 3, 4, and 5. In the case of country singing, no need for a country singer to use special formant frequencies producing a singer's formant in singing (Stone, Cleveland & Sundberg, 1999) as the singers need not concern about the audibility of their voice since it is a technical problem handled by the sound engineer rather than by the singer himself.

Sundberg, Cleveland, Stone & Iwarsson (1999) studied the voice source characteristics from inverse filtering. They analyzed 6 country singer's speech and singing. He reported that the closed quotient varied systematically with vocal loudness, and that glottal compliance decreased with increases in fundamental frequency but remained unaffected by vocal loudness. No significant differences were found in source characteristics between speech and singing within subjects. An increase in phonatory press reduces the sound pressure level (SPL). The subject's voices often tended to sound more pressed at high than at low pitches. The result indicates that these singers tended to use more phonatory press when singing in a high rather than in a low pitch range.

Lawrence (1979) reported that those singers who exhibited the least vocal pathology had the greatest amount of vocal training. Brown, Hunt, & Williams (1988) said that better performance by trained singers was due to the benefits of better vocal training rather than their superior physiologic characteristics. Thus, the skills acquired through vocal training appear to have a modifying effect on the extent of laryngeal incompetence resulting from vocal abuse or misuse.

Breathing is the subconscious process that happening everyday life is also important for singing. The three main stages in natural breathing consist of: breathing-in period, a breathing out period, and a resting or recovery period. These stages are not usually consciously controlled. According to Titze (1994) there are four stages of breathing during singing which must be under conscious control by the singer until they become conditioned reflexes. These stages include breathing-in period (inhalation); a setting up controls period (suspension); a controlled exhalation period (phonation); and a recovery period. Many of the singers increase conscious controls before their reflexes are fully conditioned which will finally leads to chronic vocal pathologies. (http://en.wikipedia.org/wiki/Vocal_resonation)

Most of the researchers reported that trained singers have more capability than others. Devadas, Rajashekhar & Aithal (2009) used a standard group comparison study design and the fundamental frequency [F0], speaking fundamental frequency [SFF], jitter percent [JITT], shimmer dB [SH dB], noise to harmonic ratio/NHR, maximum phonation duration(MPD) and S/Z ratio of Bhagavata's voice were compared with age matched nonsingers. Their results revealed, significantly higher fundamental frequency, speaking fundamental frequency and reduced MPD in Bhagavatas as compared to their non-singing counterparts.

Indian music tradition

Indian music is the great wealth of Indian culture and it is considered as a gift of God. India is considered as a "Sangitha Bhumi" (musical land). *'Naadam'* is the word used to represent the musical sound which is the basis of *'shruthi'* which is the musical tone, ‘*shruthi’* gives rise to ‘*swaram’* which is the musical notes and *‘swaram’* gives rise to *‘raagam’* which is the musical scale (http://shodhganga.inflibnet.ac.in/bitstream/10603/4551/.../07_chapter%202.pdf). History of Indian music is not only about the cultural value, but also enables us to understand about the concepts of “raga” and “tala” systems. The concept of “raga” is India’s gift to the musical world. The ragas are artistic facts and it can be perceived by anyone who has little training in music. Indian music is distinguished from other music. Carnatic and Hindustani music are bifurcation in Indian music. ‘Carnatic system’ is usually a South Indian art where as ‘Hindstani system’ is a North Indian art. In Carnatic music, there are mainly seventy two ‘melakarta raagas’.

The Indian musical scale is evolved from a set of seven primary notes or ‘swaras’ (‘sapta swaras’). A scale is divided in to 22 shruthi or intervals that constitute the basis of musical notes or swaras. The ‘sapta swaras’ are “sa, ri, ga, ma, pa, da, ni”. The entire singing range in Carnatic music is classified in the three ‘sthaayis – mandra, madhya and taara’ i.e., low, mid and high respectively. Sthaayi is the octave of music. The three sthaayi’s are also known as ‘mandra saptak’ ‘madhya saptak’ and ‘taara saptak’. A ‘saptak’ consists of seven notes. According to the Indian conception, the fundamental note is called the ‘aadhara shadja’ and this will always belong to ‘madhya sthaayi shadja’ and is known as ‘madhya shadja’. The notes, which are sung below this ‘madhya shadja’, belong to ‘mandra sthaayi’. The notes, which are sung above the ‘madhya sthaayi nishaada’, belong to ‘tara sthaayi’ (http://shodhganga.inflibnet.ac.in/bitstream/10603/4551/.../07_chapter%202.pdf)

Resonance in singers

Like all acoustic instruments such as the guitar, trumpet, piano, or violin, voice has its own special chambers for resonating the tone. When the sound is produced by the vocal cords, it vibrates in and through the open resonating chambers, producing four primary resonances such as chest, mouth, nasal (or mask) and head. In the lower pitch range, the chest resonance is dominant; in the middle range, the mouth-nasal resonance predominates and in the higher range, the head-nasal resonance (bright color) predominates. The resonance also depends on the emotional content of the lyric or phrase suggests and also the personal choice of the artist. Head resonance is used primarily for softer singing in either register throughout the range. Mouth resonance is used for a conversational vocal color in singing and, in combination with nasal resonance. Chest resonance adds richer, darker, deeper tone coloring and it creates a feeling of depth and drama in the voice. Nasal or mask resonance is present at all times in a well-produced tone, except, perhaps, in the instance of the pure head tone or at very soft volume. Nasal resonance is bright and is used in combination with mouth resonance. In an over-all nasal resonance gives clarity and projection to the voice. There are some singers who are recognized by their pronounced nasal quality such as a deep, dark and *chesty* sound or their breathy or heady sound. Such individuality depends on the structure of the singer's vocal instrument, that is, the inherent shape and size of the vocal cords and resonating chambers. The quality the voice also depends on the ability to develop and use various resonances by controlling the shape and size of the chambers through which the sound flows. According to Sundberg (2004) “occasional oral–nasal coupling might tune the resonating system and strengthen the singer’s formant during classical singing”.

As we know nasal resonance occurs during the production of nasal phonemes during speech. The unresolved question exists is whether classically trained singers use nasal resonance during the production of non-nasal phonemes. Monahan (1978) proposed two questions about nasal resonance as “whether singers consciously use nasal resonance to achieve a beautiful tone and how is nasal resonance incorporated into the vocal tone by conscious or natural means”. Generally nasal resonance occurs without any conscious effort in normal speakers but controversies regarding nasal resonance during singing imply that velar adjustments during singing are more controlled and/ or refined.

Perception of nasality in singers

Perception of nasality during singing is researched by various authors. House and Stevens (1956) found that smaller velopharyngeal port (VP) openings were needed to produce a perception of nasality in the vowels /i/ and /u/ compared to /a/ to produce a perception of nasality**.** Also three times the amount of oral/nasal coupling was needed to nasalize /a/ than was needed to nasalize /u/. The evidence proved that the perception of nasality is closely associated with different sizes of velopharyngeal port (VP) and different sounds. Several authors reported in literature that the velopharynx must reach a critical degree of closure for perception of good speech. The investigation of House and Stevens (1956) showed that when vowels produced with a port area of $25mm^2$, listeners did not perceive vowels as being more nasal than vowels produced with complete velopharyngeal port closure. It was noted that complete VP closure depends on target phonemes and speech is perceived as being hypernasal when critical minimum closure of $20\text{-}30mm^2$ is not reached.

Singers use large oral opening while singing. So on perception to judge whether a singer uses open VP postures is problematic. Yanagisawa, Estill, Mambrino, & Talkin (1991) examined the role of the soft palate in singers with increase in pitch. The study included nine professional singers and two untrained subjects. Audio and video recordings were taken as the subjects produced a continuous glide from one pitch to another on the nasal sound /N/ (glissando). Also the three subjects recorded vocal productions in speech, falsetto, sob, and operatic qualities at 10%, 50% and 90% of their frequency ranges using the same sound. The authors reported that under all vocal conditions laryngeal height, soft palate height, and the medial movement of the lateral pharyngeal walls all increased as the pitch increased and velopharyngeal port closure was also greater during sob and falsetto qualities as compared to speech and operatic qualities. The authors also reported the pattern of velopharyngeal closure to be more sphincteric during falsetto and sob qualities, whereas during speech and opera, the closure pattern appeared to be of the trap-door type. These results suggest that, independent of the velopharyngeal morphology and depending on the musical style and their intended result singers are able to vary their VP closure patterns. These results would have been beneficial if information were provided as to whether changes in the shape of the velopharyngeal opening in singers were frequency or vowel dependent.

Aerodynamic measures

Singers may show a wide variety of tendencies regarding velopharyngeal opening during singing. Gramming, Nord, Sundberg, & Elliot (1993) investigated the use of the velopharyngeal port during singing. They used three different analysis techniques, flexible nasofiberoscope, recordings of oral and nasal flow and experiments on a vocal tract model. Four professional singers were included in the study, two sopranos (F1 and F2), one bass (Ml), and one baritone (M2). In these, F1 was an internationally renowned opera singer, F2 an advanced student, also with considerable experience of solo singing, MI an experienced professional opera singer, and M2 a highly experienced singing teacher. A number of speaking and singing tasks which included stops, nasals, and vowels were included in the protocol. Speech samples involving velar activity using the word [punta], singing tasks consisted of ascending/ descending fifth-wide scales. For soprano F1, there was no evidence of velar opening during the production of scales was observed. Soprano F2 showed a nasal DC (constant) airflow in all tasks indicating a constant velopharyngeal opening. The bass singer M1 also revealed nasal leakage in most of the tasks. No evidence of nasal DC airflow was shown by baritone M2 for any of the tasks. Nasofiberoscopic data reveals a small opening in the velopharyngeal port only at the higher pitch. For the other subjects, the two results correlated. The vertical position of the velum found to change with pitch suggesting velum plays a role of articulator in singing to shape their vocal tract to arrive at the target formant frequencies. Inter individual variability using velopharynx in singing is evident in the study. Even though soprano F1 was the teacher of Soprano F2, still they exhibited velopharyngeal opening, which reveals an improper vocal technique used in singing.

Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) analysed velopharyngeal opening in 17 professional operatic singers, 3 high sopranos, 3 sopranos, 2 mezzo-sopranos, 3 tenors, 2 baritones, 2 bass-baritones, and 2 basses singing the vowels [a, i, u] as in the stimulus /panta/, /pinti/, and /puntu/ at middle degree of vocal loudness in an ascending scale of seven pitches throughout their pitch range. Three methods were used in the study, naso fiberoscopy for the visualisation of the naso pharynx. A divided oral-nasal pneumotach flow mask was used to measure the oral and nasal airflow. Both flow signals were recorded together with an audio signal on separate tracks of a multichannel data recorder and after that all three signals were then digitized. Average DC components of the oral and nasal airflows during each word for each pitch were measured. The results suggested that oral flow varied between vowels, with pitch, and across singers. Nasal flow for the vowels /a/ and /u/ varied according to the pitch sung where as nasal flow was detected on the vowel /i/ for only one tenor. These findings suggest that the singers use VPO during singing.

The authors also proposed that the poor contact between the face and mask may render the presence of airflow and thereby the presence of velopharyngeal opening (VPO). To avoid this possibility, the difference between the level of the fundamental in the nasal (LO_n) and oral (LO_o) airflows was calculated as an alternative measure ((LO_n-LO_o). The researchers opined in the case of VPO, the LO_n should be above -15 dB below the level of the fundamental in the oral airflow. Therefore they calculated the used narrow band spectrograms of the nasal and oral AC (alternating current) signals for all /a/ productions and the difference (LO_n – $LO_{o)}$ was calculated. In cases where the nasal DC airflow was greater than zero, the difference between LO_n – LO_o was above -15 dB. There were also cases where no detected nasal DC flows were also associated with LO_n – LO_o differences above -15 dB. These singers were also considered to sing with a VPO. Visual and perceptual data were also obtained in addition to the airflow measurements. To record visual images of VPO, a nasofiberscope was used. Four phoniatricians rated the degree of VPO using a 100-mm-long visual analogue scale (VAS) for the production of the second vowel in the word *panta* as it was sung in mezzo forte only. Nine of the 17 singers were rated as utilizing a VPO. Observed VP openings were divided into different types such as coronal, sagittal and constricted categories. A high correlation was reported between VPO and the production of the vowel /a/. Alternately, low intrarater reliability and correlation between airflow and perceived nasality were reported. These findings are not surprising as the subjects were highly skilled classical singers who, in typical fashion, probably sang with large oral openings, thereby reducing the perception of nasality due to the interplay of oral and nasal impedances.

The authors pointed that the acquisition of DC flow data was dependent on a proper placement of the mask without any leakage. Therefore they concluded that a zero nasal DC airflow and the inability to visually document VPO was not sufficient evidence to rule out its presence. Even though, they believed that the presence of VPO could only be proven by the presence of airflow and/or visible observation. These criteria were demonstrated in nine of the singers. In six additional singers a difference of less than 15 dB between LO_n – LO_o was found, suggesting the presence of a VPO. Taking the 15 dB differential into account, there was evidence of VPO in 15 of the 17 subjects. The authors concluded that the different patterns of VPO observed in different singers suggested “that singers carefully tune the degree of opening, perhaps in order to color the timbre”.

The third method was to compare the level of fundamental in the nasal and oral airflow signals. In airflow measures, in some singers, oral airflow decreased with increasing pitch and they could not find significant nasality probably due to the leakage of the airflow through the mask. Nasofiberoscopic results did not correlated with the airflow measures completely as it showed a velopharyngeal opening. An open velopharynx was observed in high soprano 3, soprano 1, tenor1, while no DC nasal airflow was measured. This study gives us the information that at higher pitches, singers use their velopharyngeal opening to tune their vocal timbre or to color their vocal tone and it is evident they have an opened velum while singing at higher pitches.

Nasalance in singers and non-singers

Fowler (2004) investigated and compared the Nasalance between 36 trained female singers and 36 female non-singers by sustaining phonation of /i/, /ae/, /u/, and /a/ for six seconds across three frequency levels. Oronasal Nasality System 1.5 hardware/software system (Glottal Enterprises, 2000) was used for measuring nasalance and intensity was not controlled in the study. They could see a difference in nasalance between front and back vowels but could not see any statistically significant difference between singers and non-singers, even though singers had a low nasalance scores for the back vowels.

Tanner Roy, Merrill, & David (2005) studied the status of the velopharyngeal (VP) port during classical singing. They investigated nasal airflow (ml/s), oral pressure (cm H_2O), and VP orifice area estimates (cm) in 10 classically trained sopranos during singing and speaking. Nasal cross sectional area measures were taken for all participants and were within normal limits. For evaluating the effects of vowel height on VP valving, three nonsense words were taken- hampa/, /hampi/ and /humpu/. Each of these contains the blend /mp/ and three cardinal vowels. Each subject had to sing and speak these three words /hampa/, /hampi/ and /humpu/ at three loudness levels (loud, comfortable and soft) and in three different pitches also (high, comfortable and low). All the words were produced three times at a rate of one syllable/sec with the help of a metronome. The participants were asked to sing using classical style with vibrato. They were instructed to repeat the nonsense words as speech like and also naturally as possible for the speaking task.

The authors also used aeromechanical instrumentation. Nasal airflow, nasal pressure, and oral pressure values were acquired using the PERCI (Palatal Efficiency Ratings Computed Instantaneously)—Speech Aeromechanics Research System. Flexible polythene tubing which was connected to the pneumotachometer, was used to acquire the nasal airflow values. This was fitted to the nostril of the participant. The participant's opposite nostril was inserted by a foam cork and it was connected to a pressure transducer for measuring the nasal pressure. Nasal airflow (ml/sec), nasal pressure (cm H_2O), oral pressure (cm H_2O) and velopharyngeal orifice area estimates were recorded for each of the three nonsense words.

Anticipatory nasal airflow was seen in 9 of 10 participants for singing and speaking and was significantly greater in the first vowel in /hampa/ compared to /himpi/ and /humpu/. This suggestive of vowel height has a significant effect on nasal airflow. The nasal airflow was significantly greater for loud phonation during /m/ and soft phonation. They concluded that nasal airflow decreased as pitch and intensity reduces from high to low in phonation, more so for singing compared to speaking task. Their results suggested that velopharyngeal area measures, nasal airflow, and oral pressure were significantly greater for the singing task than speech task. It was found that nasal airflow was greater in singing task compared to speaking during the time maximum intraoral pressure i.e. at the point of /p/. These results suggesting the singers allow an amount of nasal flow through the VP port during the production of oral consonant /p/; that means, these singers permit to leave the VP port slightly open followed by the point of maximum nasal airflow i.e., during the production of /m/. The authors reported one possible explanation that the singers might allow a little amount of VP opening that leads to the midfacial vibratory sensations which is associated with forward–focused resonance in classical singing.

Jennings & Kuehn (2008) studied the nasalance in singers. They investigated 21 amateur singers and 25 classically trained singers during singing an ascending five-tone scalar passage in different pitch ranges (low, mid, and high frequency ranges). The Nasometer was used to obtain the nasalance. The amateur singers had significantly higher nasalance scores than classically trained singers in all ranges and on all vowels except /o/. Dynamic loudness level had a significant effect on nasalance for all subject groups except for female majors in the mid- and high frequency ranges. The vowel, /i/, received significantly higher nasalance than all of the other vowels. Although results of the study show that dynamic loudness level, vowel, and level of training in classical singing have a significant effect on nasality, nasalance scores for most subjects were relatively low. Only six of the subjects, all of whom were amateur singers, had average nasalance scores that could be considered hypernasal.

Velum has to be lowered for the production of nasal consonants such as /m/, /n/, /ng/. When producing these nasal consonants, a buzzing or tingling effect is felt in the cheeks on both sides of the nose. This area is known in singing literature as the ‘‘mask.’’ In classically trained singers, efficient singing is produced by sympathetic vibrations in the mask, which are similar to the buzzing sensation of nasal consonants. As a consequence, many teachers of singing advise singing students to use nasal consonants and humming in vocal exercises to simulate the feeling of resonance in the mask. However, some pedagogues believed this use of nasality is a means to an end. That means, a nasalized sound will help the singer in ‘‘placing’’ the tone in the mask. Once a forward placement has been established, the nasal component will be abandoned. For other singing teachers, some nasality in the tone is desirable because it helps in the projection of voice. But how much nasality is actually present in classical singing which is yet to be answered.

Many singing pedagogues argued that there is no nasality in sung vowels because an elevated velum creates more resonating space in the oral cavity and blocks the nasal cavity to avoid an undesirable nasal tone and thereby increased damping inherent in nasal sounds. McIver & Miller (1996) studied 30 trained singers using the Nasometer to obtain nasalance scores by singing non-nasal phonemes. Their results suggest that several singers obtained nasalance scores near zero as evidenced on the nasogram and thus concluded that oral/nasal coupling was not a contributing factor to efficient singing. Here the authors did not indicate a cut-off score for hypernasality or include nasalance scores for individual subjects. Although Miller attributed that velopharyngeal port opening is not harmful to the singing voice, he opined that ‘‘nasality intruded into non-nasals is not aesthetically pleasing.’’

Even though, other singing pedagogues hypothesized that “some nasality or ‘‘nasal resonance’’ as called in the singing literature contributes to the vocal ring of a classically trained voice. Acoustically, this ring is caused by a cluster of energy around 3 KHz typically found in spectrographic analysis of singing by classically trained vocalists.

This is also known as the singer's formant". This envelope of acoustic energy is ''rather independent of vowel and pitch'' and enables the voice to be heard over an orchestra, which has an average spectrum around 500 Hz. Alderson (1993) suggests that a little nasality contributes a well-produced sound and he recommends ''directing a portion of the sound waves through the nasal cavity to add a more brilliant ring to the tone.''

Instrumental analyses of velopharyngeal valving in singers

Other researchers proposed that singers show a wide variety of tendencies regarding velopharyngeal opening. Volo, Farnetani, Troup, & Ferrero (1986) suggested that velopharyngeal opening may be dependent up on the style. Using xeroradiographic images of two professionally trained baritone subjects who were instructed to sing all the Italian vowels /a,e,i,o,u/ starting on ''do'' moving to ''sol'' and back to ''do'' in a key of their choosing. Then the singers were asked to sing a two-octave arpeggio on all the Italian vowels. The xeroradiographic images showed that the slower sustained singing had complete closure of the velopharyngeal port for both singers, whereas the more florid arpeggios did not.

Carlo & Autesserre (1987) investigated the movement of velum in six professional singers with the phonation of /a/, /i/, /u/ and /ae/ using endoscopy and xero radiography. The study focused upon two questions, first 'why the velum was in a specific position in the upper register' and 'how singers could think that the velum is raised when it is actually in a relatively low position?'. A physiological and perceptually explanation were given regarding the particular position of the velum. Physiologically, pharyngeal tightening in the upper register occurs due to tension of the muscles. In order to avoid the excessive contraction of velar and pharyngeal muscles, singer will adjust the velum in a particular position without letting the velopharyngeal contact occur through the simultaneous action of levator palate and the palate pharyngeus muscle. Perceptually the same voice was rated and those which was sung with a raised velum was rated as ‘flat’, ‘crushed’, and ‘dull’ while those sung with a lowered velum was rated as ‘beautiful’, ‘round’, and ‘powerful’. The authors answered the second question with the help of exo- and endo-buccal endoscopy where they found that, in the upper register, the transverse tension of the velum and the stretching of the posterior faucial pillars is being accompanied by the hyper retraction of the uvula. This substantial raising of the uvular area makes singers feel as though they are raising their entire velum.

Troup, Welch, Volo, & Tronconi (1989) studied nine professional sopranos singing the following pitches spanning a three-octave range: E3 (165 Hz), E4 (330 Hz), E5 (660 Hz), C6 (1000 Hz), and E6 (1320 Hz) using xeroradiographic images. He reported that two of the nine sopranos had an open velopharyngeal port across all pitches, one singer had a closed velopharyngeal port across all pitches, and the remainder of the singers had a mixture of open and closed positions. Overall, as the pitch increased, the number of subjects with oral-nasal coupling decreased. Results show that seven subjects had an open velopharyngeal port on E3 (165 Hz), six subjects on E4 (330 Hz), four subjects on E5 (660 Hz), and three subjects on C (1000 Hz). Interestingly, five of the nine subjects showed an open port on the highest pitch, E6 (1320 Hz). The authors concluded that ‘‘total velum closure is language dependent, education dependent, style dependent, pitch dependent, and anatomically dependent.’’

Austin (1997) investigated velopharyngeal port activity in four classically trained female singers during speech and operatic singing, using a photodetector system. With the photodetector in place, the subjects had spoken and then sang the sentence ‘‘Connie came to Free Ontario for the firm’s money.’’ The subjects sang the sentence in recitative style (vocal style that reflects natural speech rhythms and inflections) in different vocal ranges such as low, medium, and high. Then subjects sang the vowel series /i,e,a,o,u/ on a repeated pitch at the three different frequencies selected for the singing samples. Each subject had to perform the task five times. The averaged value of five repetitions for each task was taken. During the sentence task, the duration of opening in speech was 39%; for low voice singing, 45%; for medium voice singing, 50%; and 29% for high voice singing. From the results authors concluded that as frequency increased, the duration of velopharyngeal opening decreased.

CHAPTER III

METHOD

Participants

Fifteen professional female singers and 25 female non-singers who were in the age range of 20 to 60 years served as participants. All participants use Kannada as their primary language. Background information regarding medical history and hearing ability was collected. Each participant was evaluated by an experienced speech pathologist to check, oral structure and function. Normal speech and language ability were also evaluated informally before recording. All the participants were normal in GRBAS scale. Participants with any history of upper respiratory tract infection, cold, asthma or allergic diseases at the time of recording were not included in the study. None of the participants reported symptoms of hoarseness, loudness disturbance, and loss of range, vocal abuse, breathiness, choking sensation, phonation break and pitch break. All participants were non smokers.

Professional singers or group I includes fifteen professional singers who are currently practicing Carnatic singing or those who have selected their profession as singing, with ten years of minimum experience in singing. Non-singers or Group II have not received any kind of training on formal singing from church choirs, music bands, singing troops etc.

Stimuli

The two groups, the professional singers and non-singers were evaluated under two different conditions.

- Condition I: The participants have to sustain the phonation of the vowels /a/, /i/ and /u/ with an ascending pitch in three different frequencies (low, middle and high) and with an increase in vocal intensity were recorded for singers and non-singers. The phonation should be minimum of 6 sec. for each vowel.

- Condition II: Non words were given as oral and nasal stimulus for singing task with three ascending pitch in three different scales (low, middle and high) and with an increase in vocal intensity for singers and non singers.

Before the actual recording ten minutes of practice was given. During practice session the model was provided with audio and video. The model pitches for the vowels were 240Hz, 360Hz, and 482Hz for low, mid, and high pitch respectively. For oral non words 245Hz, 373Hz, and 497Hz were used for the respective pitches and for nasal non words 250Hz, 376Hz, and 501.4Hz were used. All the participants were able to match the model pitch and obtained above 90% matching score (APPENDIX I). As the non-singers were not able to vary the pitch and intensity independently, pitch and intensity variation was taken together. It was found that as pitch increases the intensity also increasing. The non-singers who were not able to match the model pitch by 90% were eliminated from the study. All the recordings were done in a quiet room using an Aeroview system, version 1.5.0 and using the digital audio recorder. Table 1 shows the stimuli for two different conditions.

Table 1: *List of stimuli for condition I and II*

Condition I			Condition II					
Vowels			Non words					
Low pitch	Mid pitch	High pitch	Low pitch		Mid pitch		High pitch	
/a/	/a/	/a/	/pava/*	/mava/#	/pava/*	/mava/#	/pava/*	/mava/#
/i/	/i/	/i/	/piva/*	/miva/#	/piva/*	/miva/#	/piva/*	/miva/#
/u/	/u/	/u/	/puva/*	/muva/#	/puva/*	/muva/#	/puva/*	/muva/#

(- oral non-words, # - nasal non-words)*

Instrumentation

Aeroview system, version 1.5.0, developed by Martin Rothenberg and manufactured by Glottal Enterprises was used for the aerodynamic measurements. The Aeroview consists of two transducers, one measures airflow and other measures the intraoral pressure. The Oro-nasal mask is used in the instrument which is connected by the transducers. It is dual chamber mask so that both oral and nasal airflow and pressure can be separately recorded. The average nasal airflow is calculated by placing the two cursors on the two peaks of adjacent waves which gives the measured value in ml/sec.

Procedure

Aerodynamic measurements

Aeroview was setup in a suitable quiet recording room. The instrument was calibrated prior to the recording based on the instructions provided in the manual. The subjects were recorded individually. They were seated comfortably, and practiced the singing task before recording by providing appropriate video models. They were practiced to place the mask correctly and asked not to breathe through the mask while recording. The subjects were instructed to phonate the vowels /a/, /i/, and /u/ in three different pitches such as low, middle and high with an increase in intensity as provided in the model. The subjects were asked to follow the same pitch as in the recorded video sample. Each vowel were recorded individually like low /a/, mid /a/ and high /a/ in one breath and then low /i/, mid /i/, and high /i/. After completing the recording of vowels singing task of non words (oral and nasal) were recorded in similar way.

The nasal airflow trace was monitored continuously throughout each recording to ensure that the data were being captured. In conditions where the subjects made an error during the singing task and phonation, retrial was taken. The correct version was included for data collection. After the completion of data collection of singing task, the nasal airflow trace was stored in a computer file for further data analysis.

Perceptual measurement:

Phonation and singing task was evaluated by 5 qualified Speech Language Pathologists for the perceptual measurement of nasality in different conditions (Increasing F0 and Intensity). Consensus Auditory-Perceptual Evaluation of Voice (CAPE-V) used to rate the nasality. Only nasality parameter has been rated in 100 point scale. The SLPs were asked to rate the nasality only for the vowel /a/, the oral non-word /pava/, and the nasal non-words /mava/ for all three pitches.

Statistical analysis

Aerodynamic measurements:

SPSS, 17.0 software was used for statistical analysis. Wilcoxon Signed Rank test was done in order to obtain the pair wise significant difference in the parameters for the two groups. Mann-Whitney U test was done to compare the aerodynamic analysis between singers and non-singers for vowels, oral non-words and nasal non-words.

Perceptual measurement:

For analysis of perceptual measurement the average perceptual nasality is calculated from the ratings of five SLPs for the vowel /a/, the oral non-word /pava/ and the nasal non-word /mava/ at three different pitches such as low, mid and high. Then the mean of the perceptual nasality was taken for singers and non-singers for each stimulus in different pitches. Using Wilcoxon Signed Rank test, the perceptual nasality within the groups were analyzed across pitch for vowel /a/, oral non-word /pava/ and nasal non-word /mava/. Spearman's coefficient of correlation was used to obtain the correlation between aerodynamic and perceptual measurements.

CHAPTER IV

RESULTS

In the present study, there were two groups of participants, group I with professional singers having 15 participants and group II with the non-singers having 25 participants. The study was aimed to find out the effect of vocal training on nasal airflow and perceived nasality with variation in F0 and intensity and also to find correlation between perceptual and objective measurements of nasality. Descriptive statistical analysis was done to observe the mean and standard deviation for both the groups in each parameter. Since the standard deviation of nasal airflow was high for the vowels, the oral non words and for the nasal non words, non parametric statistical tests were used to compare the parameters within the groups and between the groups. The results of the study sub grouped under three main headings.

I. Aerodynamic analysis
II. Perceptual measures
III. Comparison of aerodynamic & perceptual measures

I. Aerodynamic analysis

Wilcoxon signed Rank test was done in order to find the pair wise significant difference in the parameters for the two groups, professional singers and non-singers and Mann-Whitney U test was used to compare the aerodynamic analysis between singers and non-singers for vowels, oral non-words and nasal non-words.

a. Comparison of aerodynamic analysis between singers and non-singers

Mann-Whitney U test was done to compare the aerodynamic analysis between singers and non-singers for vowels.

i. Vowels

Table 2 shows the mean, standard deviation (SD), 'Z' and *p-value* for all the vowels between singers and non-singers.

Table 2: *Mean, SD, Z, and p-value of vowels in singers and non-singers*

	Stimuli	Nasal airflow		Z	*p-value*
		Mean & SD of singers	Mean & SD of non-singers		
Vowel /a/	Low pitch /a/	61.63(69.09)	30.89(31.10)	-1.467	0.142
	Mid pitch /a/	52.05(58.37)	50.20(49.07)	-0.237	0.812
	High pitch /a/	80.81(84.41)	64.94(67.28)	-0.014	0.989
Vowel /i/	Low pitch /i/	92.05(123.88)	37.82(42.01)	-0.894	0.371
	Mid pitch /i/	108.55(115.34)	57.30(84.09)	-1.076	0.282
	High pitch /i/	124.21(129.68)	80.86(87.67)	-0.433	0.665
Vowel /u/	Low pitch /u/	51.25(97.52)	18.31(24.09)	-0.852	0.394
	Mid pitch /u/	37.11(70.22)	18.36(17.54)	-0.321	0.748
	High pitch /u/	81.35(90.16)	43.18(58.38)	-0.740	0.459

There is no statistically significant difference found between singers and non-singers across pitch and vowel. Results also showed that over all nasal airflow of singers is high compared to non-singers in all the vowels as well as in different pitches. The vowel /i/ showed more nasal airflow compare to other vowels in both the groups. For majority of the stimuli it showed that the nasal airflow is increasing as the pitch increases in both the groups. But in the vowels /a/ and /u/ nasal airflow is lower in mid pitch compares to low and high pitches in singers whereas in non-singers, nasal airflow is increasing as the pitch increases in these vowel.

ii. Oral non words

Table 3 shows the mean, SD, Z and *p-value* of nasal airflow for singers and non-singers in oral non words at three different pitches.

Table 3: *Mean, SD, Z, and p-value of the oral non words in singers and non-singers*

	Parameter (Nasal airflow)	Nasal airflow		Z	*p-value*
		Mean & SD of singers	Mean & SD of non-singers		
Oral non word /pava/	Low pitch /pava/	45.84(62.34)	17.03(18.33)	-1.523	0.128
	Mid pitch /pava/	79.72(93.22)	27.63(27.77)	-1.383	0.167
	High pitch /pava/	104.42(115.19)	39.81(38.18)	-1.020	0.308
Oral non word /piva/	Low pitch /piva/	79.62(121.53)	39.33(55.43)	-0.265	0.791
	Mid pitch /piva/	65.78(85.05)	46.35(64.56)	-0.265	0.791
	High pitch /piva/	65.06(93.45)	64.98(85.06)	-0.545	0.586
Oral non word /puva/	Low pitch /puva/	30.98(47.52)	14.78(18.94)	-0.629	0.530
	Mid pitch /puva/	31.96(88.45)	22.68(27.73)	-1.131	0.258
	High pitch /puva/	54.21(100.23)	27.28(35.25)	-0.349	0.727

Result shows that no statistically significant difference found between singers and non-singers in oral non words across different pitches. However, the mean value of nasal airflow shows that singer had more airflow than non singer in all the vowels across three different pitches. Nasal airflow was seen more in the stimulus /piva/ across the three pitches for both the groups. Also increase in nasal airflow was seen for majority of the stimuli as the pitch increases for both the groups.

iii. Nasal non words

Table 4 shows the mean, SD, Z and *p-value* of nasal airflow in singers and non-singers in the nasal non words.

Table 4: *Mean, SD, Z, and p-value of the nasal non-words in singers and non-singers*

Stimuli		Nasal airflow: Mean & SD of singer	Nasal airflow: Mean & SD of non singer	Z	*p-value*
Nasal non word /mava/	Low pitch /mava/	152.88(129.13)	92.90(61.48)	-1.020	0.308
	Mid pitch /mava/	157.58(200.40)	127.75(80.79)	-0.489	0.625
	High pitch /mava/	170.35(146.65)	165.86(103.83)	-0.377	0.706
Nasal non word /miva/	Low pitch /miva/	223.74(142.71)	160.39(97.40)	-1.299	0.194
	Mid pitch /miva/	222.44(126.88)	161.78(94.66)	-1.662	0.096
	High pitch /miva/	179.06(123.91)	185.36(102.57)	-0.168	0.867
Nasal non word /muva/	Low pitch /muva/	193.49(81.22)	114.83(105.47)	-3.031	0.002
	Mid pitch /muva/	135.05(94.82)	138.71(115.22)	-0.279	0.780
	High pitch /muva/	117.43(109.18)	147.34(121.49)	-0.545	0.586

The results revealed that only for low pitch /muva/ there is a significant difference shown between singers and non-singers (*p<0.01*). Even though there is no statistically significant difference between singers and non-singers, there is a high nasal airflow in singers than the non-singers in other parameters. In singers as the pitch increases from low to high there is a decrease in nasal airflow is seen /miva/ and /muva/ whereas it is not seen in non-singers i.e., as the pitch increases the nasal airflow also increases in non-singers for these stimuli. In both the groups /miva/ is having higher nasal airflow compared to other nasal non words.

b. Aerodynamic analysis of group I (Professional singers)

Using Wilcoxon Signed Rank test the nasal airflow within both the groups were analyzed for across vowels, oral non words and nasal non word stimuli.

i. Vowels

Results showed that majority of comparison across vowel and pitch did not show significant difference. This showed that singer maintained the nasal airflow across pitch and vowel without much of variation. Only mid pitch /i/ Vs mid pitch /a/ and high pitch /u/ Vs mid pitch /u/ showed significant difference in nasal airflow of singers. Table 5 shows the mean, SD, Z and *p-value* of nasal airflow of vowels in singers and table 6 shows the comparison of three vowels across pitch in singers.

Table 5: *Mean, SD, Z, and p-value of vowels for the singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Mid pitch /i/	108.55(115.34)	-2.158	0.031
	Mid pitch /a/	52.05(58.37)		
2	High pitch /u/	81.35(90.16)	-2.669	0.008
	Mid pitch /u/	37.11(70.22)		

Table 6 shows that there is no much variation in nasal flow occurred in singers.

Table 6: *Comparison report of three vowels across pitch in singers*

		Low			Mid			High		
		/a/	/i/	/u/	/a/	/i/	/u/	/a/	/i/	/u/
Low	/a/									
	/i/									
	/u/									
Mid	/a/					+				
	/i/				+					
	/u/									+
High	/a/									
	/i/									
	/u/						+			

(+ = $p < 0.05$)

ii. Oral non words

Results showed that majority of comparison across oral non word and pitch did not show significant difference. This showed that singer maintained the nasal airflow across pitch and oral non word without much of variation. Only low pitch /puva/ Vs low pitch /piva/, mid pitch /puva/ Vs mid pitch /pava/, high pitch /puva/ Vs high pitch /pava/ and high pitch /puva/ Vs mid pitch /puva/ showed significant difference in nasal airflow of singers. Table 7 shows the mean, SD, Z and *p-value* of nasal airflow of oral non words in singers and table 8 shows the comparison of three oral non words across pitch in singers.

Table 7: *Mean, SD, Z, and p-value of oral non words for the singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /puva/	30.98(47.52)	-2.726	0.006
	Low pitch /piva/	79.62(121.53)		
2	Mid pitch /puva/	31.96(88.45)	-2.385	0.017
	Mid pitch /pava/	79.72(93.22)		
3	High pitch /puva/	54.21(100.23)	-2.442	0.015
	High pitch /pava/	104.42(115.19)		
4	High pitch /puva/	54.21(100.23)	-2.215	0.027
	Mid pitch /puva/	31.96(88.45)		

Table 8 shows that there is no much variation in nasal airflow occurred I in singers

Table 8: *Comparison report of three oral non words across pitch in singers*

		Low			Mid			High		
		/pava/	/piva/	/puva/	/pava/	/piva/	/puva/	/pava/	/piva/	/puva/
Low	/pava/									
	/piva/			+						
	/puva/		+							
Mid	/pava/						+			
	/piva/									
	/puva/				+					+
High	/pava/									+
	/piva/									
	/puva/						+	+		

(+ = *p< 0.05*)

iii. Nasal non words

Results showed that majority of comparison across nasal non word and pitch did not show significant difference. This showed that singer maintained the nasal airflow across pitch and nasal non words without much of variation. Only low pitch /miva/ Vs low pitch /mava/, mid pitch /mava/ Vs mid pitch /muva/, mid pitch /miva/ Vs high pitch /muva/ and high pitch /muva/ Vs low pitch /muva/ showed significant difference in nasal airflow of singers. Table 9 shows the mean, SD, Z and *p-value* of nasal airflow of nasal non words in singers and table 10 shows the comparison of three nasal non words across pitch in singers.

Table 9: *Mean, SD, Z, and p-value of oral non words for the singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /miva/	223.74(142.71)	-2.101	0.036
	Low pitch /mava/	152.88(129.13)		
2	Mid pitch /miva/	222.44(142.71)	-2.329	0.020
	Mid pitch /mava/	157.58(200.40)		
3	Mid pitch /muva/	135.05(94.82)	-2.499	0.012
	Mid pitch /miva/	222.44(126.88)		
4	High pitch /muva/	117.43(109.18)	-2.442	0.015
	High pitch /miva/	179.06(123.91)		
5	High pitch /muva/	117.43(109.18)	-2.385	0.017
	Low pitch /muva/	193.49(81.22)		

Table 10 shows that there is no much variation in nasal airflow occurred in singers for nasal non words.

Table 10: *Comparison report of three nasal non words across pitch in singers*

		Low			Mid			High		
		mava	miva	muva	mava	miva	muva	mava	miva	muva
Low	Mava		+							
	miva	+								
	muva									+
Mid	mava					+				
	miva				+		+			
	muva					+				
High	mava									
	miva									+
	muva			+					+	

(+ = *p*< *0.05*)

c. Aerodynamic analysis of group II

Similar to group I, the Wilcoxon Signed Rank Test was used to analyze the nasal airflow within group II across vowels, oral non words and nasal non words.

i. Vowel

Results showed that majority of the comparison across vowel and pitch showed significant difference in nasal airflow. This shows that non-singers not able to maintain the airflow constantly across the vowel and pitch. Table 11 shows the mean, SD, 'Z' and *p-value* of vowels across pitch and table 12 shows comparison of three vowels across pitch in non singer.

Table 11: *Mean, SD, Z, and p-value of vowels for the non-singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /u/	18.31(24.09)	-3.350	.001
	Low pitch /i/	37.82(42.01)		
2	Mid pitch /u/	18.36(17.54)	-3.996	.000
	Mid pitch /i/	57.30(84.09)		
3	Mid pitch /u/	18.36(17.54)	-3.646	.000
	Mid pitch /a/	50.20(49.07)		
4	High pitch /u/	43.18(58.38)	-2.812	0.005
	High pitch /i/	80.86(87.67)		
5	High pitch /u/	43.18(58.38)	-2.650	0.008
	High pitch /a/	64.94(67.28)		
6	Mid pitch /a/	50.20(49.07)	-3.431	0.001
	Low pitch /a/	30.89(31.10)		
7	High pitch /a/	64.94(67.28)	-2.301	0.021
	Mid pitch /a/	50.20(49.07)		
8	High pitch /a/	64.94(67.28)	-3.592	0.000
	Low pitch /a/	30.89(31.10)		
9	High pitch /i/	80.86(87.67)	-3.269	0.001
	Mid pitch /i/	57.30(84.09)		
10	High pitch /i/	80.86(87.67)	-3.431	0.001
	Low pitch /i/	37.82(42.01)		
11	High pitch /u/	43.18(58.38)	-3.646	0.000
	Mid pitch /u/	18.36(17.54)		
12	High pitch /u/	43.18(58.38)	-3.511	0.000
	Low pitch /u/	18.31(24.09)		

Table 12: *Comparison report of vowels across pitch in non-singers*

		Low			Mid			High		
		/a/	/i/	/u/	/a/	/i/	/u/	/a/	/i/	/u/
Low	/a/				+			+		
	/i/			+					+	
	/u/		+							+
Mid	/a/	+					+	+		
	/i/						+		+	
	/u/				+	+				+
High	/a/	+			+					+
	/i/		+			+				+
	/u/			+			+	+	+	

(+ = $p < 0.05$)

Table 12 shows that variation in nasal airflow across and vowel is more in non-singers.

ii. Oral non words

Results showed that majority of the comparison across oral non words and pitch showed significant difference in nasal airflow. This shows that non-singers not able to maintain the airflow constantly across the oral non-words and pitch. Table 13 shows the mean, SD, 'Z' and *p-value* of nasal non-words across pitch and table 14 shows comparison of three nasal non-words across pitch in non singer

Table 13: *Mean, SD, Z, and p-value of oral non words for the non-singers*

Sl No.	Stimuli	Mean & SD of nasal air flow	Z	p-value
1	Low pitch /piva/	39.33(55.43)	-3.108	0.002
	Low pitch /pava/	17.03(18.33)		
2	Low pitch /puva/	14.78(18.94)	-3.565	0.000
	Low pitch /piva/	39.33(55.43)		
3	Mid pitch /puva/	22.68(27.73)	-2.301	0.021
	Mid pitch /piva/	46.35(64.56)		
4	High pitch /puva	27.28(35.25)	-3.108	0.002
	High pitch /piva/	64.98(85.06)		
5	High pitch /puva/	27.28(35.25)	-2.166	0.030
	High pitch /pava	39.81(38.18)		
6	Mid pitch /pava/	27.63(27.77)	-3.027	0.002
	Low pitch /pava/	17.03(18.33)		
7	High pitch /pava/	39.81(38.18)	-2.422	0.015
	Mid pitch /pava/	27.63(27.77)		
8	High pitch /pava/	39.81(38.18)	-3.700	0.000
	Low pitch /pava/	17.03(18.33)		
9	High pitch /piva/	64.98(85.06)	-3.108	0.002
	Mid pitch /piva/	46.35(64.56)		
10	High pitch /piva/	64.98(85.06)	-2.139	0.032
	Low pitch /piva/	39.33(55.43)		
11	Mid pitch /puva/	22.68(27.73)	-2.906	0.004
	Low pitch /puva/	14.78(35.25)		
12	High pitch /puva/	27.28(35.25)	-2.180	0.029
	Mid pitch /puva/	22.68(27.73)		
13	High pitch /puva/	27.28(35.25)	-3.484	0.000
	Low pitch /puva/	14.78(18.94)		

Table 14 shows that more variation is seen in nasal airflow of oral non words in non-singers

Table 14: *Comparison report of the oral non-words across pitch in non-singers*

		Low			Mid			High		
		/pava/	/piva/	/puva/	/pava/	/piva/	/puva/	/pava/	/piva/	/puva/
Low	/pava/		+		+			+		
	/piva/	+		+					+	
	/puva/		+				+			+
Mid	/pava/	+						+		
	/piva/						+		+	
	/puva/			+		+				+
High	/pava/	+			+					+
	/piva/		+			+				+
	/puva/			+			+	+	+	

(+ = $p < 0.05$)

iii. Nasal non words

Results showed that majority of the comparison across nasal non words and pitch showed significant difference in nasal airflow. This shows that non-singers not able to maintain the airflow constantly across the nasal non-words and pitch. Table 15 shows mean, SD, ‘Z’ and *p-value* of nasal non-words across pitch and table 16 shows comparison of three nasal non-words across pitch in non singer.

Table 15: *Mean, SD, Z, and p-value of nasal non words for the non-singers*

Sl No.	Stimuli	Mean & SD of Nasal air flow	Z	p-value
1	Low pitch /miva/ Low pitch /mava/	160.39(97.40) 92.90(61.48)	-3.767	0.000
2	Low pitch /muva/ Low pitch /miva/	114.83(105.47) 160.39(97.40)	-2.785	0.005
3	Mid pitch /miva/ Mid pitch /mava/	161.78(94.66) 127.75(80.79)	-2.543	0.011
4	Mid pitch /muva/ Mid pitch /miva/	138.71(115.22) 161.78(94.66)	-2.112	0.035
5	High pitch /miva/ High pitch /mava/	185.36(102.57) 165.86(103.83)	-2.166	0.030
6	High pitch /muva/ High pitch /miva/	147.34(121.49) 185.36(102.57)	-2.112	0.035
7	Mid pitch /mava/ Low pitch /mava/	127.75(80.79) 92.90(61.48)	-2.892	0.004
8	High pitch /mava/ Mid pitch /mava/	165.86(103.83) 127.75(80.79)	-2.274	0.023
9	High pitch /mava/ Low pitch /mava/	165.86(103.83) 92.90(61.48)	-3.162	0.002

Table 16: *Comparison report of three nasal non words across pitch in non-singers*

		Low			Mid			High		
		/mava/	/miva/	/muva/	/mava/	/miva/	/muva/	/mava/	/miva/	/muva/
Low	/mava/		+		+			+		
	/miva/	+		+						
	/muva/		+							
Mid	/mava/	+				+		+		
	/miva/				+		+			
	/muva/					+				
High	/mava/	+			+				+	
	/miva/							+		+
	/muva/								+	

(+ = $p < 0.05$)

Table 16 shows that the more variation is seen in the nasal airflow of nasal non words in non-singers.

II. Perceptual analysis

For analysis of perceptual measurement the average perceptual nasality is calculated from the ratings of five SLPs for the vowel /a/, the oral non word /pava/ and the nasal non word /mava/ at three different pitches such as low, mid and high. Then the mean of the perceptual nasality was taken for singers and non-singers. Table 17 shows the mean and SD of perceptual nasality in singers and non-singers.

Table 17: *Mean & SD of perceptual analysis of singers and non-singers*

	Stimuli	Perceptual nasality	
		Mean & SD of singers	Mean & SD of non-singers
Vowel /a/	Low /a/	9.97(3.40)	10.42(3.16)
	Mid /a/	12.51(4.19)	13.01(3.15)
	High /a/	15.22(5.03)	15.34(3.18)
Oral non word /pava/	Low/pava/	11.82(2.30)	12.53(3.12)
	Mid /pava/	13.68(2.66)	15.69(2.66)
	High /pava/	16.62(3.29)	19.06(3.14)
Nasal non word /mava/	Low /mava/	19.26(2.47)	21.63(3.83)
	Mid /mava/	22.97(3.98)	24.73(4.27)
	High /mava/	25.62(3.32)	29.46(3.83)

The findings show that perceptually the nasality is more in non-singers than singers. As pitch increases from low to high the nasality is also increasing perceptually in both the groups.

Using Wilcoxon Signed Rank test the perceptual nasality within the groups were analyzed across pitch for vowel /a/, oral non word /pava/ and nasal non word /mava/. Table 18 and table 19 show the pair wise comparison of perceptual analysis of singers and non-singers respectively.

Table 18: *Pair wise comparison of perceptual analysis in singers*

	Low Vs Mid	Mid Vs High	Low Vs High
/a/	+	+	+
/pava/	+	+	+
/mava/	+	+	+

(+ = $p < 0.05$)

Table 19: *Pair wise comparison of perceptual analysis in non-singers*

	Low Vs Mid	Mid Vs High	Low Vs High
/a/	+	+	+
/pava/	+	+	+
/mava/	+	+	+

(+ = $p < 0.05$)

Results showed that variation in perceived nasality present for all the stimuli across pitch in singers and non-singers.

III. Comparison of aerodynamic and perceptual measures

Spearman's coefficient of correlation was used to obtain the correlation between aerodynamic and perceptual measurements of singers and non-singers. Table 20 shows the correlation coefficient between perceptual and aerodynamic analysis in singers and non singers for the vowel /a/, oral non-word /pava/ and nasal non-word /mava/ in three pitches.

Table 20: *Correlation between perceptual and aerodynamic analysis of singers and non-singers*

Stimuli	Correlation coefficient for singers	Correlation coefficient for non-singers
Low /a/	0.066	-0.075
Mid /a/	0.292	0.130
High /a/	-0.200	0. 098
Low /pava/	-0.428	-0.109
Mid /pava/	-0.165	0.154
High /pava/	-0.002	-0. 231
Low /mava/	0.354	0. 205
Mid /mava/	0.014	0. 317
High /mava/	-0.174	0.260

The results revealed that there is poor correlation present between aerodynamic and perceptual measures either in singers or non-singers. However, singers showed more negative correlation between nasal airflow and perceived nasality in comparison with non singers.

CHAPTER V

DISCUSSION

Many researchers are of the view that velum opens greatly when singing in higher pitches and which is negatively correlated to the perceived nasality. Few research evidence shows that trained singers have more capability than non-singers and the researchers reported that singers uses specific velar adjustments while singing in upper registers. Since there are very few studies focused on the effect of vocal training and perceived nasality in singing especially in Indian music. The present study compared the nasal airflow between vocally trained (professional singers) and untrained (non-singers) with increasing frequency and intensity. The current study investigated 40 female participants which consisted of 15 professional singers and 25 non-singers. Nasal airflow was compared between singers and non-singers in vowels, oral non-words, and nasal non-words with three different pitches and with the assumption that intensity will also increase with increase in pitch. Later aerodynamic and perceptual measurements were compared between group I and group II.

I. Aerodynamic analysis

a. Comparison of aerodynamic analysis between singers and non-singers

The comparison of aerodynamic analysis of vowels, oral non-words and nasal non-words between singers and non-singers suggested that overall nasal airflow of singers is higher compared to non-singers. One of the possible explanations is that singers uses velopharyngeal opening (VPO) more compared to non-singers during singing. Since

VPO is more beneficial in singing, singers use the nasal murmer such as /ma/, /mi/, and /mu/ as classical exercises to initiate phonation, is an evidence to that. Presence of VPO in classical singers is found by various methods such as x-ray imaging, nasometer, airflow measurements photodetector and by nasofiberscopy. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) reported that a narrow VPO can be regarded as a slit and acoustic impedance of VPO increases as frequency increases. Hence the lowest force in the VPO will lead to squeeze even through narrow opening. They also reported that VPO may exist even in the absence of nasal DC flow. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) suggested that singers use VPO during singing and also found different pattern of VPO in different singers and suggested that "singers carefully tune the degree of opening, in order to color the timbre". They suggested that singers are capable of using even a wide VPO without producing high degree of nasal quality. The present study also supports this finding that singers are able to use the VPO to color their timbre thereby the nasal airflow was increased in singers than non-singers and without producing much nasality.

Even though nasal airflow shows higher value, the perceived nasality in singers has no significant difference compared to non-singers as the study by Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002). This also suggests that trained singers have ability to control their velum movement to project their voice and make it better. Contradicting to this view, using photodetector Austin (1997) found that small or no VPO present in singers. He concluded that as frequency increased, the duration of VPO is decreased. The present study is not supporting his view that VP is closed during classical singing. According to Miller (1996) VPO is not harmful to the singing voice, and he also postulated that "nasality intruded into non-nasals is not aesthetically pleasing." The above discussion is based on the assumption that there is positive correlation between VPO and nasal airflow and in turn with perceived nasality also. However, literature shows that there may be no correlation between VPO and the nasal airflow. Hence, the reader has to interpret with caution.

i. Vowels

Findings of vowels in the present study suggest that there is no statistically significant difference found between singers and non-singers. Also the nasal airflow of vowels showed that vowel /i/ has more nasal airflow compared to other vowels in both the singers and non-singers. Jennings & Kuehn (2008) reported the similar results in singers using nasometer. In accordance with this, Fowler (2004) reported that singers had a low nasalance score for the back vowels. These findings suggested that since /i/ is a high front vowel, greater nasal airflow in /i/ is due to the anterior constriction and which is correlated with more oral impedance. This information is consistent with literature. Lewis, Watterson & Quint (2000) and Von Berg (2002) revealed that vowel /i/ had greatest mean nasalance score compared to the other four vowels /a,u, ae/. Similar trends were seen in this study compared to the other to vowels /a/ and /u/.

The present finding is also supporting by Carlo & Autesserre (1987). They used x-rays to obtain the velum behavior during singing and reported that a total occlusion was found in the velum when the vowel /i/ was spoken whereas 1mm opening was observed during /i/ was sung in the lower vocal register and about 2 mm opening found when it was sung in the higher register. In upper register pharyngeal tightening occurs because of the tension of the muscle. Singers will adjust their velum in a specific position to avoid the excessive contraction of pharyngeal and velar muscles. Their result shows that perceptually the voice was rated as beautiful and powerful for those who sung with a lowered velum whereas 'dull' was rated for those who sing with raised velum. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) found that the nasal flow varied with increasing pitch in singers. They found that nasal airflow was present for the vowels /a/ and /u/, while nasal airflow was observed for the vowel /i/ only in one tenor singer. Several studies have shown that nasal resonance is still accepted and is used in singing. Singing teachers and voice clinicians should suggest the students to produce the vocal quality as forward rather than backward.

ii. Oral non-words

Findings of oral non-words in the present study suggest that there is no statistically significant difference found between singers and non-singers, same as the findings of vowels. However, it was observed that nasal airflow was seen more in the stimulus /piva/ across pitch for both the groups. Similar as vowel /i/ during singing, the oral non-word with the high vowel /i/ also shows the findings in consensus with the findings of Jennings & Kuehn (2008) and Fowler (2004). Their results suggest that the anterior constriction and more oral impedance in the vowel /i/ cause more nasal airflow. This suggestion can also be attributed to the production of /piva/. Due to the higher intra oral pressure of /p/ and the oral impedance and tongue constriction of /i/ would give a combined effect in the production of /piva/ which results in increased nasal airflow. The production of stop consonants is considered as the point of maximum VP closure and also has maximum intra oral pressure.

iii. Nasal non-words

Similar as in vowels and oral non-words, the nasal non-word with /i/, i.e., /miva/ has more nasal airflow in both the groups. Compared to the findings of vowels and oral non-words, the results of nasal non-words revealed that there is a significant effect present for the low pitch /muva/ between singers and non singers. Also it was observed that as the pitch increases from low to high there is a decrease in nasal airflow is seen in /miva/ and /muva/. This finding suggests that in nasal context singers are able to control their nasality as pitch increases. According to Carlo & Autesserre (1987) velum is lowered for the nasal vowel and lateral pharyngeal walls were apart than oral vowel. Present study also supports the view of these authors that in the findings, only non-words with nasal vowels showing a variation between singers and non singers. They concluded that "VPO is increased as singers going from lower to the upper registers." However, Tanner, Roy, Merrill & David (2005) reported that the nasal airflow was higher in singing compared to speaking in the production of /p/ in the /mp/ blend. It is discussed that this is due to the carryover effect of the preceding nasal consonant /m/ in the blend. In the view of this study, the findings in nasal airflow of /miva/ also can be attributed to the anticipatory effect of /m/ and oral impedance and tongue constriction of /i/ would result in combined effect of increased nasal airflow.

The comparison across vowels, oral non-words and nasal non-words across pitch did not show significant difference in singers in many of the comparison, in contrast to the non-singers. This suggests that singers are able to maintain the nasal airflow across pitch and vowel without much of variation. The singers are controlled to use velar adjustments with varying pitch. Whereas non-singers are not able to maintain the airflow constantly which suggests that non-singers are not able to control their velum during singing with increasing pitch and intensity.

II. Perceptual analysis

The comparison of perceptual nasality between singers and non singers revealed that nasality is more seen in non singers than singers. However, it was not statistically significant. As pitch increases perceived nasality was also increasing in both the groups. Pair wise perceptual nasality findings shows that there is a variation in nasality present with varying pitch in both singers and non singers. This suggests that even though the nasal airflow was varied between singers and non-singers, the perceived nasality was same. This is correlated with effect of vocal training on nasality i.e., the singers use their VPO during singing to color their voice without much change in the perceptual nasality.

III. Comparison of aerodynamic and perceptual measure

The results revealed that there is poor correlation present between aerodynamic and perceptual measures, both in singers and non singers. It was also found that singers showed more negative correlation between nasal airflow and perceptual nasality compared to non-singers. Birch, Gumoes, Stavad, Prytz, Bjokner, & Sundberg (2002) also found a lack of correlation between perceived nasality and nasal DC (constant) airflow. The correlation would have been better if the airflow data and audio recording were done at the same session. The finding suggests that singers produce more nasal airflow during singing but it is not sensing as much nasality to the listeners. That is the singers are trained to use specific velar adjustments in singing which will not affect perceived nasality and it is some extent same in the present study.

Results of the present study suggest that majority of the singers had a higher nasal airflow during upper registers in most of the stimuli. Only those who got sufficient vocal training and have been judged to be proficient in singing shows less nasal airflow than non singers. This leads to two different conclusions, i.e., either the singers are taught to reduce or avoid nasality in their singing or they have tendency towards nasal airflow. This suggests that vocal training has an effect on nasal airflow while increasing pitch. In this study, even though the singer's perceived nasality was lower than the non singers which did not give a significant difference because only few of the singers were effectively trained.

Habitual pitch was not measured in the study. Nasal airflow measure on habitual pitch would have given some insight for the study. Also rate of singing was not controlled in this study. Participants were given the model to sing in the same rate but some of them sing at different rate. Most of the singers start with a classical style in the initial part of singing. This will leads to more nasal airflow than the steady state. But when they reached the steady vowel position it may reduced. Hence, the classical style also contributed to increased nasal airflow during singing. Also as singers demonstrated more energy during singing for singer's formant, would also result in increased airflow.

Another observation seen was that the participants are controlling their singing when sung in the upper register through the mask. Some of the participants are not comfortable to sing through the mask. They had to be trained to sing through mask for some time. Also the inadequate seal between the mask and the face will render the acquisition of nasal airflow. Mask also prevented the normal auditory feedback to the singers. So VPO could only be proved by the presence of nasal airflow and also observation of it through nasofiberscopy, x-rays and photodetector which was not used in the study. If it was used this would give a better result regarding the VPO and nasal airflow during singing. According to Sundberg (2004) “occasional oral–nasal coupling might tune the resonating system and strengthen the singer’s formant during classical singing”. Thus it was revealed that VPO is not harmful to the singers. Singers use this to color their voice. If proper vocal training is not achieved, this would result in increased perceptual nasality. Present study also supports the same findings that VPO leads to an increase in nasal airflow however, it is not perceived as high nasality to the listeners. If the singers were not trained properly they would not achieve the velar adjustments during singing and will result in inadequate nasal airflow. Authors reported that in most efficient singers, the presence of VPO would not result in presence of nasal airflow. This is not occurring in non-singers or untrained singers.

Most of the singers use specific technique in their singing style. One of that is wide oral opening. This was not much achieved when using oral-nasal mask. Oral opening would color their voice and result in singer’s formant. Also wrong techniques in singing adversely affect their voice. Any conscious attempt to maintain lowered or elevated velopharynx during singing would result hyperfunctional in some cases and which will also increase the risk of developing different vocal and velar pathologies.

Only few of the singers showed a pattern of nasal airflow when increasing pitch which was not significant difference. Pattern of nasal airflow is found in some studies which mean that there is a trend in singers with decreased nasalance when they sing from low to high pitch. However, the variation in nasal airflow was more shown in non-singers compared to singers which suggest that singers have the ability to control the VPO when sung at different pitches whereas non-singers not have this capability. Their velum is not tuned to that.

The variation in nasal airflow between participants (singers and non-singers) was more in the study. This variability is occurred for reasons other than independent variable and it also affects the overall results of the study. In future it can be studied the factors that contribute wide range of nasal airflow observed in the study. Literature shows significant difference in nasal airflow would be seen when comparing the various styles of singing, different language, gender and experience level. Troup, Welch, Volo & Tronconi (1989) also concluded as “total velum closure is language dependant, education dependant, style dependant, pitch dependant and anatomically dependant.”

Limitations of the study

- Rate of singing was not controlled in the study.
- The oro-nasal mask used in the airflow measurements was not comfortable to some participants.
- The nasal habitual pitch and nasal airflow of habitual pitch was not measured in the study.
- The perceptual rating scale used in the study felt inappropriate for the listeners.
- Nasal airflow measurement and the recordings for perceptual measurements were not done simultaneously

Implications

- The results of the present study add the knowledge in the field of physiology behind singing, especially in Indian music. Also give some insight in the relation between nasal airflow and perceived nasality in singers.

- Since the individual variation in the nasal airflow is more the single subject design will give more information than group design.

Future directions

- The study can be compared between gender, age, music style, language and duration of experience in vocal training.

- The study can be done with aerodynamic and acoustic measurements and also using various methods such as x-ray imaging, nasometer, airflow measurements photodetector and by nasofiberscopy.

CHAPTER VI

SUMMARY AND CONCLUSIONS

Vocal resonance is most important in singing. Out of the four primary resonances such as chest, mouth, nasal and head, nasal resonance gives clarity and projection to the singing voice. These resonances are used depending on the style of singing. This nasal resonance occurs due to the oro-nasal coupling mainly during the production of nasal phonemes during speech. In normal individuals, it occurs without any control or conscious effort. But authors have reported that trained singers use nasal resonance during singing. Various studies have been done to find whether singers use nasal resonance during singing.

Several researchers investigated the velopharyngeal opening (VPO) during singing and suggest that there is VPO present with increasing pitch and it is negatively correlated with the perceived nasality. If nasality is not controlled while singing it will be distracted to the listeners. Even though singing consists of both oral and nasal consonants like speech, it is not heard as noisy or dull. So how the singers are able to project their voice when there is an opened velum, is worth of investigation. There are only few number of studies focused on the effect of vocal training and perceived nasality in singing. So the present was aimed to find out the effect of vocal training on nasal airflow and perceived nasality with variation in F0 and intensity and also to find correlation between perceptual and objective measurements of nasality, in Indian Carnatic singers.

Two groups of participants were included in this study. Group I included 15 female professional singers and group II included 25 non-singers with an age range of 20-

60 years. Professional singers had minimum ten years of experience in Carnatic singing and non singers have not received any kind of training on formal singing. The participants were evaluated under aerodynamic and perceptual measurements. The first condition in aerodynamic measurements was to phonate the vowels /a/, /i/ and /u/ with an ascending pitch in three different frequencies (low, mid, and high) and with an increase in vocal intensity. In the second condition the participants were instructed to sing oral (/pava/, /piva/, and /puva/) and nasal (/mava/, /miva/, and /muva/) non-words with ascending pitch in three different scales and increase in intensity.

Ten minutes practice session was given before actual recording and provided with an audio and video model and they were instructed to match the pitch as the model. Aerodynamic measurements (nasal airflow) were recorded using Aeroview syste, version 1.5.0. Perceptual nasality for the two conditions was rated by five SLPs using CAPE-V. Only nasality parameter has been rated in 100 point scale. All the participants were able to match the pitch and scored more than 90 % of matching.

The current study compared the aerodynamic and perceptual measurements between singers and non-singers. Mann-Whitney U test used to compare the aerodynamic analysis between singers and non-singers and Wilcoxon Signed Rank test used to find the pair wise significant difference within the groups and parameters in aerodynamic and perceptual analysis. In aerodynamic analysis, the study results found a significant difference between singers and non-singers only in the low pitch /muva/. However, the mean value of nasal airflow shows that singers had more airflow than non-singers in all the vowels, oral non-word and nasal non-words across pitch. The vowel /i/ showed more nasal airflow compare to other vowels in both the groups. Also in the vowels /a/ and /u/

nasal airflow is lower in the mid pitch compare to low and high pitches in singers whereas in non-singers, nasal airflow is increasing as the pitch increase in these vowels. In oral non-words, nasal airflow was seen more in the stimulus /piva/ and in nasal non-words /miva/ showed more nasal airflow in both the groups. For majority of the stimuli it showed that the nasal airflow is increasing as the pitch increases in both the groups.

The results of aerodynamic analysis in singers showed that majority of comparison across vowel Vs pitch, oral non-words Vs pitch and nasal non-words Vs pitch did not show significant difference. This suggested that singer maintained the nasal airflow across pitch and stimuli without much of variation. Whereas the results of non-singers showed that majority of comparison across the stimuli and pitch showed a significant difference in nasal airflow. This shows that non-singers are not able to maintain the airflow constantly across the pitch and different stimuli.

The results of mean value of perceptual nasality between singers and non-singers show that the nasality is more in non-singers than singers. Also as pitch increasing from low to high the nasality is also increasing in both the groups. Variation in perceived nasality present for all the stimuli across pitch in both the groups. The results of comparison of aerodynamic and perceptual measures in singers and non-singers revealed that there is poor correlation present between the two measures in both the groups. However, singers showed more negative correlation between nasal airflow and perceived nasality in comparison with non-singers. However, the correlation values were poor.

The results of the study are in consonance with some of the previous literature. The present study revealed several points of interest. ***First,*** the nasal airflow was higher in majority of the stimuli in singers in comparison with non singers. ***Second,*** the analysis of perceptual measurements shows that the mean value of perceived nasality is higher in non-singers compared to non-singers. These findings suggest that singers use the VPO to project and color their voice but it is not perceived as much while singing. ***Third,*** majority of the comparison across the stimuli and pitch did not show significant difference in singers whereas non-singers showed a significant difference for majority of the comparison across pitch and stimuli. These findings suggest that singers are able to maintain the airflow constantly across pitch and the different stimuli whereas non-singers are not able to maintain it. This showed the effect of vocal training in singers with ascending pitch. ***Fourth,*** there is more negative correlation found between aerodynamic and perceptual measurements in singers.

REFERENCES

Alderson, A. (1993). Positioning the velum. *The Journal of Research in Singing and Applied Vocal Pedagogy*, 16, 25-32.

Aronson, A. E., & Bless, D. M. (2009). Clinical Voice Disorders**.** *Thieme Medical Publishers, Inc. New York.*

Austin, S. F. (1997). Movement of the Velum during Speech and Classically Trained Singers. *Journal of Voice*, 2(2), 212-221.

Birch, P., Gumoes., Stavad, H., Prytz, S., Bjokner & Sundberg, J. (2002). Velum behavior in professional classic operatic singing. *Journal of Voice,* 16, 61-71.

Brown, L. & Behnke, E. (1883). Voice, Song, and Speech, A practical guide for singers and speakers, London, Sampson Low

Brown, W. S., Hunt, E., & Williams, W. N., (1988). Physiological differences between the trained and untrained speaking and singing voice. *Journal of Voice*, 2(2), 102-10.

Brown, W.S., Jr., Rothman, H., & Williams, W. (1978). Physiological differences between singers and non-singers. In V. Lawrence (Ed.). *Transcripts of the Seventh Symposium on Care of the Professional Voice*. New York, NY: Voice Foundation, 11-18.

Bunch , M. (1982). Dynamics of Singing Voice. *Springer Verlag, New York* .

Bunch, M. (1995). Dynamics of Singing Voice (*III* edition). *Disorders of Human Communication Disorders, Springer Verlag, New York* .

Bunch, M. (2009). Dynamics of the Singing Voice, *5th edition, Springer Wein, New York.*

Carlo, D., S. & Autesserre, D. (1987). Movement of Velum in Singing. *Journal of Research in Singing,* 10, 3-13.

Chakraborty, S., & Debashis. (2012). Pattern Classification of Indian Classical Ragas based on Object Oriented Concepts. *International Journal of Advanced Computer Engineering & Architecture, 2(2),* 285-294

Devadas, U., Rajashekhar, B., & Aithal, U. V. (2009). Analysis of Voice in Yakshagana Singers. *Journal of AIISH*, 28, 59-64.

Fowler, P. L. (2004). Comparison of Nasalance between Trained Singers and Non-singers, A Dissertation submitted to the Department of Communication Disorders In partial fulfillment of the requirements for the degree of Doctor of Philosophy, *Florida State University.*

Gauffin, J., & Sundberg, J. (1989). Spectral correlates of glottal voice source waveform characteristics. *Journal of Speech and Hearing Research, 32,* 556-565.

Gramming, P., Nord, L., Sundberg, J., & Elliot, N. (1993). Does the nose resonate during singing?, *STL-QPSR*, 34 (4), 35-42

Griffin, B., Woo, P., Colton, R., Casper, J., & Brewer, D. (1995). Physiological Characteristics of the Supported Singing Voice. A Preliminary Study. *Journal of Voice,* 9(1), 45-56.

Hamdan, A. L., Deeb, R., Tohme, R. A., Rifai, H., Husseini, S., & Fuleihan, N. (2008). Vocal Technique in a Group of Middle Eastern Singers. *Folia Phoniatrica Logopedics,* 60, 217–221

Hoit, J. D., Jenks, C. L., Watson, P. J., & Cleveland, T. F. (1996). Respiratory Function During Speaking and Singing in Professional Country Singers. *Journal of Voice,* 10(1) 39-49

House, S., & Stevens, K. N. (1956). Analog Studies of the Nasalization of Vowels. *The journal of Speech and Hearing Disorders,* 21 (2), 218-232

http://en.wikipedia.org/wiki/Vocal_pedagogy

http://en.wikipedia.org/wiki/Vocal_resonation

http://shodhganga.inflibnet.ac.in/bitstream/10603/4551/.../07_chapter%202.pdf

Jennings, J. J., & Kuehn, P. D. (2008). The Effects of Frequency Range, Vowel, Dynamic Loudness Level, and Gender on Nasalance in Amateur and Classically Trained Singers. *Journal of Voice*, 22(1), 75-89.

Lawrence, V. L. (1979). Laryngological observations on belting. *Journal of Research Singing,* 2(1), 26-8.

Lewis, K. E., Watterson, T. L., & Quint, T. (2000). The effect of vowels on nasalance scores. *Cleft Palate Craniofacial Journal*, 37, 584-589.

McIver, W., & Miller, R. (1996). A brief study of nasality in singing. *Journal of Singing,* 52, 21-25.

McCrea, C. R., & Morris, R. J. (2001). Effects of Vocal Training and Phonatory Task on Voice Onset Time. *Journal of Voice,* 21(1), 54-63.

McGlone, R. (1976). Lingual pressure variation during singing by trained and untrained individuals. Paper presented at the Fifth Symposium on Care of the Professional Voice, New York.

McGlone, R. (1977). Supraglottal air pressure variation from trained singers while speaking and singing. In: Lawrence, V. (ed.) *Transcripts of the Sixth Symposium on Care of the Professional Voice*. New York: The Voice Foundation, 48-49.

McKinney, & James (1994). The Diagnosis and Correction of Vocal Faults, Nashville, TN: Genovex Music Group.

Monahan, B. J. (1978). The art of singing; a compendium of thoughts on singing published between 1777 and 1927. New Jersey, The Scarecrow Press

Punt, N. A. (1979). The way to sing. Boston: Birchard.

Shipp. T., & Izdebski, K. (1975). Vocal frequency and vertical larynx positioning by singers and non-singers. *Journal of the Acoustical Society of America, 58*, 1104-1106.

Stone, E. R., Cleveland, F.T., & Sundbergt, J. (1999). Formant Frequencies in Country Singers' Speech and Singing. *Journal of Voice*, 13(2), 161-167.

Sundberg, J., & Rothenberg, M. (1986), Some phonatory characteristics of singers and nonsingers. *STL-QPSR*, 27(4), 065-077

Sundberg, J., Cleveland, E. T., Stone, E. R., & Iwarsson, J.S. (1999). Voice Source Characteristics in Six Premier Country Singers. *Journal of Voice*, 13(2), 168-183.

Sundberg, J. (2001). Level and Center Frequency of the Singer's Formant. *Journal of Voice*, 15(2), 176–186

Tanner Roy, K. N., Merrill, R. M., & David, P. (2005). Velo pharyngeal port status during classical singing. *Journal of Speech, Language, and Hearing Research,* 48, 1311-1324.

Titze, Ingo. (1994). Acoustics of the Tenor High Voice. Journal of the Acoustic Society of America, 95(3), 1133-1142

Troup, G. J., Welch, G. F., Volo, M., Tronconi, A., Ferrero, F., & Farnetani, E., (1989). On velum opening in singing. *The Journal of Research in Singing and Applied Vocal Pedagogy*, 13, 35–39.

Von Berg, S., (2002). The effect of vowels on nasalance measures and nasality judgments [dissertation]. Reno, Nevada, University of Nevada.

Vennard, W. (1964). An experiment to evaluate the importance of nasal resonance in singing. *Folia Phoniatrica Logopedics,* 16, 146-153.

Volo, M., Farnetani, E., Troup, G. J., Ferrero, F. E., (1986) A pilot study of nasal aerodynamic flow in singing. Quaderni del Centro di Studio per le Ricerche di Fonetica del C.N.R, 5, 395-404.

Yanagisawa, E., Estill, J., Mambrino, L., & Talkin, D. (1991). Supraglottic contributions to pitch raising videoendoscopic study with spectroanalysis. *Annals of Otology, Rhinology and Laryngology,* 100, 19-30.

APPENDIX I

Percentage of Matching the Model Pitch in Participants Pitch (Singers & Non-Singers)

(1-15 = singers, 16-40 = non-singers)

Vowels

Participants	Low /a/	Mid /a/	High /a/
1	98.33	99.81	96.62
2	98.63	98.53	98.07
3	100.00	99.64	98.55
4	98.20	98.81	100.00
5	99.38	99.31	98.82
6	98.13	98.31	98.18
7	94.42	94.95	96.69
8	95.67	96.29	95.55
9	98.92	98.28	97.76
10	98.13	97.48	96.58
11	98.88	99.11	97.35
12	94.92	96.70	95.05
13	99.00	99.14	97.91
14	96.33	98.86	95.92
15	97.83	97.92	97.89
16	96.54	99.28	97.31
17	99.92	98.92	96.19
18	98.92	98.03	99.44
19	99.04	98.59	99.59
20	96.25	96.15	95.19
21	98.08	96.20	98.74
22	98.22	98.53	99.46
23	99.25	97.73	99.25
24	97.12	98.46	100.00
25	99.13	100.00	98.82
26	99.21	98.06	97.39
27	95.63	98.23	97.72
28	98.25	98.59	96.83
29	96.33	96.34	94.82
30	89.25	91.20	88.48
31	91.79	98.31	92.34
32	96.75	92.87	80.13
33	98.29	95.65	96.71
34	90.74	97.87	99.73
35	100.00	97.62	100.00
36	99.63	98.06	99.21
37	99.75	98.53	98.84
38	98.63	97.75	97.33
39	97.54	99.42	98.84
40	98.29	98.13	97.24

Participants	Low /i/	Mid /i/	High /i/
1	96.21	100.00	96.87
2	100.00	100.00	98.74
3	97.04	100.00	99.46
4	100.00	98.64	100.00
5	98.42	99.42	99.32
6	100.00	99.75	99.42
7	97.71	98.72	97.43
8	95.38	96.42	96.21
9	100.00	98.75	100.00
10	98.42	97.98	97.62
11	99.58	97.81	97.80
12	97.75	97.92	97.45
13	98.58	98.84	99.11
14	97.08	96.37	95.69
15	100.00	99.22	98.51
16	96.54	98.97	99.19
17	99.92	97.98	93.99
18	98.91	100.00	100.00
19	99.04	97.45	96.66
20	96.25	94.51	96.79
21	98.08	97.50	95.63
22	96.21	99.14	90.70
23	99.54	98.31	98.94
24	94.46	94.76	98.11
25	96.75	98.17	100.00
26	99.46	98.59	99.09
27	99.38	98.02	98.20
28	96.92	98.86	91.94
29	99.46	96.59	98.22
30	91.54	94.87	92.77
31	90.29	97.17	90.56
32	96.67	99.14	90.11
33	97.33	89.71	97.51
34	90.33	91.24	97.61
35	95.67	100.00	98.94
36	99.42	98.72	98.78
37	98.83	97.39	97.33
38	98.21	97.98	96.19
39	96.92	97.62	96.08
40	90.42	98.34	95.12

Participants	Low /u/	Mid /u/	High /u/
1	95.38	99.42	97.95
2	98.75	99.22	98.11
3	96.04	99.36	96.89
4	100.00	98.50	100.00
5	99.42	96.51	96.46
6	98.58	99.45	99.11
7	98.29	99.83	99.94
8	95.46	96.62	96.37
9	98.46	99.36	98.57
10	94.17	97.78	97.53
11	99.79	97.89	97.85
12	91.75	91.99	90.41
13	100.00	98.39	98.74
14	96.08	97.12	95.88
15	100.00	99.03	98.82
16	100.00	100.00	99.46
17	99.00	97.42	95.46
18	99.04	97.42	98.53
19	100.00	100.00	99.54
20	97.50	97.48	96.42
21	99.67	97.50	92.44
22	99.25	98.36	94.78
23	98.54	96.84	99.50
24	93.96	97.84	95.03
25	99.38	99.56	100.00
26	98.58	100.00	98.74
27	98.13	98.17	97.64
28	100.00	98.28	97.45
29	99.75	95.79	96.15
30	92.92	98.81	94.63
31	90.42	93.18	97.24
32	100.00	94.65	90.95
33	97.96	93.79	98.40
34	92.58	92.13	95.73
35	94.20	90.34	94.28
36	98.04	98.25	98.26
37	99.71	97.26	97.74
38	99.08	96.65	94.70
39	97.21	99.64	95.19
40	96.92	93.74	94.56

Oral non-words

Participants	Low /pava/	Mid /pava/	High /pava/
1	95.56	97.11	95.40
2	95.52	95.83	96.18
3	92.55	94.78	93.53
4	98.41	98.77	98.73
5	98.49	96.12	97.51
6	97.48	96.44	96.67
7	97.84	96.98	98.25
8	95.93	98.23	96.26
9	97.80	98.58	95.98
10	97.64	97.89	95.94
11	98.66	98.47	96.77
12	95.32	95.34	94.21
13	97.56	94.67	94.23
14	91.98	93.77	93.45
15	99.10	95.29	95.32
16	95.56	97.56	95.00
17	95.89	96.31	92.71
18	96.09	96.25	96.50
19	98.05	97.78	96.50
20	98.70	97.08	97.51
21	96.46	98.13	91.57
22	95.32	98.88	93.59
23	98.24	98.66	98.94
24	97.72	95.32	94.60
25	96.38	96.04	95.38
26	95.20	97.35	98.45
27	96.50	96.04	95.60
28	98.86	98.53	98.11
29	95.81	93.18	95.12
30	90.90	90.78	91.34
31	90.00	100.00	93.81
32	98.29	96.66	92.67
33	96.29	97.86	98.53
34	98.94	99.06	97.93
35	92.14	94.19	96.89
36	99.02	99.09	97.99
37	99.51	97.46	98.29
38	96.34	96.79	96.26
39	98.70	97.08	97.65
40	98.94	98.25	93.45

Participants	Low /piva/	Mid / piva /	High /piva /
1	96.82	99.25	95.78
2	97.35	96.84	96.00
3	97.76	94.43	94.21
4	97.11	98.94	99.30
5	98.62	98.58	97.99
6	97.92	99.36	98.47
7	100.00	99.41	98.17
8	95.52	98.93	98.03
9	96.38	95.77	95.86
10	97.80	96.31	99.24
11	98.53	96.52	96.30
12	97.23	95.83	95.62
13	96.05	94.94	94.90
14	93.57	93.15	90.82
15	97.11	96.17	95.82
16	93.69	95.48	93.69
17	95.85	93.90	93.73
18	100.00	97.97	98.71
19	100.00	97.51	97.33
20	97.43	94.65	95.32
21	97.03	98.88	92.41
22	93.61	99.12	96.20
23	98.98	99.06	98.29
24	100.00	99.25	98.27
25	98.25	96.04	95.70
26	97.43	99.84	99.46
27	93.53	92.61	95.20
28	96.70	93.82	92.29
29	90.68	96.23	94.56
30	90.57	86.89	90.99
31	90.01	98.64	90.78
32	92.59	96.63	93.45
33	94.91	95.75	98.43
34	95.24	98.88	98.53
35	95.77	98.34	100.00
36	98.57	98.85	97.51
37	99.76	93.63	96.93
38	96.66	95.16	95.70
39	98.25	95.93	98.27
40	98.58	96.81	98.20

Participants	Low /puva/	Mid /puva /	High /puva /
1	97.84	99.14	97.85
2	98.09	95.34	94.70
3	94.34	92.99	94.13
4	96.70	98.64	99.42
5	98.57	98.42	98.33
6	100.00	100.00	99.22
7	100.00	100.00	99.74
8	97.35	99.20	98.92
9	97.64	100.00	98.13
10	98.94	97.14	99.02
11	99.23	98.98	97.17
12	97.76	97.97	96.63
13	94.83	95.85	95.70
14	92.39	92.94	92.73
15	96.95	96.17	94.96
16	96.13	97.89	94.31
17	94.42	94.35	91.86
18	100.00	99.12	99.06
19	93.40	91.89	92.71
20	99.43	96.36	96.28
21	96.38	95.56	92.27
22	95.85	99.36	97.75
23	99.10	98.50	98.61
24	97.96	98.47	97.89
25	96.86	96.60	96.10
26	96.17	97.75	100.00
27	100.00	99.84	99.50
28	98.57	99.20	93.93
29	99.63	96.55	94.09
30	85.91	82.95	90.78
31	90.66	93.74	91.67
32	97.80	98.31	92.00
33	98.21	97.19	100.00
34	92.47	95.16	100.00
35	98.98	93.68	95.58
36	99.47	98.72	97.69
37	99.71	98.26	97.79
38	98.33	96.28	96.52
39	99.67	99.52	96.32
40	97.76	97.74	94.78

Nasal non-words

Participants	Low /mava/	Mid /mava/	High /mava/
1	98.04	97.64	95.57
2	94.64	94.95	94.26
3	91.44	91.66	93.74
4	98.60	98.75	98.70
5	96.56	97.82	97.33
6	99.60	98.38	97.85
7	98.28	99.65	98.34
8	95.56	98.11	97.93
9	97.48	97.08	97.19
10	100.00	97.90	98.98
11	96.92	96.41	95.49
12	89.96	93.23	92.54
13	93.72	94.66	93.72
14	89.04	90.73	90.13
15	94.80	93.92	95.15
16	95.40	95.30	94.99
17	92.48	92.46	91.74
18	97.48	98.51	98.78
19	100.00	97.16	97.61
20	98.88	97.56	97.23
21	90.60	94.85	90.27
22	98.92	99.39	97.83
23	99.24	99.55	99.20
24	98.40	97.34	97.85
25	97.92	98.65	99.12
26	96.36	97.40	98.70
27	91.28	92.03	92.38
28	99.28	99.28	98.98
29	95.52	94.63	96.07
30	91.52	83.00	93.78
31	100.00	97.74	93.56
32	97.76	95.06	91.34
33	97.04	102.39	99.60
34	97.20	95.99	96.11
35	93.76	92.19	92.12
36	93.16	96.81	97.81
37	99.56	98.65	91.72
38	98.88	93.12	97.19
39	98.64	97.69	97.79
40	97.24	95.41	98.11

Participants	Low /miva/	Mid /miva /	High /miva/
1	95.24	99.15	96.17
2	96.16	96.39	94.04
3	91.92	92.40	91.94
4	100.00	99.87	99.02
5	96.52	96.71	95.65
6	98.16	99.26	97.79
7	97.48	100.00	98.98
8	97.00	96.20	96.35
9	97.08	98.09	97.15
10	100.00	96.84	96.89
11	97.48	98.22	97.57
12	95.00	92.91	92.76
13	93.92	93.94	93.64
14	91.24	89.80	89.29
15	96.20	96.47	95.85
16	95.00	95.86	94.10
17	94.44	90.92	91.20
18	99.65	98.99	99.32
19	98.08	98.03	100.00
20	95.16	95.09	95.33
21	96.48	94.53	90.77
22	96.12	99.31	97.75
23	98.64	98.67	98.76
24	96.22	98.34	98.01
25	95.40	99.52	96.07
26	96.64	98.06	99.12
27	95.44	94.56	93.82
28	94.25	98.25	97.51
29	100.00	100.00	99.36
30	89.36	94.34	93.68
31	91.00	94.66	91.18
32	99.72	99.26	90.57
33	99.08	95.41	99.50
34	96.34	95.51	99.48
35	92.80	97.53	97.19
36	96.04	97.24	98.86
37	99.44	97.88	92.78
38	98.72	94.98	92.50
39	98.32	98.41	97.47
40	99.63	98.06	93.82

Participants	Low /muva/	Mid /muva/	High /muva/
1	97.84	97.85	97.11
2	93.96	94.24	94.32
3	91.76	93.04	91.14
4	97.12	99.23	97.77
5	97.48	95.33	94.79
6	97.44	96.79	96.71
7	98.24	73.73	98.92
8	96.48	97.26	97.09
9	93.48	93.81	92.70
10	100.00	98.11	98.34
11	97.92	97.16	97.51
12	90.72	92.78	94.40
13	94.80	95.75	95.35
14	90.88	91.34	90.45
15	95.08	94.42	94.60
16	97.04	97.95	97.89
17	91.16	92.64	91.01
18	99.88	98.38	98.48
19	96.54	97.50	99.76
20	100.00	98.57	97.49
21	100.00	96.10	90.21
22	95.00	98.30	99.32
23	99.52	99.58	99.40
24	99.76	99.47	98.52
25	95.56	95.96	93.90
26	99.04	99.60	99.70
27	96.60	95.83	96.33
28	98.25	98.59	97.03
29	97.64	96.71	95.33
30	90.90	91.23	89.29
31	100.00	95.01	89.03
32	100.00	98.94	90.05
33	97.24	94.18	98.92
34	100.00	97.85	97.11
35	98.52	99.81	100.00
36	96.52	97.10	97.47
37	99.72	96.07	93.08
38	97.48	94.37	95.45
39	97.84	97.18	95.45
40	85.91	94.56	93.90