ACOUSTIC PARAMETRS IN SINGING REGISTERS

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DEDICATED

TO

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CERTIFICATE

This is to certify that the dissertation entitled "ACOUSTIC PARAMETERS IN SINGING REGISTERS" has been prepared under my supervision and guidance.

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DECLARATION

This dissertation "ACOUSTIC PARAMETERS IN SINGING REGISTERS" is my own work done under the guidance of Mr. N.P. Nataraja, Prof. and Head of the Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any University for any Diploma or Degree.

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INTRODUCTION

Singing in the recent past has been studied by many scientific communities, besides musicologists, by laryngologists, acoustic engineers and psychologists. It is a mystery to many. More so,because of the different styles of music, the different terminologies have emanated from different schools of thought.

Hence, amongst the research carried out on music, a few constitute those in the field of 'REGISTERS'. The concept of register is understood to be a series of consecutive, similar vocal tones which the musically trained ear can differentiate at specific places from another adjoining series of likewise internally similar tones. There is little reference to the musical expression of the voice, to vocal registers in pedagogical literature. But these are often conditioned by feeling rather than fact and are loosely organised, ambiguous, opinionated and controversial; like ambiguous terminology subjectivity in teaching approaches are also apparent. The teacher observes the singing performance as the embodiment of certain esthetic values which in his opinion, cannot be dissociated from the vocal act. So, it is important for singers to know how and where he needs to do the adjustment for an efficient voice quality in the range. Throughout the song, evenness of vocal quality must be regulated by adjusting the registers in the correct places in the range and balancing the intensity and dynamics of sound. Hence, if the adjustment of vocal folds occurs abruptly,the singer will sound as if he has several different voices. Unskilled singers tend to stay in one register without trying to bridge the gap, because they are usually dissatisfied with the change in quality as they go from one to another and they are unable to equalise voice quality. A good teacher can correct this by showing the singer how to bridge the gaps in his transition of register, thus giving the impression of a single register with notes of equal quality but different pitch.

The innate musical ear and the trained vocal technique of the teacher of singing must of necessity remain the ultimate judges of the artistic applicability of scientific findings. Conversely, the voice scientist must be familiar with their psychoacoustic reasons for the established musical terminology. Otherwise, the two groups would continue to confuse each other. Combination of the professionally trained singer with the physicist or voice scientitist in one person would be ideal. Such fortunate combinations are not rare, such as in the person of F Winckel of Berlin (Singer and acoustician) or Godfrey E Arnold (Musicologist and Laryngologist).

Most of the studies have been carried out in Western music - classical style. Much needs to be explored into the avenues of Indian classical music, especially Karnatic music. Indian music is rich with it's heritage and content that there is wider scope for research. Studies on the same being scanty, those on registers are very limited. Hence, it is necessary for us to know the changes in the vocal mechanics with respect to singing of different notes in different registers. Experiments carried out with electroglottography, spectrograms, and the like, would throw more light on the same for better training strategies which could be adopted by the teachers of singing. Hence the need, for the current study.

In order to carry out this study, five female singers trained in Karnatic style of music will be chosen as subjects. They will be asked to phonate /a/ at different musical notes from lowest to highest in Raga Shankarabharana of Karnatic music. Meanwhile, electroglottographic signal and acoustic output will be recorded, analysed, subjected to statistical analysis and significance of difference for different parameters within and across registers will be noted.

The scientific analysis of voice register is of primary importance to professional voice instruction. The currently wide spread and which employs the vocal mechanism great above our voices, through the crude styles of so-called pop singing is another reason why the knowledge of vocal physiology should be propagated to wider circles. Otherwise, the early ruin of promising voices with the inherent danger to laryngeal health including the precipitation of cancer will continue to increase. Overall, we should preserve and promote the cultural heritage of artistic singing in the great traditions of the past.

The basic limitations of this study however, would be-

-the number of subjects-which is limited to only five.

-only electroglottographic and long term average spectral parameters are considered.

REVIEW OF LITERATURE

Music is the universal language of mankind

- Longfellow

Communication is a process by which we develop and share meaning. (Bradley 1974). Moreover,it is fascinating to note that the same vocal apparatus is used for speech as well as singing, but differently. Singing needs sophisticated use and precision of the speech apparatus.

"The act of speaking is a very specialised way of using the vocal mechanism. The act of singing is even moreso. Speaking and singing demand a combination and interaction of the mechanisms of respiration, phonation, resonance, and speech articulation". -Boone 1977.

Buteschn and Borechgrevink (1982) have contended that (i) in principle there is no difference between the sounds of speech and of singing, (ii)but, singing employs continous flow of vocal sound for consonants as against that in speech, (iii) singing also demands considerable resonance and articulation.

Luchsinger(1965) has found that in singing, vowels are prolonged, since they are especially suited to carry melody. It follows that the rhythmical, dynamic and melodic quallilties of speaking and singing differ only in regard to quantity and quality.

The rhythmic progression from sound to sound and use of vowels accounts for another difference. Bunch(1982) has quoted that singing makes some poor habits difficult or impossible and that a good speech habit involves good breathing habit, good control of subglottic pressure, proper shaping of supraglottic air spaces and active use of articulators.

Sundberg(1977) explains that there is a major difference between the way the formant frequencies are chosen in speech and the way they are chosen for singing.

Greene(1972) along with all the other characteristics mentioned above, contends that singing requires a complete mastery of techniques, the control not merely of the mechanics of singing but of fine shades of tome colour which defy analysis but convey the emotional message of the passage as compared to the act of speaking.

The main differences between speech and singing are hence,

a) Isochronism of vibration of vocal fold which is not much stressed in speech as while in singing.

b) More controlled breathing is seen in singing.

c) Greater vocal range is used in singing as compared to speech.

d) Vibrato, singer's formants are used by singers.

e) Vocal apparatus is under greater stress during speaking than speech.

Physiology of the singing voice

A melodious singing voice is a product of the intricate interaction amongst all the sub systems involved viz., respiration, phonation, resonance, articulation, prosody.

Comparison of respiration during quiet breathing, speaking and singing have shown that more air is used in singing as compared to quiet breathing. Alveolar pressure ranges from high negative pressures during inspiration to relatively high positive pressures during expiration while singing. It has also been found that the expiratory airflows are low in speech and singing, with higher inspiratory airflow associated with speech and much higher in singing. Further, Proctor(1980) states, that phonation, either for speech or singing doesnot demand high degree of pressure but delicacy of use of breathing mechanism.

Now coming to singing as such, the most efficient inspiration is the one that allows the desired amount of air to be drawn in rapidly and inconspicuosly without inducing undue muscular tension which might interfere with the functioning of the lips, tongue, jaw, pharynx and larynx.

By the assumption of appropriate posture, the well trained singer doesnot need to move the ribs very much. The diaphragm and other muscles act in a coordinated fashion to produce the desired effect. For controlled expiration during phonation, as well as for increasing the intensity or duration of sound , the voluntary muscular activity is called to play. These muscles tend to diminish the size of the thorax, in addition to the elastic recoil of the expanded lungs and enlarged rib cage and the erect posture gravity.

The support of tone is dependent upon the maintenance of subglottic pressure. A trained singer mayu develop fully as an artist when the muscular control has become an unconscious reflex and his concentration is devoted to intepretation. As

Winckel (1967) has stated "... breath is the liaison between the excitement of feeling and the physiological effects. The trained singer especially feels this, since he must form the tone on the breath as a modulating process- and his success-apart from the of mastering of the basic technique-is qualititatively dependent upon the requirements in the area of the soul".

The commonly accepted theory by which, the mechanism of phonation is explained is the myoelastic aerodynamic theory(van den Berg 1966). Accordingly, just before the singer's first note is sounded, the vocal folds begin to close; the breath then streams from the lungs and then pushes against the partially adducted folds, initiating the vibratory activity and allows puffs of air to escape and sound to be produced in response to the nerve impulses transmitted from the brain to the muscles of the larynx.

Here, it is necessary to know about the attack which tells us how the vocal folds close at the onset of sound, that is, how accurately and precisely they meet in the midline. This attack involves a precise co-ordination of the onset of sound with the oscillating movements or the rhythmic vibration and opening and closing of the folds.

Vennard (1967) in terms of physiological aspects of phonation has outlined five factors in laryngeal function;

1) motor power produced by the flow of air;
2) contraction of the lateral crico-arytenoids;
3) contraction of the inter-arytenoid muscles;
4) pitch which depends on the longitudinal tensions within and thickness of the vocal folds;
5) registration which comes from the relative activity or pasivity of vocalis muscles in the vocal folds.

In the various singing registers again, the vocal folds vibrate differently at low and high registers.

Titze(1979) has emphasized the importance of balance of muscular activity within the larynx as well as the role of opposing muscles in efficient vocal production. This balance maximises vocal efficiency in the dynamics of voice production.

A well trained singer has to go through a seemingly formidable and intimidating checklist. In order to pretune, he needs to conceive the pitch, quality and emotion desired, then take an adequate breath with no interfering tension, and attack the tone with clarity and precision. Throughout the song, the evenness of vocal quality needs to be regulated by adjusting the register in the correct places in the range and balancing the intensity and dynamics of sound in the proper emotional context.

Changes in the shape of the vocal tract will alter the resonances and inevitably pitch. Here, the formation or the strength of formant frequencies depends on the relationship of the vibrating frequency of the vocal folds to the resonant frequency of the pharynx and further depends on the amount of damping.

Sundberg(1977) explains an insertion of an extra formant between the normal third and fourth formants producing a peak seen in the spectrum of the sung vowel. This is considered the singer's formant. Hence there is unquestionable evidence, that in singing, the vocal tract should be free to respond dynamically by blending spacious areas and without constriction, and the tone should be properly focussed; and the singer who blends his efforts to these ends will almost certainly be rewarded with a noticeable improvement in vocal quality.

Further, proper articulation is important not only for anr and precise diction and meaning but also because of the effect it has on facial expresion. Good vocal production and efficient articulation go hand in hand.

With reference to the studies abroad, the Japanese grouped by Hirano(1981) have been concentrated on neuromuscular (EMG) findings related to singing. Sundberg (1974,1977,1979,1982,1994,1995), leading the Stockholm group aimed at the acoustic properties of singing. Bunch(1982), Large(1973,1975) constituting the Europeans and Americans have been interested in specific aspects like physiology, laryngeal behavior, aerodynamics and registers.

Indian music is enriched with the content and intricacy that it provides us with a lot of avenues for explanation. The variety of it's composition, though widely accepted and appreciated for years, has chawed attention of researchers only in the recent past. Bharatamunl has been one of the pioneers in musicology.

Hindusthani classical music was being researched at the Sangeeth Research Academy of Calcutta. A few more have been taken up by the Indian Institute of Technology branches in India. In addition, Gupta(1984), Sujatha(1987), Ragini(1989), Vijaya (1990) have also contributed to the immense, yet unrevealed treasure of Karnatic music.

However, most of the studies done on registers are on Western music. There have hardly been any study on Indian classical music and the venture towards registers is very limited. Hence this study aims at evaluating the differentiating or remarkedly shown acoustic factors in singing registers by means of electroglottography and long term average spectrum. The results may be utililsed in training the singers in better use of techniques like covering or voluntary control of formant tuning for better performances thereby making the world dance to the musical tunes of ecstacy.

Indian Music : Evolution

Music forms a necessary link in the great family of arts. It being the least material of all arts easily surpasses the other arts, and is hence called the 'Art of Arts'.

Music can be divided into folklore and classical music: where the former originated from the moods of the common man. Indian music rich with heritage had evolved with volumes of philosophy when most of the other nations had been enjoying only folk songs. Literature cites the contribution of Bhattacharya, 1978; Nijenhins, 1978; Sathyanarayana, 1982; Sambamurthy, 1982, 1983.

The Harappa and Mohenjadaro excavations, those of Indus Valley civilization provide evidences to show that singing and dancing was present in those days, the era prior to the Vedic period (2000 B.C. 600 A.D) which has been termed to be the origin of Indian music since then, to this day. Indian music has undergone various distinct transformations, including those of rhythm, melody into vedic hyms which marked the beginning of music. This vedic period is synonymous to samaganas (singing in unison), using only three notes -udatta (high pitched tone) anudatta (low pitched tone) and svarita (the middle of the two tones) which may be corresponding to the present rishabha (Re), nishadha (Ni) and shadaja (Sa). Thus chanting extended from single tone to two and then three tones- the musical pattern being called the arcika, gastrika and sarnika respectively.

Later on, the lower octave and the middle octaves were added making a pentatonic scale - a scale with five notes. The 'audva' Scale (five note) has fascinating etymological value, it's roots found in Sanskrit - 'uda' meaning to 'fly', which has a predominance of space element and is a manifestation of higher states of mind. A reference of seven vedic notes viz.,'prathama', 'dvitiya', 'thrithiya', 'chathurtha', 'mandra', atisurya', and 'krutha' corresponding to the present seven notes has also been found. Once Narada (100 A.D) and Bharata (200 A.D) gave the concept of 'shruthi' which is a smallest division of octave, the seven tones were divided into twenty two subdivisions giving an unique tonal structure to music.

This account of 'swaras' shruthis' grimas' 'mruchanas' has been also given by Bharata in his 'Natyashastra' or 'science' of 'Dramaturgy'. Now, the 'Raga system' was also introduced in 'Bharatdevi' of Matanga in around 400 A.D. Later, there was a shift from jatis to ragas. Literary works like 'Shakuntala' of Kalidasa also followed the rules of the environment laid down by Bharata.

By the 13th century, Indian culture along with music was influenced to a great extent by Mohammadan invasion. The Persian models like those of Amir Khusrau widened the gap between Karnatic and Hindusthani styles of Indian classical music.

A look at the intricate details - 'Shabdathathva' (eternal verbum) or 'shabdhabrahman' (supreme word) is the supreme reality in the philosophy of Sanskrit grammar. This is a highly subtle metaempirical principle which transcends all that possesses a pragmatic significance. The eternal verbum is a nature of consciousness, the best light for any realisation.

The eternal verbum is also conceived as 'para vak' and Abhinavagupta (1000 A.D) has described the way in which this gets transformed into three stages in physical form. The paravak assumes the first stage of 'pashyanti', the flash of insight or the principle of consciousness, when through its innate autonomous spontaneity, externalises itself. The next stage, is the madhyama' which is purely intellectual where the differentiations between the denotes and its denotations become slightly manifested. 'Vaikhari', is the last stage of distinct manifestation as difference between denotes and its denotation - the articulated word. Shankaran (1981) has provided scientific explanations to these concepts where he correlates the infra-structure of the subjective perception to 'para' in short, the time taken for this. The time taken for converting this into the motivating structure is pashyanti. The time taken through the conducting neuronal and muscular pathways is known as madyama and finally, the produced sound may show variable oscillations and effects on the surrounding objects which is known as 'vaikhari'.

Indian music is a powerful tool because it was born out of madhyama. Apishal (200 A.D) quotes that by alert restful relaxed inspiration the mind and body are one. A system of intact autoregulated phonation reflects intact bio-feedback mechanism as an out come of 'madhyama', the energized breath leading to phonation. Hence 'madhyama' -means a vehicle of breath which had a form of a sound pattern which is plastic and adaptable and hence scientifically ideal for vowelization speech or singing act. Hence, the input needs to be healthy for a healthy output. Nandikeshwara (1943) has shown how the cardinal vowels 'a', 'e', 'u' are intervowen with the musical notes 'sa' 'ri' 'ga', further stating that the unique postulate of intimacy, inter-relation,integration, all are born out of auto-regulated principle in phonation with madhyama.

According to Hindu Mythology, the seven notes emanated from animal cries -

'Sa' - sound produced by peacock at its highest rapture

'Ri' - sound of a cow calling her calf.

'Ga' - is the bleat of a goat.

'Ma' - is the cry of a heron.

'Pa' - is the call of the Indian nightingale.

'Da' - is the neigh of a horse

'Ni' - is the trumpeting of an elephant.

These 7 notes are synonymous to the 'Do,Re,Mi,Fa,So,La, Si/Ti' of Western classical music.

The basic component of music is 'sound' which is referred to as 'nada' by musicologists. The 'nada' gives rise to the 'shrutis' which can give rise to 'swaras' and 'swaras' to raga'. The basic notes or swaras are seven in number and are sung in 3 registers mainly i.e. seven notes are placed in an interval of one octave. The various permutations and combinations of these 'swaras' constitute different ragas. These notes correspond to Do Re Mi Fa So La Si/Ti of Western music which can be sung in the ascending as well as the descending order. While moving from one *Sa' to another 'Sa' in sets, a range . of one octave is covered i.e. the second 'Sa' is one octave higher than the first one. Similarly the lower 'Sa' is lower by one octave by 'Sa'. In musicologists basically five registers are considered 'anumandara', mandhra' 'madhya', Tara, Aritara. However, due to physiological limitations all the seven notes cannot be sung in all the three registers.

Definition :

Registration is observed in both speaking and singing. Moses (1954) defines a register as a physical acoustic event which results from an energetic change within muscular coordination of vocal cords.

Garcia (1805, 1906) a famous singing teacher and inventor of the 'Laryngoscope' (1854), first emphasized the laryngeal basis for vocal registers. He defined so:

By the word register, we mean a series of succeeding sounds of equal quality on a scale from low to high produced by the application of the same mechanical principle, the nature of which differs basically, from another series of succeeding sounds of equal quality produced by another mechanical principle (Garcia, 1840).

Hence borrowed from the organ terminology (Merkel, 1863), the designation 'register' has been used in the vocal sense from at least the thirteenth century (Duey, 1951). Garcia's and Nadoleczny's concept has been described in an "adjustment of the larynx which produces tones of a particular quality for particular demands of range, dynamics etc" (Vennard, 1967).

The number of registers and their names is a great confusion.

The early theorists were primarily 3 register oriented, but a two register system also had strong support. Three divisions of the voice called the chest voice, throat voice, head voice was given by John of Garland (cll93-cl270) and Jeroma of Malacia (cl250). This agreement was sustained in the sixteenth century sources also. In the 17th and 18th century 'belcanto' pedagogical literature, increasing attention is given to voice registers. Here, is found the beginning of the controversy over the number and names of registers.

The names given to vocal registers by the early theorists and teachers clearly reflect their origin in the subjective sensations of vibration and illusions of singers. These sensations are very useful feedback mechanism reassuring the singer that she/he is producing her/his voice in the manner prescribed by the singing teacher or by the manner by which previous success had been attained.

Mackwort-Young (953) suggest that the practice of placing falsetto between chest and head registers had been the custom of the physiologists of the first three-quarters of the nineteenth century. Nicoli-Scott Dicarlo (1994) studied the internal voice sensitivities in Opera Singers and concluded that (i) because, the position of the larynx is raised to varying extents due to variable degree of contraction of laryngeal elevators while singing in the upper register the vibratory energy is sensed in the craniofacial bone structures and hence singers perceive their voice as resonating in the head; (ii) these subjects impressions are at the root of the notions of placement of the voice and of the expressions chest voice, chest resonance head voice and head resonance, used by singers and singing teachers.

Stanley (1929), 1945) claimed that there were only two groups of muscles - the arytenoid and the cricothyroid, thereby only two registers - the lower and upper or falsetto. This over simplification is reflected in the two-register system of Wilcox (1935) "light mechanism" and "heavy mechanism".

Morner (196), a Swedish teacher and scientist reviewed the terminology dilemma on both sides of the Atlantic and suggested five basic registers as; deepest range, deep level, mid level, high level and highest range.

Typical speaking registers are pulse, modal and falsetto (Hollien, 1974) : typical singing registers are chest, head, and falsetto. In general, modal and chest register (the one that produces vibratory sensations in the trachea and sternum) are similar, both being the typical male quality in speech and low pitched singing. Because physiologic and acoustic descriptions of vocal registers has been incomplete, there has been much room for debate over the number of identifiable registers, their names, origins, and their pedagogical utility in voice training (Colton and Hollien, 1972).

Register boundaries :

Generally, a singer's singing range would include all the artistically usable tones (Luchsinger and Arnold, 1965), the range a singer is willing to use before the public.

Priessler (1939) on his systematic study of register limits within the singing range established that : (a) as the classification of the voice becomes lengthier, the register transition points are higher (b) the female transitions are an octave higher than the male transitions, the so-called 'octave phenomenon'.

Type	Upper and lower limits of the middle voice		
Bars	D (147 Hz)	-	D (294 Hz)
Baritone	E (165 Hz)	-	E (330 Hz)
Tenor	F (175 Hz)	-	F (349 Hz)
Contralto	D (294 Hz)	-	D (587 Hz)
Mezo-soprano	E (330 Hz)	-	E (659 Hz)
Soprano	F (349 Hz)	-	F (695 Hz)

Table 1: Average Transition tones for Voice Registers (Priessler, 1939)

Luchsinger and Arnold (1965) advise the following limits for the auxiliary registers : for the strohbass or churchbass register, which extends below the chest register of very deep bass voices (basso profouno) from F (87 Hz) as low as 40 or 35 Hz); for the flagelot or whistle register, which extends above the highest head tones of the coloratura soprano from D

(1175 Hz) or C (2093 Hz). There has been a variability of registers boundaries which is attributable to over-lapping (Garcia, 1855; Sokolowsky, 1912; Nadoledzny, 1923; Smith, 1957).

Many eminent scientists are working for exploring facts and fictions in the field of vocal research especially voice registers. But there has been discrepancy between the way the music teacher feels and the results compounded by the voice scientists. The terminology used to a large extent is ambiguous.

The vocal register has rather baffled many singers and teachers of singing and the most puzzling phenomenon is that some of them have never encountered the register in their singing performance. This supports that a register break is the voice may be the result of maladjustment rather than a natural physiologic action. But it has not be justified as yet.

Most register advocates also discuss remedial techniques for bridging or blending registers, mending the register break, or merging one register into the other. Covering has been one of the suggested techniques - Hertegard et al., (1990). Measurement of air volumes have shown that the same note sung by the same singer uses upto double the amount of air in covered voice than used in open singing, since greater tension of outer laryngal muscles as well as of the inner ones is involved, both of which tense the folds, the larynx is pulled downwards in covering while it rises and falls with the pitch in open singing.

Effect of parameters

The most common parameters of vocal analysis are pitch, intensity and quality. But the register in singing concerns itself mainly with an interruption of the pitch line. Victor (1973), Victor et al., (1973) have listed the determinants of vocal pitch as density, thickness, width and longitudinal tension i.e. those factors that affect the firmness or elasticity of the glottal margins. The degree of breath pressure directed against the. underside of the glottis is also considered a pitch factor and a chronaxic theory of timed nerve impulses is also advanced supporting this.

In a study of female chest and middle registers in singing, Large (1968) proposed the term 'isoparametric tones' to describe phonation of the same fundamental frequency, phonemic category and sound pressure level produced in different registers. With sonographic analysis, it was found that for a given pair of isoparametric tones, the female voice in chest register was characterized by greater energy in the higher partials while the female middle register had more energy in the fundamental.

Light thrown on the physiology of vocal register reveal the facts involving the laryngeal muscles and cartilages. Radiological findings do substantiate these results.

However, proponents of a psychological approach do not support the theory of registers. They trust that when a vocal utterance is motivated by communicative intent, the intonation will be directed unconsciously by the ear and the entire vocal instrument will be predisposed to correct action. Reflexes take over. They argue that the awareness of the need to control and cover certain pitches crates anxiety about higher tones and induces tensions that interfere with normal responses in the vocal tract. Inflections of speaking voice also acts as a guide to pitch movement.

Acoustical correlates of vocal register

Fundamental Frequency

The range of fundamental frequencies a vocal register occupies is its most frequency specified acoustic correlate.

Hollien, Dew and Beathy (1969) researched on the total phonational range (modal plus falsetto registers) of 332 males and 202 females and concluded that the mean phonational ranges for males was 38 semitones frequency Level (FL) and for-the females 37 semitones FL.

Colton (1969) also reports the total phonational ranges for 35 male non-singer subjects and eight male singer subjects and it was found that the mean phonational range of the non-singers was slightly smaller than the range reported by Hollien et al., (1969) which may be due to the differences in the method used for determining the ranges.

Colton (1969) further reported data on the ranges of modal and falsetto registers for nononsinger and singer subjects and found a phonational range of about 18 sometimes each for the former group in the modal and falsetto register. Hollien and Michel (1968) reported ranges of 19 and 14 semitones respectively. In all, it has been proved that for males, the vocal fry register occupies very low fundamental frequencies (5-60 Hz) whereas the falsetto register exhibits high fundamental frequencies (250-750 Hz). The phonational range of females in vocal fry in similar to the males the modal occupies 50-540 Hz whereas falsetto 500-1100 Hz. there may be some overlapping of Fo however.

Joseph and George (1962) studied the intralaryngeal relationships during pitch and intensity changes and found that pitch is independent of length of the vocal bands but not of the vertical position of larynx.

Harry and John (1968) in an attempt to study vocal fry as a phonational register tried to find out whether or not the range of Fo associated with vocal fry falls below the range of frequencies associated with modal register. They found that almost half the subjects exhibited no frequency overlap between these registers.

Vocal breaks from the modal to falsetto register was studied by Suec and Pesak (1994) in an untrained barytone. The breaks here were achieved by increasing the expired air flow. It was found that with increase in the modal frequency break intervals reduced and in the high tone region only the falsetto register could be produced.

Mean of ratios of fo across registers studied by Sujatha (1987) revealed that for males the ratio for low register differed significantly from that of mid and high; for females ratios of low and mid register differed significantly from that of high register.

Vocal Intensity :

Can intensity of phonations produced in one vocal register be greater or less than the intensity of phonations produced in another register has been a question. It may be - has been the answer according to some writers (Vennard, 1967; Ruth, 1963). But unfortunately comparisons of the vocal intensity between two vocal registers is difficult due to limited data. Colton (1969) reported data from different intensity conditions produced in modal and falsetto registers and at the same fundamental frequencies. English' singers and eight naive subjects produced their minimum most comfortable and maximum sustainable vocal intensity levels at three points within the common range of fundamental frequencies in both registers. It was found that, the maximum intensity in falsetto is about 15 dB less than for modal. Hence this led to the conclusion that intensity of phonations produced in the modal register can be greater than the intensities that accompany phonation in falsetto register.

Murry and Brown (1970) found that the intensities which accompanied vocal fry phonations are lower in overall magnitude than intensities of tones produced in the modal register.

The intralaryngeal relationships during pitch and intensity changes studied by Joseph and George (1962) revealed that there may be important sex differences in laryngeal functions to produce intensity changes.

Gauffin and Sandberg (1989) studied the voice source waveform and spectrum and concluded that for a given SPL change, the nonsinger did not increase his glottogram amplitude as much as the singer did. The non-singer changed his phonation towards pressed phonation when he increased the loudness of phonation.

Thus most studies indicates that the 2 registers which lie adjacent to the modal register exhibit lower magnitudes of vocal intensity. The circumstances, probably relates to differences of the aerodynamic and myoelastic factors which are present in the larynx while producing the register.

Spectrum :

The frequency composition of the glottal wave varies in the different registers. A number of partials are seen exhibiting significant energy in modal register phonation than in falsetto register phonations.

An glottal amplitude by time analyze also characterize this acoustic feature.

Long term average spectrum is said to provide information on the spectral distribution of the speech signal over a period of time. The signal represents the product of sound source and vocal tract transfer function.

The first person to propose that difference between phonations of trained and untrained singers can be done by spectral analysis was Bartholomew (1934). Current premise of vocal pedagogy and of literature is that register balance must remain stable regardless of any register changes in singing. Fields (1947), Burgin, 1975; Monahen, 1978; Miller, 1977. The sonagram of the trained singer showed a remarkable band of energy in 2.7 KHz this corresponding to the singers formant. A clear distinction was also apparent between (1) the vibrato rates of trained and untrained singer. (2) distribution of partials in phonation when sung with same intensity at the same pitch on same vowel. (3) There is a clear differentiation between frequency region which provides vowel definition (upto around 1.6 KHz) and region of singers formant.

No such energy concentration was seen in untrained singers.

So what is a singer's formant?-It is a high spectrum envelop peak near 2.8K Hz characteristic of vowel sounds produced in male Western opera and concert singing. In order to achieve this

1. The cross sectional area in the pharynx must be at least six times wider than that of the larynx tube opening. Here the larynx tube is acoustically mismatched with the rest of the vocal tract and an extra formant is added to the vocal tract transfer function.

2. The sinus Morgagni must be wide in relation to the rest of

the larynx tube. This may tune the frequency of the extra formant to a value between the frequencies of the third and fourth formants in normal speech.

3. The sinus piriformis must be wide. This reduces the frequency of the fifth formant to about 3 KHz.

X-ray studies of a raised and lowered larynx revealed that these conditions may be fulfilled when the larynx is lowered. Hence, the larynx lowering, typical of male professional singing, explains the "singing formant" and other formant frequency differences between normal speech and male professional singing.

Effective center frequencies and band widths of the first and second formants are estimated on basis of the variations in amplitude of radiated sound components as well as supraglottal and subglottal pressures accompanying the vibrato-related sweep of voice harmonics.

Hence 'singers formant' being an important acoustic characteristic of male operatic singing (Winckel, 1953; Sundberg, 1974; Hollien, 1983; Bloothofft and Plomp, 1986; Sundberg, 1987) is a resonatory phenomenon arising from a clustering of F3, F4, F5 (Sundber, 1974). This has a spectral value of approximately 15 dB above the corresponding spectral value. The movement of F4 closer towards F3 boosts the vocal tract spectrum in that region relative to Fl and F2 amplitudes Sundberg (1995).

Sundberg also proposes that the larynx lowering to wider the hypopharynx, laryngeal ventricle widening, might relate to enhancement of singers formant on the basis of a laryngal acoustic tube orientation. Yanagasiwa et al., suggests that there is more constriction for louder sounds.

According to Dmitriev and Kiselev (1979) the frequency of singers formant increases from lower voices to higher voices.

The parameters of singers formant included -

1. differences in body height and length of vocal tract.
2. individual differences in possibilities of changing the shape of vocal tract. eg. anatomical factors.
3. level of professional training - Sundberg, 1974; Dmitriev, 1979.

Nag, Banerjee, Sengupta and Dey (1990) examined the spectral pattern of vocal registration during singing. They found that when a singer exhibits a glissando through the whole range of his/her voice from lower limit to the whole upper limit, there occurs one or two breaks or failure in the continuous sound. During transition from one register to the other, the amplitude of the singing formant becomes exceedingly high as compared to the region where a particular register is utilized.

Raphael and Scherer(1987) also studied a training technique named 'call' by Arthur Lessac which emphasizes quality and physical sensation and de-emphasizes vowel specificity. Here,formant tuning comes into picture. This is used as a part of training by some actors, dramatists, singers. Sopranos utilize F1 formant tuning, so do actors. Titze et al. suggest that at high pitches tenors will enhance Fl but not tune it to a voicing partial. For some vowels eg. /i/ Fl increases and F2 reduces when spoken formants are compared with sung formants.

Spectrographic analysis of the high male range by Ametrano Jackson revealed that voices of children singers in all spectra have an energy between 2.5-4KHZ the formants being characteristic of a professionally trained voice. The speech of female voices show quality in all spectra especially between 2.5 - 4KHz, the formants characteristic of professional singers.

In vocal fry the glottal amplitude by time analysis yields a pulse which decays almost to zero before the next pulse arrives (Hollien and Landahl, 1968). In the modal register however, the volume velocity pulse looks very much like an area waveform reported by Timcke Von Leder and Moore (1958). In the modal phonations, generally, the glottal pulse has a rapid onset followed by a brief open period with a long period of closing and then a period of closed time. The closed time of the pulse may vary as a function of vocal intensity (Timcke Von Leden, Moore, 1958; Sonesson 1960). In falsetto waveform the glottis exhibits a simple opening and closing with seemingly a small period of closed time (Baisler (1950).

Overtone a specialized type of singing proposed by Manual Garcia (1847) identified by Wendler wherein bass singers sing two notes at the same time where there is also an interaction of closely spaced formants-Gerrit, Eldrid, Maricke, Jolanda, Luripea and Koen (1992).

Hence acoustically, the vocal fry, modal and falsetto registers tend to (1) occupy different ranges of fundamental frequency (2) exhibit different magnitudes of vocal intensity (3) show differences of the glottal wave shape which can result in a different frequency composition.

Physiological Correlates :

Evidence primarily suggests that in the modal register frequency change is mediated primarily by changes in the per unit mass of the vocal folds which offers a variable resistance to the airflow (Hollien and Moore, 1960). Moreover, both airflow and air pressure show a tendency to increase as frequency is increased (Hollien and Moore, 1969); Hollien, Damste and Murry, 1969). Intensity changes appear to be mediated by longer closed times of the vocal folds; thereby allowing more time for greater buildup of subglottic air pressure.

In falsetto register, there is little systematic change of vocal fold length and mass as frequency is changed. Both frequency and intensity seem to be regulated by aerodynamic factors.

The physiology of vocal fry is a doubt. But it seems that pitch is regulated by the mass of the folds and there seems to be little influence of airflow and air pressure in frequency regulation although one may speculate that these parameters may be important for control of voice quality.

INDIAN MUSIC-Terms

1. Karnatic music vs. Hindusthani music

As it is evident, Karnatic music (KM) confines itself to the southern areas of India, while Hindusthani music (HM) hails from the Northern regions. The basic material of music are the same but the way they are used or handled are different.

The major 3 functions of music, the raga, tala and prabandha are different in these two forms.

Regarding developing a raga, the alap in HM is casual, cursory, highly stylised and looked upon as proceeding from a scale having two segments-purvanga and uttaranga, and this alap strictly proceeds in terms of melody weaving around focal point in the lower and upper segments. In KM alapana is taken more seriously, being elaborate.

The variations in music follows a Gharana cr a particular school in HM. Gamaka is also employed in HM based on which raga of similar structure are differentiated. Gamakas in KM an operated as and when needed by the singer and does not have to be employed in a particular manner. Hence, it becomes easier for a KM singer to get more variation in expression, better aesthetic expression and more scope for creation expression.

In terms of tala structure KM talas are identified in terms of angas, organ component usually made up of laghu, drutha and laghudrutha. In H.M the tala precedes in terms of certain syllable knit together with each syllable having a duration known as theka which defines the tala. In HM talas are classified into slow middle and fast tempo, which is not seen in KM.

Prabandha also differs in HM and KM in terms of its literal content. In latter it has a theocentric modus, whereas in the former one, it is not always so.

2. Notes and Octaves :

The musical interval between an arbitrary chosen fundamental note and its first over tone was made to cover all known contemporary melody in terms of definite number of natural style or groups containing their sharps and flats and these were called swaras or notes. Swara does not only mean a pitch but it is an expression (Brihadeshi, 1963). These include -

No.	Swaras name- classical	Solfa letters Indian	Solfa letters Western
1	Shadja	sa	doh
2	Rishaba	ri	ray
3	Gandhara	ga	me
4	Madhyama	ma	fa
5	Panchama	pa	soh
6	Dhaivatha	dha	lah
7	Nishadha	ni	si or ti

Table 3: Table showing classical India notes and the Western counterparts in classical music

The notes that form the basic scale are called pure, (Shuddha) when covered by half tone are called Komal (Flat), notes raised by half a note called tiwra or sharp.

The swaras are not regarded as definite point in the scale but as a region in the scale.

No.	Swara name HM	Swara name KM	Symbol HM	Symbol KM	Western parallels
1	Shadja	Shadjam	sa	Sa	C
2	Komal Rishaba	Shudha Rishabham	re	Ril	C_b
3	Shudha Rishaba	Chatushruti Rishabham or Shudha Ghandari	Ri	R_2 Ga_1	D
4	Komal Gandhar	Sadharana Gandharam or Chatusruti rishabham	Ga	ga_2/ Ri_3	E_b
5	Shudha Gandhar	Antar Gandharam	Ga	ga_2/ Ri_4	E
6	Shudha Mandyam	Shudha Madhyama	Ma	Ma_1	F
7	Tivra Madhyam	Prati Madhyama	Ma	Ma_2	Fb
8	Pancham	Panchamam	Pa	Pa	G
9	Komal Daivat	Shuddha Dhaivatha	Dha	dha_1	Ab
10	Shubha Daivat	Chatushruthi Dhaivatam	Dha	dha_2/ N_1	A
11	Komal Nishad	Kaishiki Nishadam or Chatushruti Nisadam	ni	N_2	B_b
12	Shuddha Nishad	Kakali Nishadam	Ni	Ni_3	B

Table 3. Table showing classical notes in Karnatic music and their Hindusthani counterparts.

Raga and Alapana

Raga connotes personality of sound created by the progression of musical notes according to some accepted laws of melody. The laws governing the progression of swaras form the technique of alapana. About 15 elements make up a raga (Danielon, 1949; Swarupa, 1980). Only alapana among the different styles of singing will be considered especially in Raga Shankarabharan.

Raga Shankaabharana, a very popular raga is one of the 65 melakartha ragas, a raga with all 7 notes. Hence, it is called Sampoornaraga. It is one of the major ragas giving plenty of hope for alapana and elaboration and is also called the Janaka raga.

The arohana and awarohana of this raga include

sa ri2 ga3 mal pa dha2 ni3 sa

sa ni3 dha2 pa mal ga3 ri2 sa

with Chathushritha ri; Anthara ga, shudha ma,
Chathushritha dha; kakali Ni.

Alapa

Alapa has been instrumental in development and growth of Indian music and is an unique feature. It is a simple form of musical progression in which the rhythmic advance and determinate degree are two principles followed. The dominant notes of raga is always seen of special prominence and it uses only vowels for musical expressions and sometimes nasals.

METHODOLOGY

The purpose of the study was to find out the behaviour of vocal folds and the resultant acoustic output in the musical notes within and across registers in -Karnatic vocal music. To study this, it was decided to obtain electroglottographic and spectral parameters at different registers. It was hypothesized that there are no significant differences in the electroglottographic and spectral parameters for individual notes within as well as across registers.

Procedure

A. Subjects

Five female trained singers between the age group fifteen to thirty years were chosen for the study. They

a) had a minimum of five years of experience is classical music and/or

b) were post graduates in music and/or

c) had experience of classical performance in concerts or had given programs on radio.

B. RECORDING ENVIRONMENT

Recordings was carried out in a sound treated room with very low noise levels at the Speech Science Laboratory of the Department of Speech Sciences, at the All India Institute of Speech and Hearing, Mysore.

C. RECORDING PROCEDURE

(a) Recording of samples : The written version of the musical notes in ascending order as given below was provided to the subjects. This was to be sung in Raga Shankarabharana, (a sampoorna raga in Karnatic classical music, comprising of all seven notes-the details of which has been given previously) in the form of alap (phonating /a/) at a comfortable scale used by the singer and throughout the range between lowest note to the highest note. Each note had to be sustained for atleast two seconds at a loudness level comfortable to the singer for singing. The notes provides were as follows:

pa dha_2 ni_3 sa ri_2 ga_3 ma_1 pa dha_2 ni_3 sa ri_2 ga_3 ma_1 pa.

b. Instructions

Each subject was instructed as follows:

"You will require to sustain the alap of the following notes in Shankarabharana raga in a pitch scale comortable for you, with each note being sung for at least two seconds. You may maintain a comfortable loudness level while singing the notes".

These instructions were given for the simultaneous rcording of the same sample for electroglottogrphy and voice recording.

c) Recording

The electrodes of the laryngograph were placed on the thyroid alae. The position of these electrodes were adjusted to obtain clear laryngeal waveforms on the computer monitor.

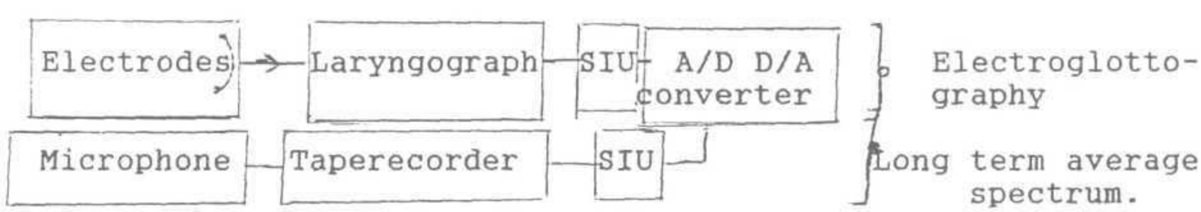


Fig.C:Block diagram of instrumental set-up used for simultaneous recording of sample for electlroglotto-graphy and voice for long term average spectrum analysis.

The output of the electroglottograph was converted into digital signal by feeding the signal through speech interface unit to the analog-digital and digital analog board on the mother board of the computer. The digitization was at the sampling rate of 8 KHz with 12 bit A/D board. These digitized signals were stored on the hard disk of the computer using 12 bit A-D/D-A convertor.

Simultaneously, the voice signal was recorded using a microphone placed approximately 6 inches from the mouth of the subject connected to Sony Tape Deck (FX 170) and a magnetic audio tape (Meltone Chronium oxide). This was used for further spectral analysis.

The recording was carried out using the record batch files provision in the computer. This provision entails for recording of individual voice sample (note) for a specified duration (two seconds each in this experiment). This provision was utilised, since it was required to analyse each note individually for its electroglottographic and spectral parameters. A total of fifteen such files were created for each subject for the same purpose. Two recordings were carried out for each subject. Repetition of recording was carried out when the experimenter and/or the singer was not satisfied.

d. Analysis

1) Electroglottography

Each laryngeal cycle was analysed at different points by moving the cursor to obtain steady, rising, falling points of the the wave wherever required,corresponding to the different phases of vocal fold vibrations. After measuring the duration between different points on each cycle of the glottograms, the different parameters of the laryngeal cycle viz. the opening time, open time, closing time, closed time, speed quotient, speed index, total period, closed phase, open phase, speed quotient,are calculated and the values are obtained for the same for each note. Ten cycles for each sample were used to calculate the parameters.

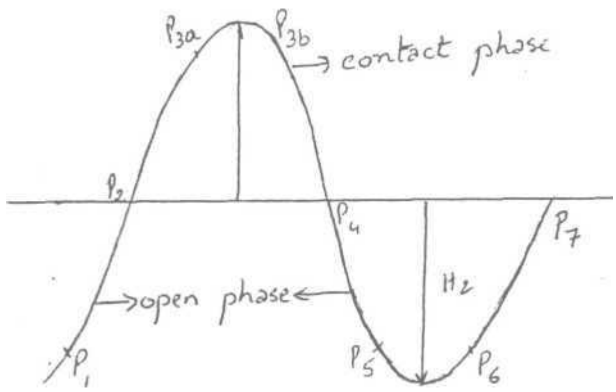


Fig. di - An Electroglottographic waveform.

P_{3a} - P_1 = closing period
P_{3b} - P_{3a} = closed period
P_5 - P_{3b} = open period
P_7 - P_2 = period of the vibratory cycle
P_4 - P_2 = B_1-Base of contact phase
P_7 - P_4 = B_2-Base of open phase
H_1 = height of contact phase
H_2 = height of open phase

$$\text{Open Quotient} = \frac{\text{Duration of open phase}}{\text{Duration of full phase}}$$

$$\text{Speed Quotient} = \frac{\text{Duration of opening phase}}{\text{Duration of closing phase}}$$

$$\text{Speed Index} = \frac{\text{Speed Quotient} - 1}{\text{Speed Quotient} + 1}$$

$$\text{S ratio} = \frac{\text{area of contact phase}}{\text{area of open phase}}$$

ii) Long term average spectrum

For carrying out spectral analysis,the program LTAS with autocorrelation was used. The taperecorded voice signals were fed to the A/D converter of the computer through the Speech Interface Unit (SIU), after making the necessary adjustments in the SIU to avoid distortion of the signal and digitised at a sampling rate of 16 KHz.

This was then used to obtain long term average spectrum. The spectral analysis was carried out for the frquency range 0-8 KHz with resolution ten and block duration of twenty. The spectral analysis thus obtained contained a graphic display of spectral patterns in the frequency range of 0-8KHz The data of energy of all the different points which were analysed by the computer included the

a) α-ratio $\frac{0-1}{1-5}$ KHz

b) β-ratio $\frac{0-2}{2-5}$ KHz

c) γ- ratio $\frac{0-1}{5-8}$ KHz

Thus for each subject at each register, the electroglottographic and long term average spectrum parameters were obtained. A set of seven notes has been considered to comprise one register. Hence, the lowest 'sa' to 'ni' comprises the 'mandhra sthayi'; the next seven notes, 'sa' to 'ni'-the 'madhya sthayi'; and the highest 'sa' to 'sa'-the 'tara sthayi'.

The obtained data was subjecteed to statistical analysis to test the null hypotheses proposed that there are no significant differences in the electroglottographic and the spectral parameters in the different notes in the different registers. The results are presented and discussed in the next chapter.

RESULTS AND DISCUSSION

The study aimed at finding out the difference in the vocal fold behavior and acoustic output at different notes and registers in Karnatic vocal music using electro-glottographic and long term average spectral parameters in differentiating the musical notes across and within registers 'mandhara sthayi', 'madhya sthayi' and 'tara sthayi', (low, mid and high pitches).

The electroglottographic parameters measured were 1) open timer, 2) closed time, 3) open quotient, 4) closing time, 5) opening time, 6) open phase, 7) closed phase, 8) speed quotient, 9) speed index, 10) total period; considering ten cycles in each note in the each register and the spectral parameters studied were a) α-ratio, b) β-ratio, c) γ-ratio, using the procedure described in the previous chapter.

The obtained data was subjected to statistical analysis using the non-parametric test (Wilcoxon test) and the significance of difference was obtained for each of the parameter relative to the notes within and across registers.

I Open Time

The results of statistical analysis to determine the significance of difference for the parameter 'open time' for different adjacent notes within the register (sa-ri, ri-ga, ga-ma,....) and corresponding notes (dha-dha, sa-sa, ri-ri,.....) are given in Table IA and Table IB respectively.

Study of Table IA and IB show that there are changes in the mean and standard values for the notes in the different registers, with a gradual decrease in the same, from mandhra to tara sthayi.

Within registers

Sl.No.	Notes	Mean	SD	Range	Significance
1	dha-m	1.03	0.45	0.87	A
2	ni-m	1.04	0.47	1.06	P
3	sa-M	0.81	0.33	0.73	P
4	ri-M	0.99	0.48	1.0	A
5	ga-M	0.83	0.69	1.67	A
6	ma-M	0.72	0.53	1.06	A
7	pa-M	0.56	0.41	1.07	P
8	dha-M	0.71	0.36	0.8	P
9	ni-M	0.53	0.24	0.62	P
10	sa-T	0.36	0.08	0.2	P
11	ri-T	0.47	0.23	0.53	P
12	ga-T	0.41	0.14	0.33	P
13	ma-T	0.27	0.09	0.13	A
14.	pa-T	0.71	0.36	0.8	P

A-not present; P-present; m-mandhra; M-madhya; T-tara

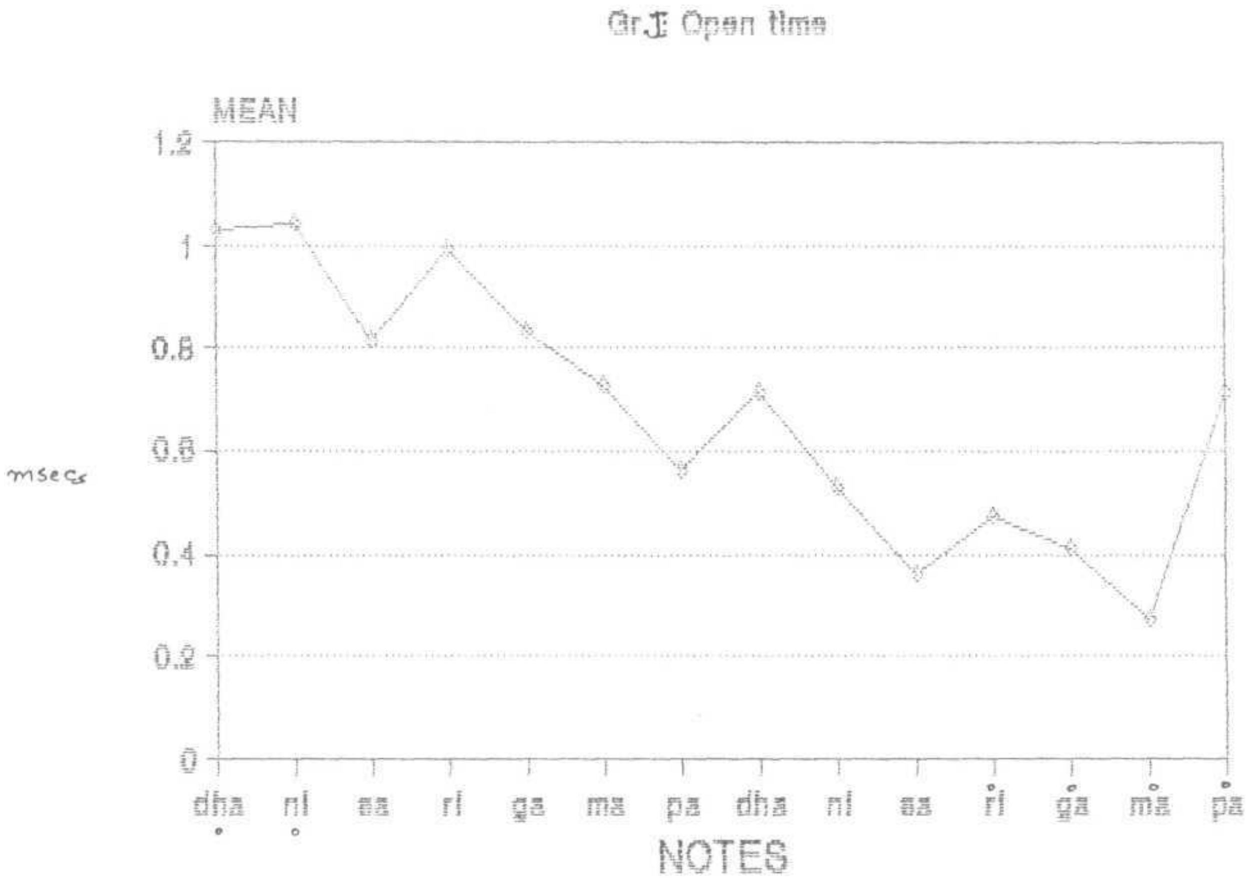
Table 1A : Table showing the results of comparison of different notes on 'open time' within three registers (mandhra, madhya and tara).

Considering dha and ni as belonging to mandhara register there has been no significant difference in terms of open time between dha and ni. This is because they belong to the low pitch range, and no significant shift in pitch has taken place from dha to ni. But a significant difference was obtained on a transition from ni to sa i.e., from mandhra to madhya sthayi, due to change in register mechanism. This is also observed in a transition from madhya to tara sthayi i.e., between ni to sa. Hence, it may be concluded that open time changes from register to register in Karnatic music.

There has been significant differences between adjacent notes within the register probably due to the change in open time of vocal folds being significant enough to bring about a perceiveable change in the fundamental frequency of the notes too. This is indicated in the Tablel A and Graph I.

In Shankarabharana Raga of Karnatic vocal music, the notes are not equally spaced on a temporal scale. eg. the difference between sa -ri2; ma_1-pa; pa-dha_2; dha2-ni_3; in terms of fundamental frequency does not occur at equal intervals on the equal ratio scale. And ri_2-ga_3, ga3-ma_1 are relatively closely spaced.

4.4



Notes of this raga are as enclosed in brackets with reference to the complete scale of notes : (Sa) ri_1 (ri_2) ga_2 (ga_3) (mal) ma2 (pa) dha_2 (dha_3) ni_2 (ni_3) sa

Hence, it has been noted that there have been no significant differences between ri_2-ga_3 and ga_3-ma_1 in the madhya register, probably due to vocal tract variations in different singers.

There are significant differences between the adjacent notes in the 'tara' register also, due to the higher pitch changes between adjacent notes in the higher tara register.

Hence, 'open time' on the whole, changes with notes and registers and thus substantiates as a factor to prove significance of difference within' registers.

Across registers

There have been significant differences between corresponding notes across registers due to the obvious change in the vocal fold mechanics for production of the same from low to higher pitches.

Hence again, open time acts as an indicator of significant change for identifying notes across register also.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	1.03	0.45	.87	P
	dha-M	0.71	0.36	0.8	
2	ni-m	1.04	0.47	1.06	P
	ni-M	0.53	0.24	0.62	
3	sa-M	0.81	0.33	0.73	P
	sa-T	0.36	0.08	0.2	
4	ri-M	0.99	0.48	1.0	P
	ri-T	0.47	0.23	0.53	
5	ga-M	0.83	0.69	1.67	P
	ga-T	0.41	0.14	0.33	
6	ma-M	0.72	0.53	1.06	P
	ma-T	0.27	0.09	0.13	
7	pa-M	0.56	0.41	1.07	P
	pa-T	0.71	0.36	0.8	

m-mandhra; M-madhya; T-tara; A-not present; P-present

Table IB: Table showing mean, standard deviation, range an significance of difference of different notes on 'Open Time' across registers.

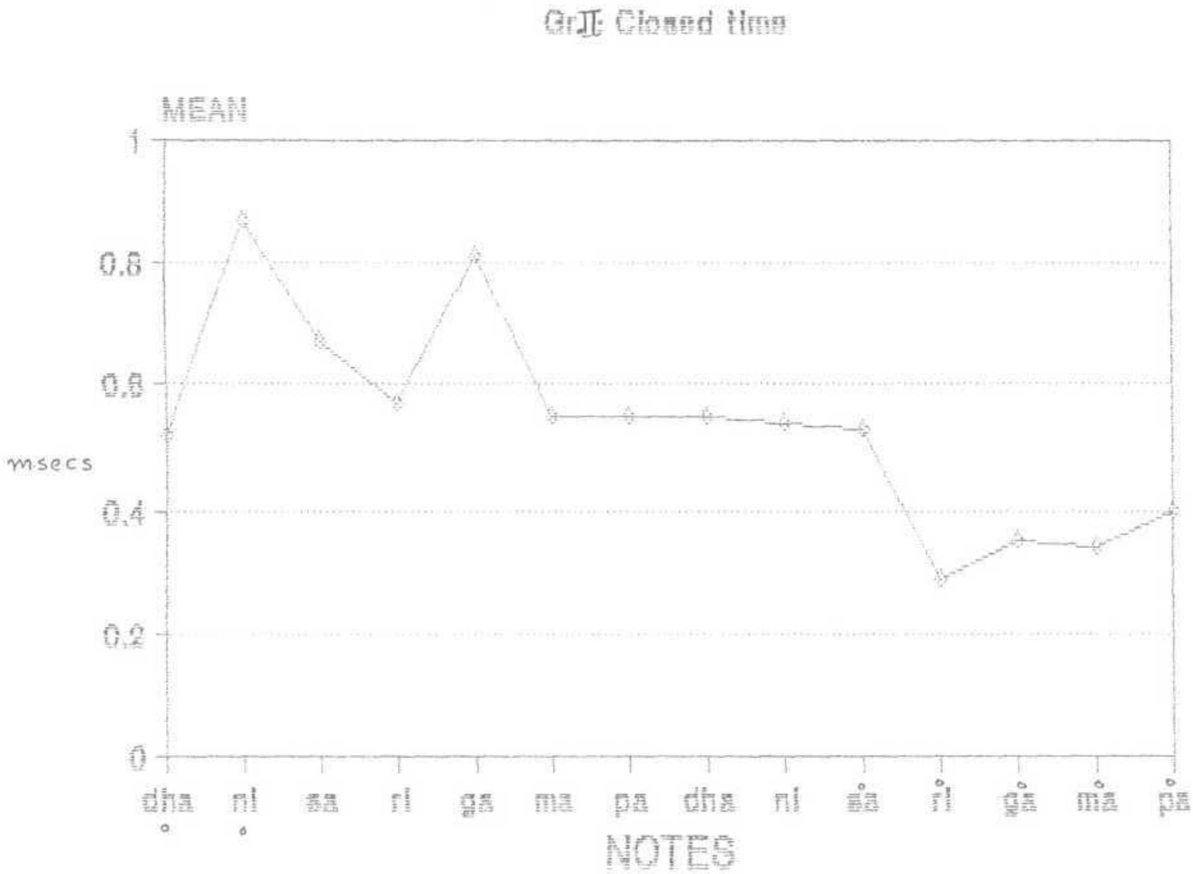
II Closed Time

SI.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	0.52	0.07	0.13	A
2	ni-m	0.87	0.84	2.06	A
3	sa-M	0.67	0.21	0.53	P
4	ri-M	0.57	0.27	0.73	P
5	ga-M	0.81	0.38	1.0	P
6	ma-M	0.55	0.3	0.8	A
7	pa-M	0.55	0.35	0.87	A
8	dha-M	0.55	0.18	0.4	P
9	ni-M	0.54	0.22	0.47	A
10	sa-T	0.53	0.13	0.33	P
11	ri-T	0.29	0.2	0.53	A
12	ga-T	0.35	0.2	0.53	A
13	ma-T	0.34	0.19	0.27	A
14	pa-T	0.4	0.1	0.14	

m-mandhra; M-madhya; T-tara; P-present; A-not present.

Table IIA: Table showing significance of difference for closed time within register.

No systematic changes in mean and standard deviation values of closed time are observed from Table IIA and Graph II.



In the 'mandhra sthayi', there is no significant difference observed in terms of the 'closed time' between the adjacent notes dha to ni. This may be due to the low pitch in voice.

In the 'madhya sthayi', there are significant differences in terms of closed time' between all adjacent notes, except between ma and pa, and pa and dha. However, closed time does not change significantly between adjacent notes in the tara sthayi.

Moreover, there is no significant difference in terms of 'closed time' between ni to sa- a transition from 'mandhra' to 'madhya' and 'madhya' to 'tara' sthayis, i.e., no significant change in 'closed time' is noticed when there is a shift in register.

Across Registers

Table IIB shows no systematically significant differences in 'closed time' across the registers. However, statistically significant differences have been observed between corresponding notes ni, sa, ri, ga; across 'mandhra' and 'madhya' for ni and 'madhya' to 'tara' for the remeaining three notes. This is due to the corresponding changes in the 'closed time' of vocal folds over a period of one octave. However, there are no significant differences for the notes ma, pa between 'madhya' to 'tara' sthayis.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-nt dha-M	0.52 0.55	0.07 0.18	0.13 0.4	A
2	ni-m ni-M	0.87 0.54	0.84 0.22	2.06 0.47	P
3	sa-M sa-T	0.67 0.53	0.21 0.13	0.53 0.33	P
4	ri-M ri-T	0.57 0.29	0.27 0.2	0.73 0.53	P
5	ga-M ga-T	0.81 0.35	0.38 0.2	1.0 0.53	P
6	ma-M ma-T	0.55 0.34	0.3 0.19	0.8 0.27	A
7	pa-M pa-T	0.55 0.4	0.35 0.1	0.87 0.14	A

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table II B: Table showing significance of difference for closed time across registers for corresponding notes.

III Opening Time

Within Registers

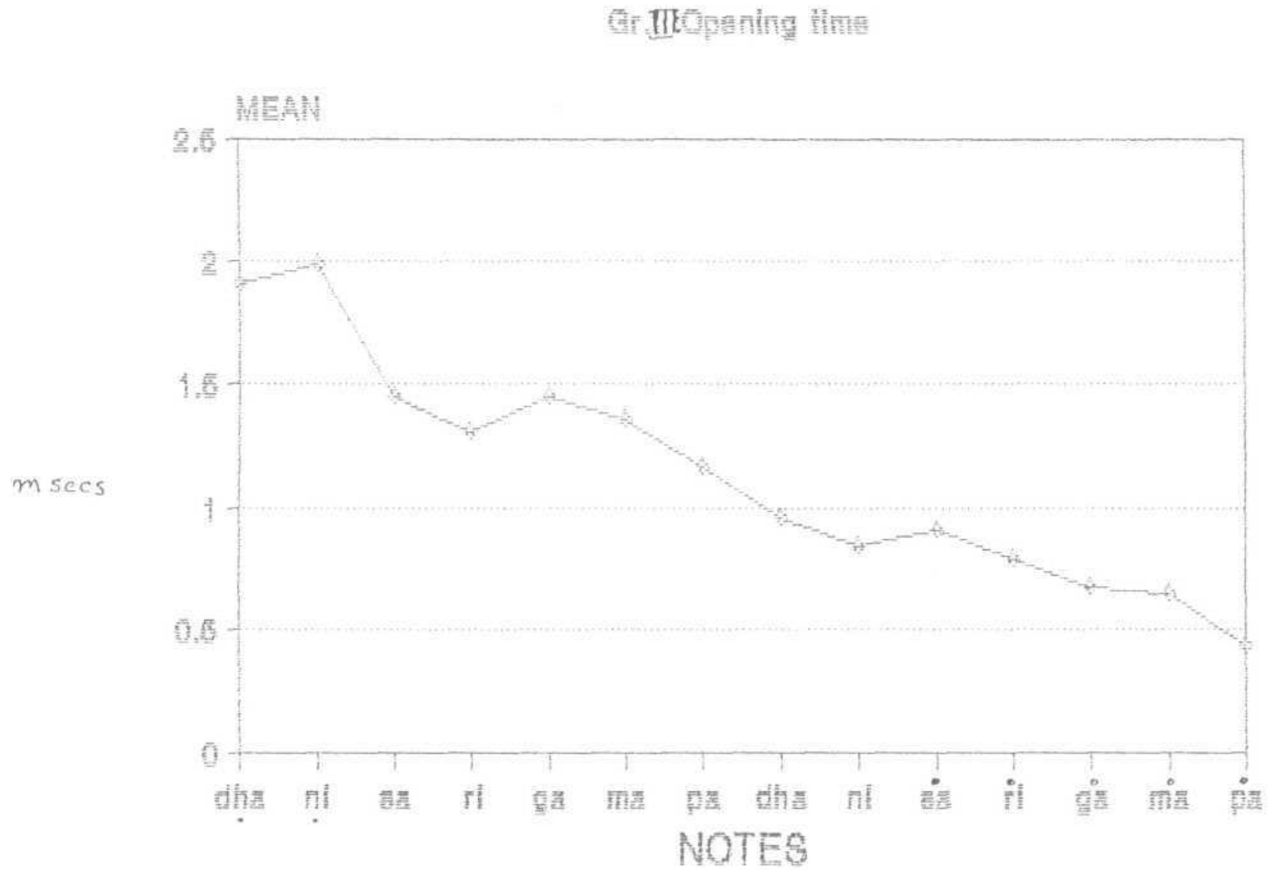
An examination of Table IIIA reveals a fairly consistant decrease in 'opening time' as the pitch increases from 'mandhra' to 'madhya' and then *tara' sthayis. However, in the 'mandhra sthayi', there is no significant difference between notes dha to ni, in terms of 'opening time'; probably due to not much change in pitch. This is also indicated in Graph III.

SI.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	1.91	0.62	1.13	A
2	ni-m	1.99	0.54	1.26	P
3	sa-M	1.45	0.44	1.14	P
4	ri-M	1.31	0.61	1.46	P
5	ga-M	1.45	0.41	1.13	P
6	ma-M	1.36	0.56	1.4	P
7	pa-M	1.17	0.5	1.26	P
8	dha-M	0.96	0.39	0.86	P
9	ni-M	0.8	0.23	0.6	A
10	sa-T	0.91	0.36	0.93	P
11	ri-T	0.79	0.2	0.53	P
12	ga-T	0.67	0.25	0.67	A
13	ma-T	0.6	0.05	0.07	P
14	pa-t	0.44	0.0	0.0	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table IIIA: Table showing significance of difference for opening time within registers between adjacent notes.

In the 'madhya sthayi', there are significant differences between all the adjacent notes in terms of 'opening time'.



In the 'tara sthayi', there is no significant difference between ga and ma, while the other notes show significant differences. This may be attributed to the variation between the subjects at high frequency vibration of the vocal folds in the 'tara sthayi'.

A significant difference is seen at the register transition point from 'mandhra' to 'madhya' sthayis in terms of "opening time'. However, there is no significant difference at the transition points of ni to sa; i.e., from "madhya[1] to 'tara' sthayis again due to no drastic change in pitch, which is evident from the study of Table IIIA.

Across Registers

There are statistically significant differences between corresponding notes across "mandhra' to "madhya' and "madhya[1] to 'tara' sthayis when "opening time' for the notes are analysed, in terms of mean values, range and standard deviation values with greater values for lower notes as compared to the corresponding higher notes, which are presented in Table-IIIB.

SI. No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	1.91 0.96	0.62 0.39	1.13 0.86	A
2	ni-m ni-M	1.99 0.8	0.54 0.23	1.26 0.6	P
3	sa-M sa-T	1.45 0.91	0.44 0.36	1.14 0.93	P
4	ri-M ri-T	1.31 0.79	0.61 0.2	1.46 0.93	P
5.	ga-M ga-T	1.45 0.67	0.41 0.25	1.13 0.67	p
6	ma-M ma-T	1.36 0.6	0.56 0.05	1.4 0.07	P
.7	pa-M pa-T	1.17 0.44	0.5 0.0	1.26 0.0	P

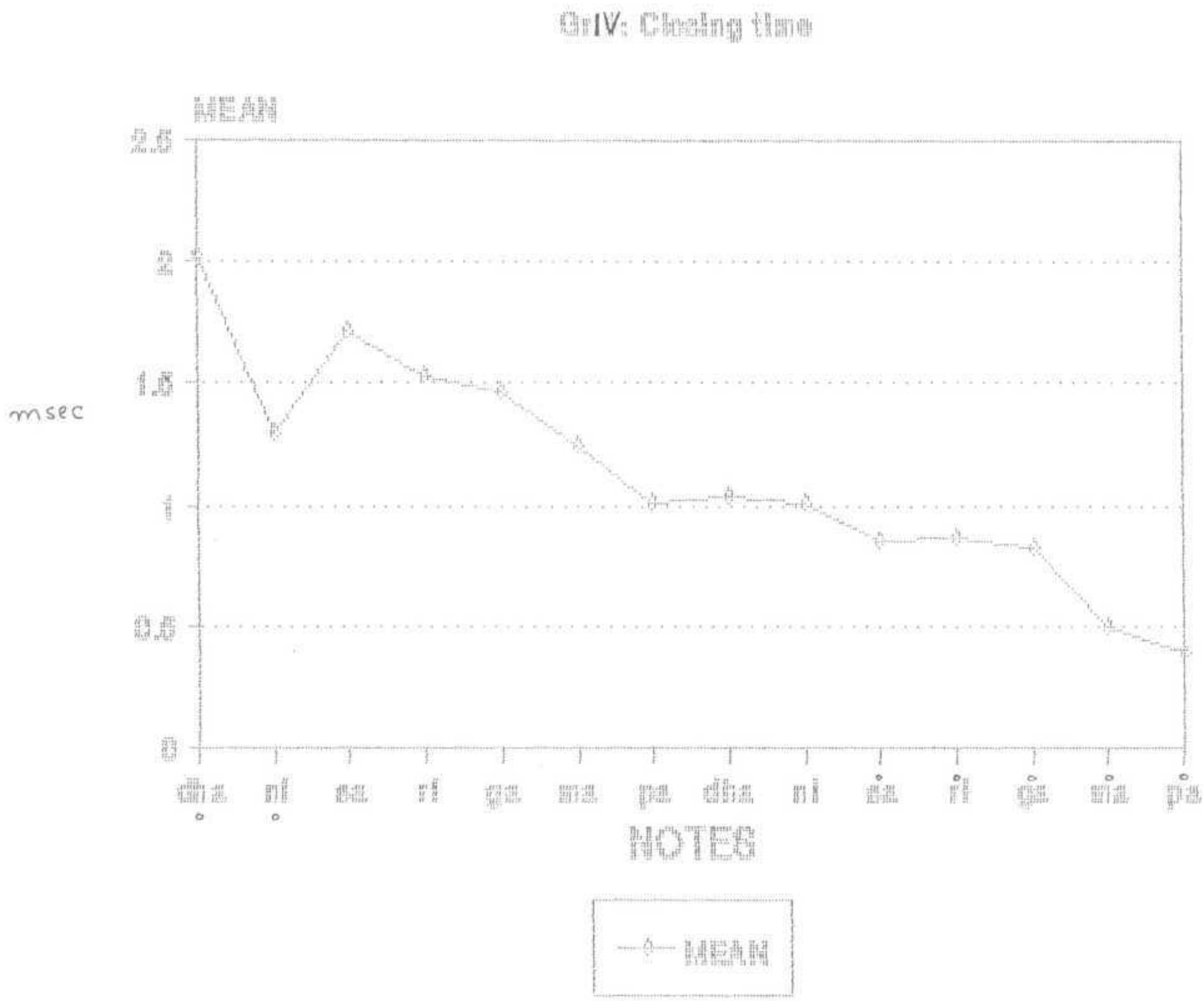
m-mandhra; M-madhya; T-tara; P-present; A-not present

Table IIIB: Table of results showing significance of difference for opening time between corresponding notes across registers.

IV Closing Time

Within registers

In 'mandhra' sthayi, there is a statistically significant difference among the adjacent notes for 'closing time' which can be observed from Table IVA and Graph IV.



Within the 'madhya' sthayi, there are statistically significant differences only between adjacent notes sa to ri; ma to pa. There are no significant differences noted between ri to ga; ga to ma; pa to dha; dha to ni, probably due to individual variation between subjects.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	2.03	0.83	1.46	
					P
2	ni-m	1.3	0.66	1.6	
					P
3	sa-M	1.72	0.38	.94	
					P
4	ri-M	1.53	0.23	0.6	
					P
5	ga-M	1.47	0.71	1.66	
					A
6	ma-M	1.25	0.34	0.8	
					A
7	pa-M	1.01	0.46	1.2	
					P
8	dha-M	1.04	0.39	0.93	
					A
9	ni-M	1.01	0.53	1.4	
					A
10	sa-M	0.85	0.3	0.8	
					A
11	ri-M	0.87	0.3	1.0	
					A
12	ga-M	0.83	0.37	0.93	
					A
13	ma-M	0.5	0.42	0.6	
					A
14	pa-M	0.4	0.0	0.0	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table IVA: Table showing significance of difference between adjacent notes in registers for closing time.

In the 'tara' sthayi, there is no significant difference between adjacent notes due to no marked change in 'closing time' at high pitch.

However, there is a significant change in 'closing time' between 'mandhra' to 'madhya' and 'madhya' to 'tara' sthayi due to the adjustment in vocal fold vibration made by the subjects during the transition from one register to the next register.

Across registers

Sl.NO.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	2.03 1.04	0.83 0.39	1.46 0.93	P
2	ni-m ni-M	1.3 1.01	0.66 0.53	1.6 1.4	P
3	sa-M sa-T	1.72 0.83	0.38 0.3	0.94 0.8	P
4	ri-M ri-T	1.53 0.87	0.23 0.3	0.6 1.0	P
5	ga-M ga-T	1.47 0.83	0.71 0.37	1.66 0.93	P
6	ma-M ma-T	1.25 0.5	0.34 0.42	0.8 0.6	P
7	pa-M pa-T	1.01 0.4	0.46 0.0	1.2 0.0	P

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table IV B: Table showing significance of difference between corresponding notes for closing time across registers.

Across 'madhya', 'mandhra', 'tara' sthayis, there have been significant differences statistically for 'closing time' in terms of mean, standard deviation as well as range values among corresponding notes.

V Open Phase

Within registers

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	0.6	0.1	0.14	P
2	ni-m	0.64	0.05	0.07	P
3	sa-M	0.88	0.22	0.53	P
4	ri-M	0.97	0.2	0.47	P
5	ga-M	1.01	0.27	0.73	A
6	ma-M	1.08	0.34	0.8	A
7	pa-M	1.23	0.51	1.34	A
8	dha-M	1.32	0.39	1.06	P
9	ni-M	1.39	0.42	1.06	A
10	sa-T	1.51	0.58	1.13	A
11	ri-T	1.63	0.68	1.47	P
12	ga-T	1.8	0.52	1.27	P
13	ma-T	1.91	1.07	2.13	A
14	pa-T	2.42	0.28	0.67	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VA: Table showing significance of difference between adjacent notes within the registers for open phase

In the 'mandhra' sthayi, there is a significant difference between adjacent notes accounted for a combined effect of the 'opening' and 'closing' time being significant at low pitches for 'open phase'.

In the 'madhya' sthayi, there are significant differences between notes sa to ri; ri to ga; dha to ni; but not between notes ga to ma; ma to pa; pa to dha; the latter may be owing to no marked shift in pitch between the two notes.

In the 'tara' sthayi again, there are no significant differences between ri to ga; ga to ma; but not for sa to ri; and ma to pa; as the changes in pitch may be a gradual one.

At the transition point from 'mandhra' to 'madhya' sthayis there is a significant difference due to the significant effect of the 'opening time'. But, there is no significant difference at the transition point from ni to sa from 'madhya' to 'tara' sthayi due to the net effect of the 'opening time' and 'closing time' of the vocal fold vibration again. This is indicated in Table VA and Graph V.

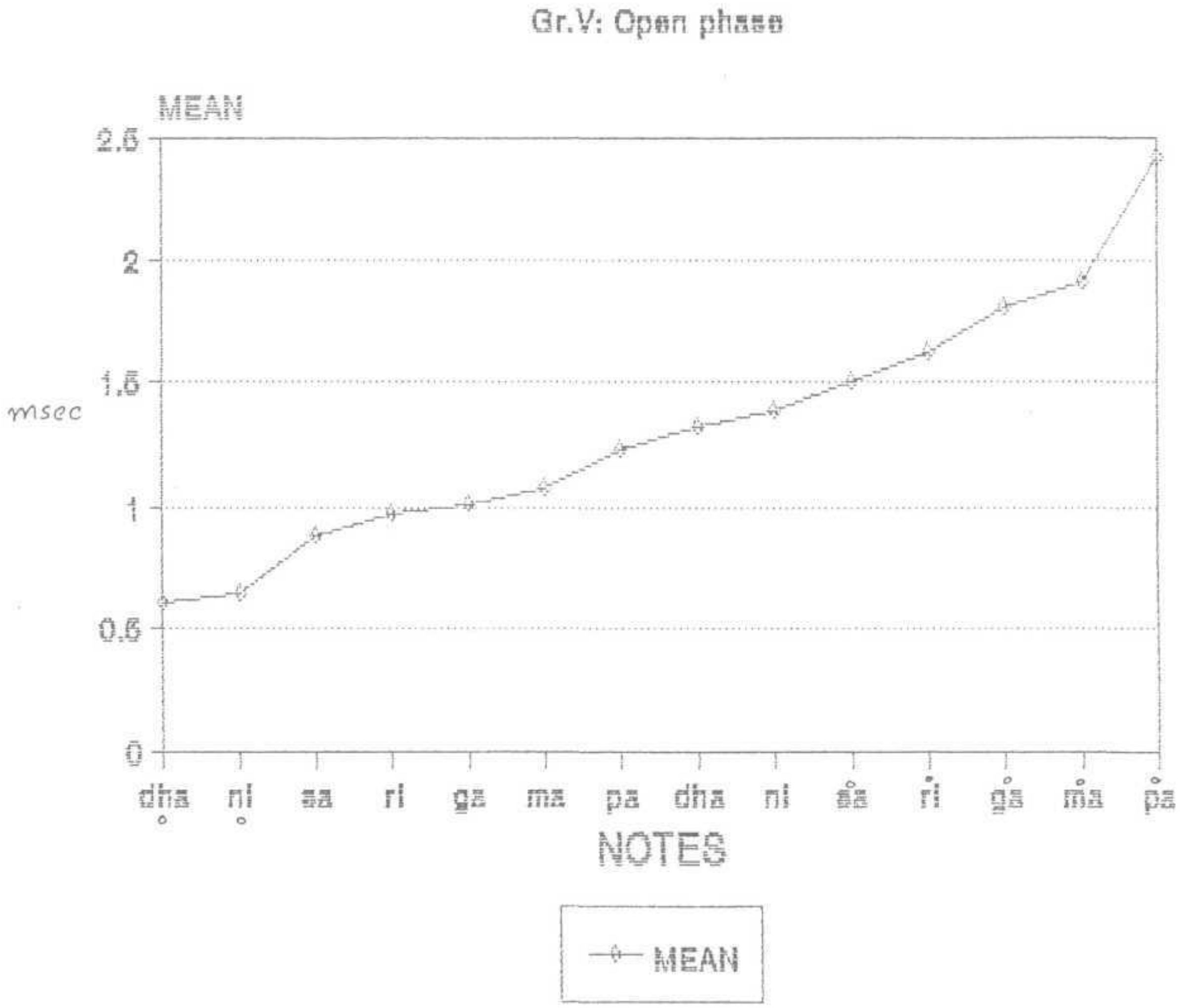
Across registers

SI.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	0.6 1.32	0.1 0.39	0.14 1.06	P
2	ni-m ni-M	0.64 1.39	0.05 0.42	0.07 1.06	P
3	sa-M sa-T	0.88 1.51	0.22 0.58	0.53 1.13	P
4	ri-M ri-T	0.97 1.63	0.2 0.68	0.47 1.47	P
5	ga-M ga-T	1.01 1.8	0.27 0.52	0.73 1.27	P
6	ma-M ma-T	1.08 1.91	0.34 1.07	0.8 2.13	P
7	pa-M pa-T	1.23 2.42	0.51 0.28	1.34 0.67	P

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VB: Table showing significance of difference among corresponding notes across registers for open phase.

There is a significant differences among corresponding notes across 'mandhra', 'madhya' and 'tara' sthayis due to an obvious change in the 'open phase' period of the cycle from low to high frequencies of glottal vibration.



VI Closed Phase

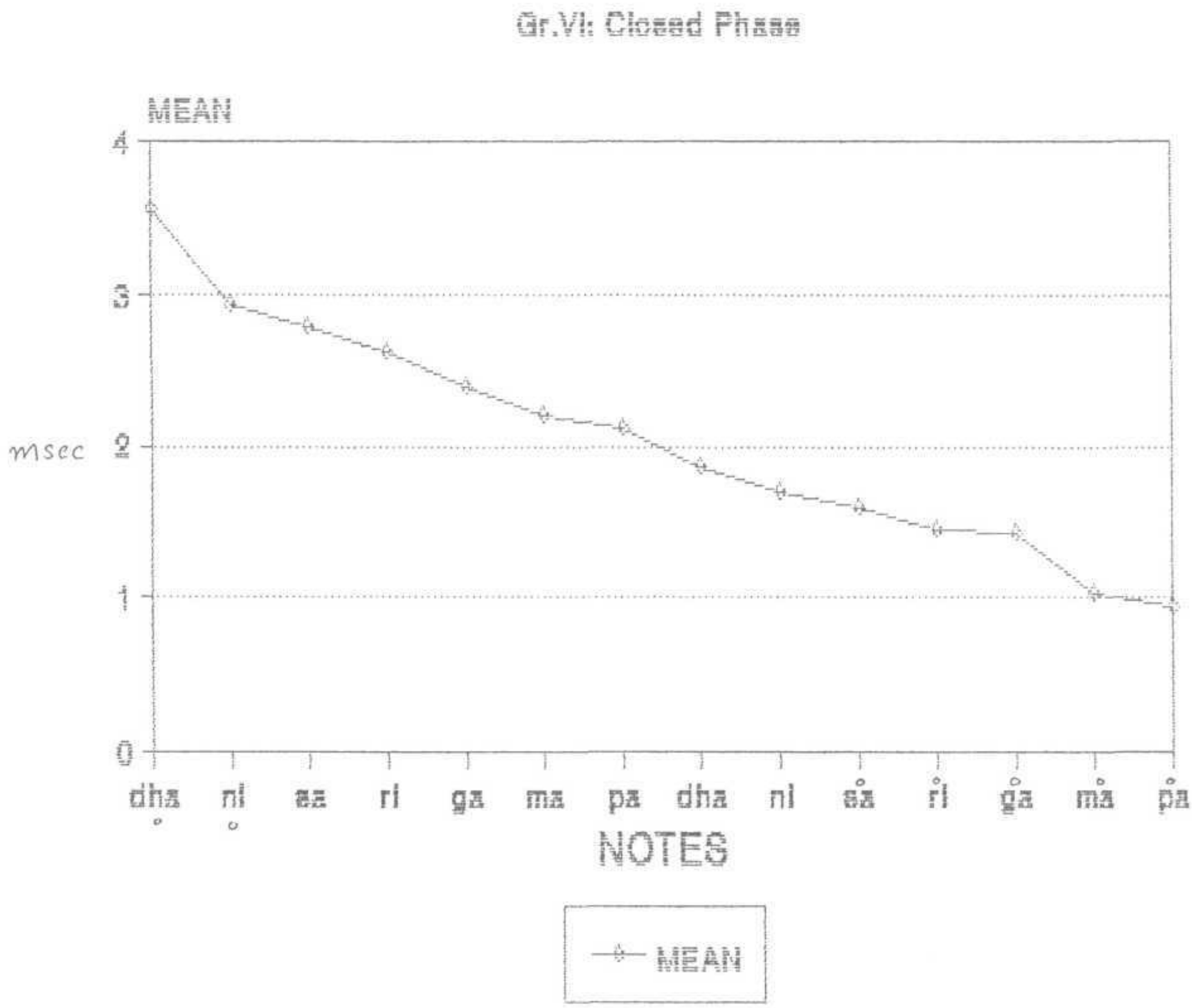
Within registers

Within the 'mandhra' sthayi there are no significant differences between adjacent notes due to low pitch and as the change is a gradual one as one can make out from Table VIA and Graph VI.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	3.55	1.35	2.33	A
2	ni-m	2.93	1.36	3.73	P
3	sa-M	2.79	0.41	0.94	P
4	ri-M	2.61	0.02	2.6	P
5	ga-M	2.39	0.78	2.0	A
6	ma-M	2.21	0.84	2.06	A
7	pa-M	2.11	0.55	1.46	P
8	dha-M	1.87	0.62	1.53	P
9	ni-M	1.69	0.67	1.73	P
10	sa-T	1.6	1.41	1.07	P
11	ri-T	1.45	0.66	1.07	P
12	ga-T	1.43	0.46	1.2	P
13	ma-T	1.03	0.23	0.33	A
14	pa-T	0.94	0.09	0.13	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VIA: Table of significance values for closed phase of glottal cycle for adjacent notes within registers.



In the 'madhya' sthayi there are significant difference indicated statistically, between notes sa to ri; ri to ga; pa to dha; dha to ni, but not between the notes ga to ma; ma to pa; probably due to the less marked and gradual change in pitch for the latter notes in Shankarabharana raga.

In 'tara' sthayi, there are significant differences between sa to ri; ri to ga; and ga to ma, due to the high pitch. But, this difference is not observed between ma to pa ma-pa, which could be accounted for the subject differences.

However, there are a significant differnce at the transition points from 'mandhra' to 'madhya' (ni-sa) sthayi and from 'mandhra' to 'tara' sthayis.

Across registers

There are statistically significant differences between corresponding notes across registers (mandhra to madhya; madhya to tara). This is due to the obvious change in pitch that takes place across registers.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	3.55 1.87	1.35 0.62	2.33 1.53	P
2	ni-m ni-M	2.93 1.69	1.36 0.67	3.73 1.73	P
3	sa-M sa-T	2.79 1.6	0.41 1.41	0.94 1.07	P
4	ri-M ri-T	2.61 1.45	0.62 0.66	1.6 1.07	P
5	ga-M ga-T	2.39 1.43	0.78 0.46	2.0 1.2	P
6	ma-M ma-T	2.21 1.03	0.84 0.23	2.06 0.33	P
7	pa-M pa-T	2.11 0.94	0.55 0.09	1.46 0.13	P

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VIB: Table showing significance of difference for closed phase across registers for corresponding notes

VII Open Quotient

Within registers

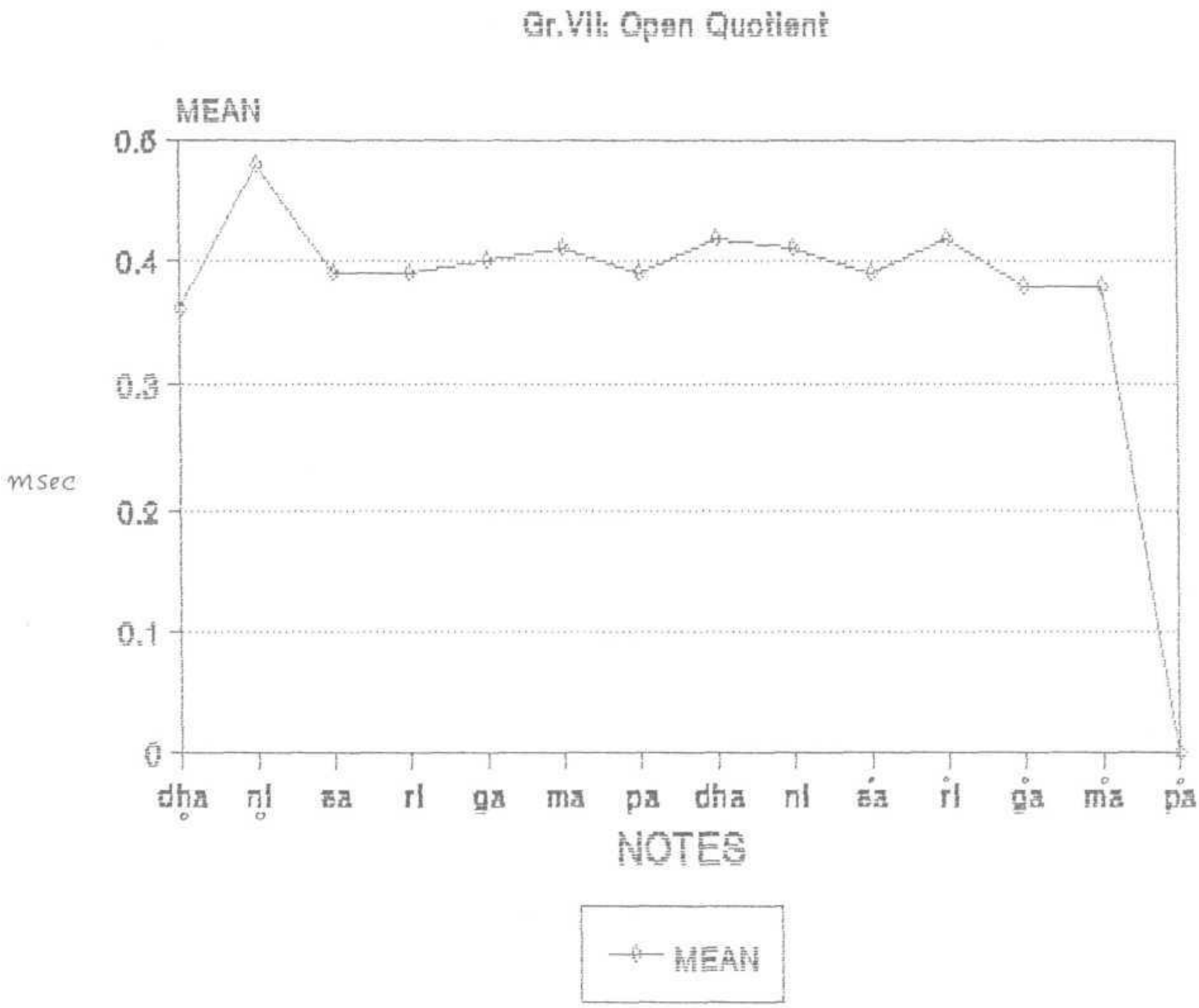
In 'mandhra' sthayi, there is a significant difference between dha to ni, the adjacent notes. However, in 'madhya' sthayi, there are significant differences betweeen ri to ga; pa to dha; but no significant differences between sa to ri; ga to ma; ma to pa; dha to ni. But again, in the 'tara' sthayi, there are significant differences between all the adjacent notes except for ma to pa.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	0.36	0.22	0.43	P
2	ni-m	0.48	0.14	0.35	P
3	sa-M	0.39	0.08	0.22	A
4	ri-M	0.39	0.12	0.21	P
5	ga-M	0.4	0.11	0.27	A
6	ma-M	0.41	0.17	0.37	A
7	pa-M	0.39	0.1	0.26	P
8	dha-M	0.42	0.13	0.33	A
9	ni-M	0.41	0.14	0.56	P
10	sa-T	0.39	0.06	0.17	P
11	ri-T	0.42	0.11	0.25	P
12	ga-T	0.38	0.07	0.17	P
13	ma-T	0.38	0.07	0.1	A
14	pa-T	data not sufficient			

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VIIA: Table showing signnficance of difference for adjacent notes within registers for open quotient

However, there are significant differences at the transition points from 'mandhra' to 'madhya' and 'madhya' to 'tara' sthayi as marked changes in vocal fold vibration occurs at these points. This is indicated in Table VIIA as well as Graph VII.



Across registers

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	0.36 0.42	0.22 0.13	0.43 0.33	A
2	ni-m ni-M	0.48 0.41	0.14 0.14	0.35 0.56	P
3	sa-M sa-T	0.39 0.39	0.08 0.06	0.22 0.17	A
4	ri-M ri-T	0.39 0.42	0.12 0.11	0.21 0.25	P
5	ga-M ga-T	0.4 0.38	0.11 0.07	0.27 0.17	A
6	ma-M ma-T	0.41 0.38	0.17 0.07	0.37 0.1	A
7	pa-M pa-T	0.39 Data not sufficient	0.1	0.26	A

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VIIB: Table showing significance of difference for open quotient for the corresponding notes across registers

Based on the statistical analysis, it can be stated that, no significant differences between the notes; dha; sa; ga, are noted, but a significant difference between notes ni; ri; ma; pa, exists along with the corresponding counterpart.

VIII Speed Quotient

Within registers

As can be seen from Table VIIIA and Graph VIII, there is no significant difference between adjacent notes dha to ni, in the 'mandhra' sthayi. However, in the 'mandhya sthayi, there are no significant differences between sa to ri; ga to ma; ma to pa; but significant differences are oboserved between ri to ga; pa to dha; dha to ni.

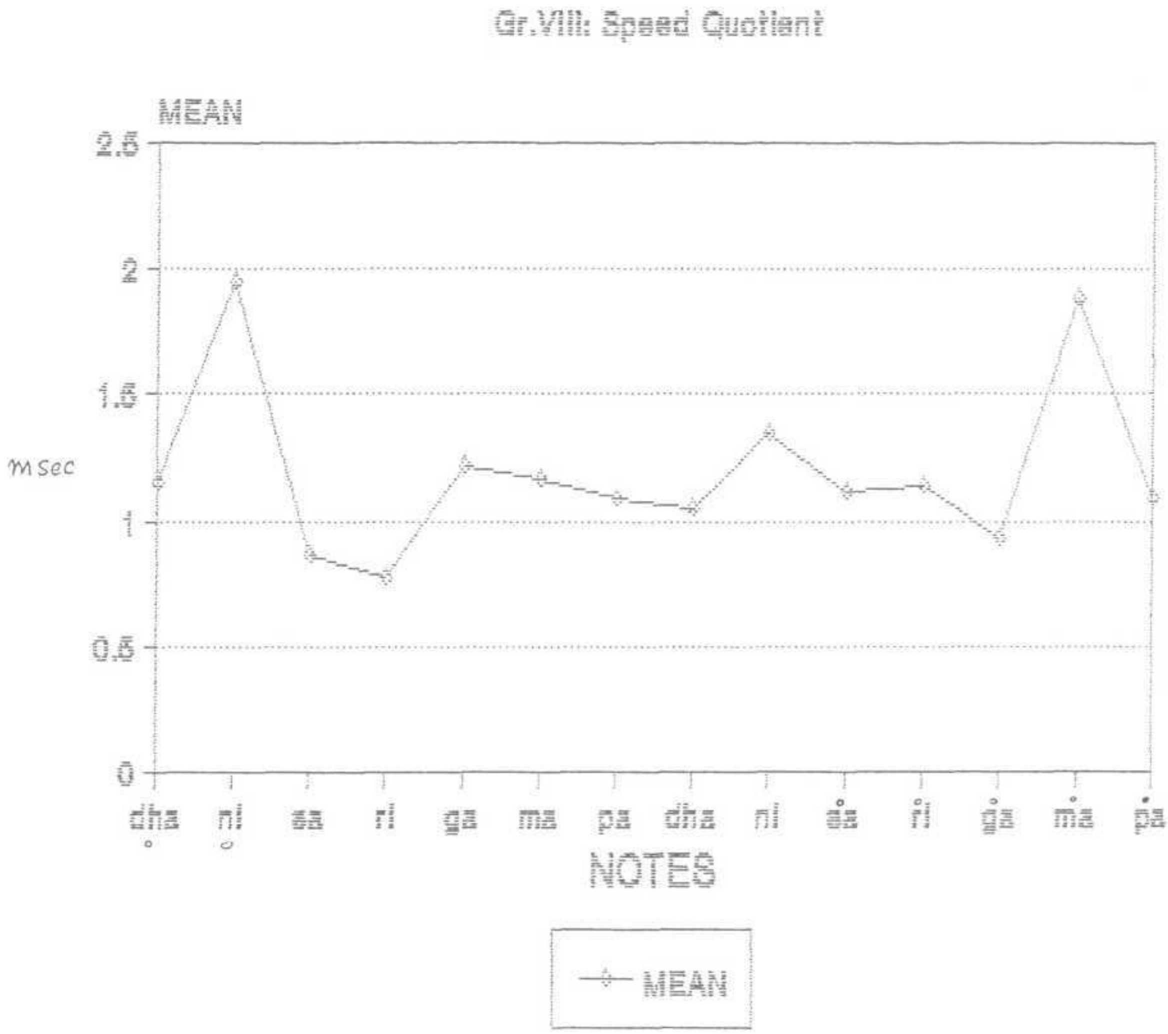
In 'tara' sthayi, there is significant difference only between ri to ga; but there are no significance of differences between sa to ri; ga to ma; ma to pa. This may be due to the absence of significance of difference in the 'closing phase' across the notes also.

There is a significant difference at the transition points from ni to sa from 'mandhra' to 'madhya' sthayis, but the same is not observed between 'madhya' to 'tara' sthayis.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	1.15	0.82	1.59	P
2	ni-m	1.95	1.23	2.77	P
3	sa-M	0.86	0.27	0.68	A
4	ri-M	0.77	0.24	0.53	P
5	ga-M	1.22	0.27	0.69	A
6	ma-M	1.16	0.47	1.02	A
7	pa-M	1.09	0.38	0.89	P
8	dha-M	1.05	0.54	1.38	P
9	ni-M	1.35	1.16	2.59	A
10	sa-T	1.12	0.4	0.98	A
11	ri-T	1.14	0.75	1.86	P
12	ga-T	0.93	0.47	1.29	A
13	ma-T	1.88	1.59	2.25	A
14	pa-T	1.09	0.12	0.17	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table VIIIA: Table of significance between adjacent notes for speed quotient within registers.



Across registers

There are significant differences in terms of speed quotient between corresponding notes across 'mandhra' to 'madhya' and 'madhya' to 'tara' sthayis except for sa across one octave.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	1.15 1.05	0.82 0.54	1,59 1.38	P
2	ni-m ni-M	1.95 1.35	1.23 1.16	2.77 2.59	P
3	sa-M sa-T	0.86 1.12	0.27 0.4	0.68 0.98	A
4	ri-M ri-T	0.77 1.14	0.24 0.75	0.53 1.86	P
5	ga-M ga-T	1.22 0.93	0.27 0.47	0.69 1.29	P
6	ma-M ma-T	1.16 1.88	0.47 1.59	1.02 1.02	P
7	pa-M pa-T	1.09 1.09	0.38 0.12	0.89 0.17	P

m-mandhra;M-madhya; T-tara; P-present; A-not present

Table VIIIB: Table of statistical values of corresponding notes in adjacent registers for speed quotient

IX Total period

Within registers

In the 'mandhra' sthayi only, there is no significant difference between dha to ni, probably due to only a gradual change in the total period of vocal fold vibration, as against the other registers.

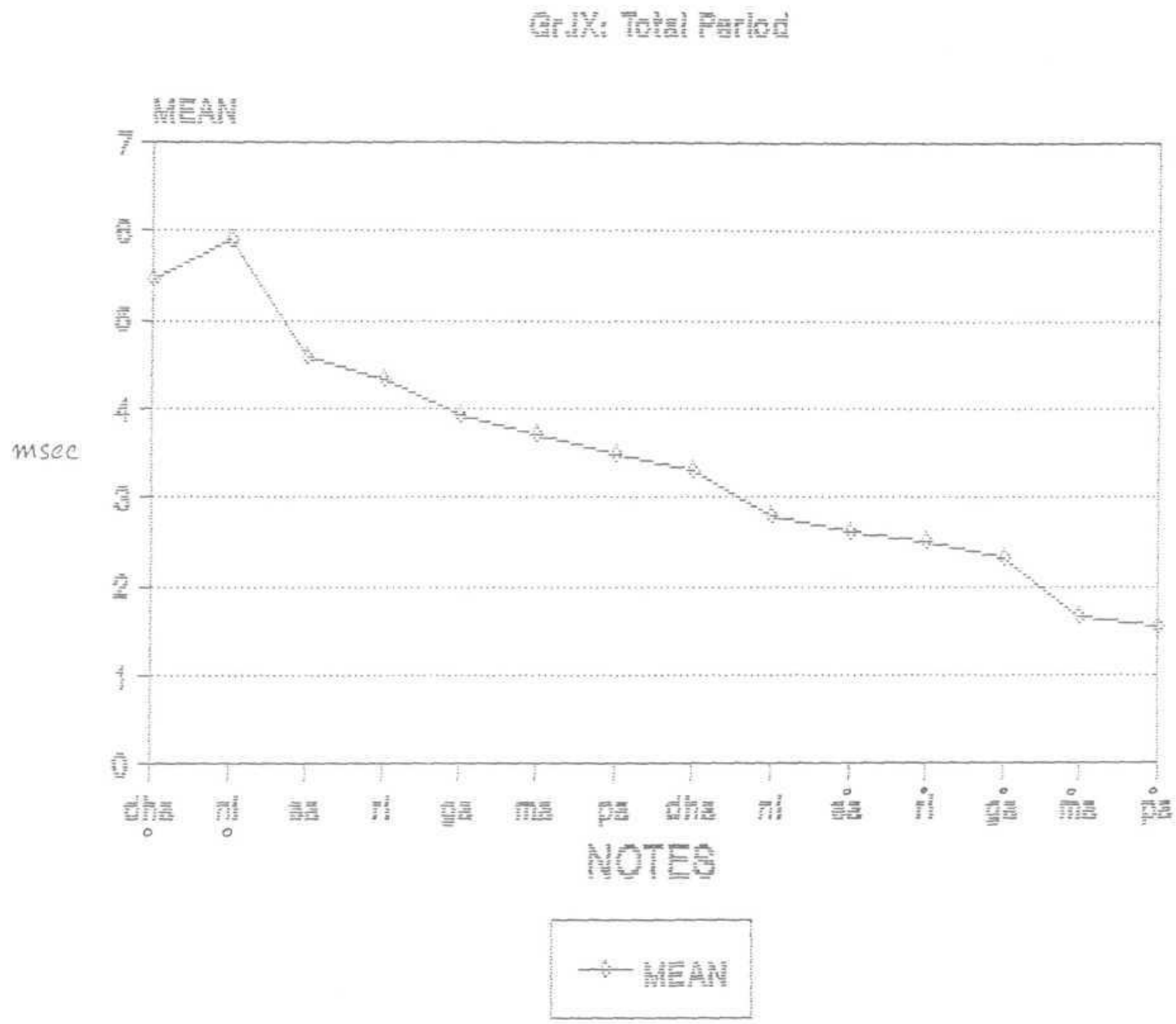
Apart from this, there are significant differences between adjacent notes in 'madhya' as well as the 'tara' sthayis.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	5.46	0.76	1.4	
					A
2	ni-m	5.91	1.04	2.6	
					P
3	sa-M	4.58	0.75	1.93	
					P
4	ri-M	4.32	0.68	1.74	
					P
5	ga-M	3.93	0.71	1.4	
					P
6	ma-M	3.72	0.49	1.33	
					P
7	pa-M	3.28	0.68	1.73	
					P
8	dha-M	3.32	0.79	0.8	
					P
9	ni-M	2.8	0.56	1.53	
					P
10	sa-T	2.61	0.6	1.6	
					P
11	ri-T	2.51	0.72	1.93	
					P
12	ga-T	2.31	0.61	1.6	
					P
13	ma-T	1.67	0.19	0.27	
					P
14	pa-T	1.54	0.19	0.27	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table IXA: Table of significance between adjacent notes within registers with respect to total period of glottal cycle.

There is no significant difference at the transition points from 'mandhra' to 'madhya' sthayis as well as 'madhya' to the 'tara' sthayis due to the obvious change in the total period of vocal fold vibration, i.e., from lowe to high pitch. The above results are summarised in the Table IXA as well as the Graph IX.



Across registers

There is a statistically significant difference between corresponding notes across registers due to the obvious shift in the total period of the vibration of vocal folds from one register to the next.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	5.46 3.32	0.76 0.79	1.4 0.8	P
2	ni-m ni-M	5.91 2.8	1.04 0.56	2.6 1.53	P
3	sa-M sa-T	4.58 2.61	0.75 0.6	1.93 1.6	P
4	ri-M ri-T	4.32 2.51	0.68 0.72	1.74 1.93	P
5	ga-M ga-T	3.93 2.31	0.71 0.61	1.4 1.6	P
6	ma-M ma-T	3.72 1.67	0.49 0.19	1.33 0.27	P
7	pa-M pa-T	3.48 1.54	0.68 0.19	1.73 1.27	P

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table IXB: Table of significance total period across registers

X Speed Index

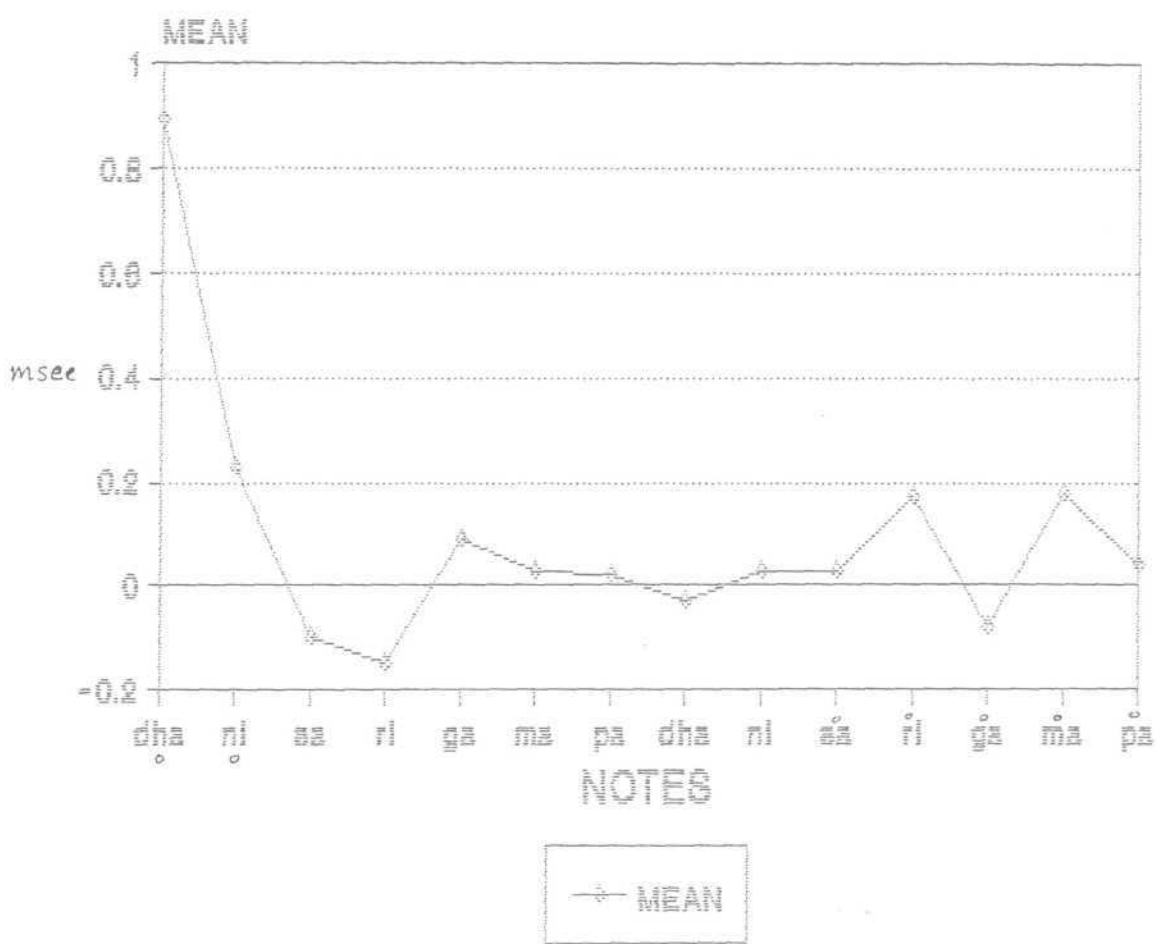
Within registers

Based on the values of statistical analysis of speed quotient, in the 'mandhra' sthayi, no significant difference between adjacent notes dha to ni is noticed.

In the 'madhya' sthayi, there are significant differences between sa to ri; ri to ga; dha to ni, but not between ga to ma; ma to pa; pa to dha. In the 'tara' sthayi, there are no significant differences between any pair of adjacent notes indicating that it is not a very effective indicator of difference of the higher register-'tara' sthayi.

At the transition point from 'mandhra' to 'madhya' there is a significant difference, but no such difference is noted at the transition opint from 'madhya' to 'tara' sthayi. These results are noted in Table XA and Graph X.

Gr.X: Speed Index



Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	0.89	1.88	3.41	A
2	ni-m	0.23	0.27	0.6	P
3	sa-M	-0.01	0.16	0.4	P
4	ri-M	-0.15	0.15	0.34	P
5	ga-M	0.09	0.12	0.29	A
6	ma-M	0.03	0.22	0.49	A
7	pa-M	0.02	0.17	0.39	A
8	dha-M	-0.03	0.28	0.33	P
9	ni-M	0.03	0.37	0.33	A
10	sa-T	0.03	0.17	0.41	A
11	ri-T	0.17	0.43	0.29	A
12	ga-T	-0.08	0.35	0.6	A
13	ma-T	0.18	0.45	0.19	A
14	pa-T	0.14	0.06	0.08	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table XA: Table of significance values for speed index of glottal cycle within registers.

Across registers

There are significant differences for speed index among corresponding notes across registers except between the sa notes of 'madhya' and 'tara' sthayis.

SI.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	0.89	1.88	3.41	P
	dha-M	-0.03	0.28	0.33	
2	ni-jn	0.23	0.27	0.6	P
	ni-M	0.03	0.37	0.33	
3	sa-M	-0.1	0.16	0.4	A
	sa-T	0.03	0.17	0.41	
4	ri-M	-0.15	0.15	0.34	P
	ri-T	0.17	0.43	0.29	
5	ga-M	0.09	0.12	0.29	P
	ga-T	-0.08	0.25	0.6	
6	ma-M	0.03	0.22	0.49	P
	ma-T	0.18	0.45	0.19	
7	pa-M	0.02	0.17	0.39	P
	pa-T	0.04	0.06	0.08	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table XB: Table of significance between corresponding notes across registers for speed index.

Long term Average Spectrum

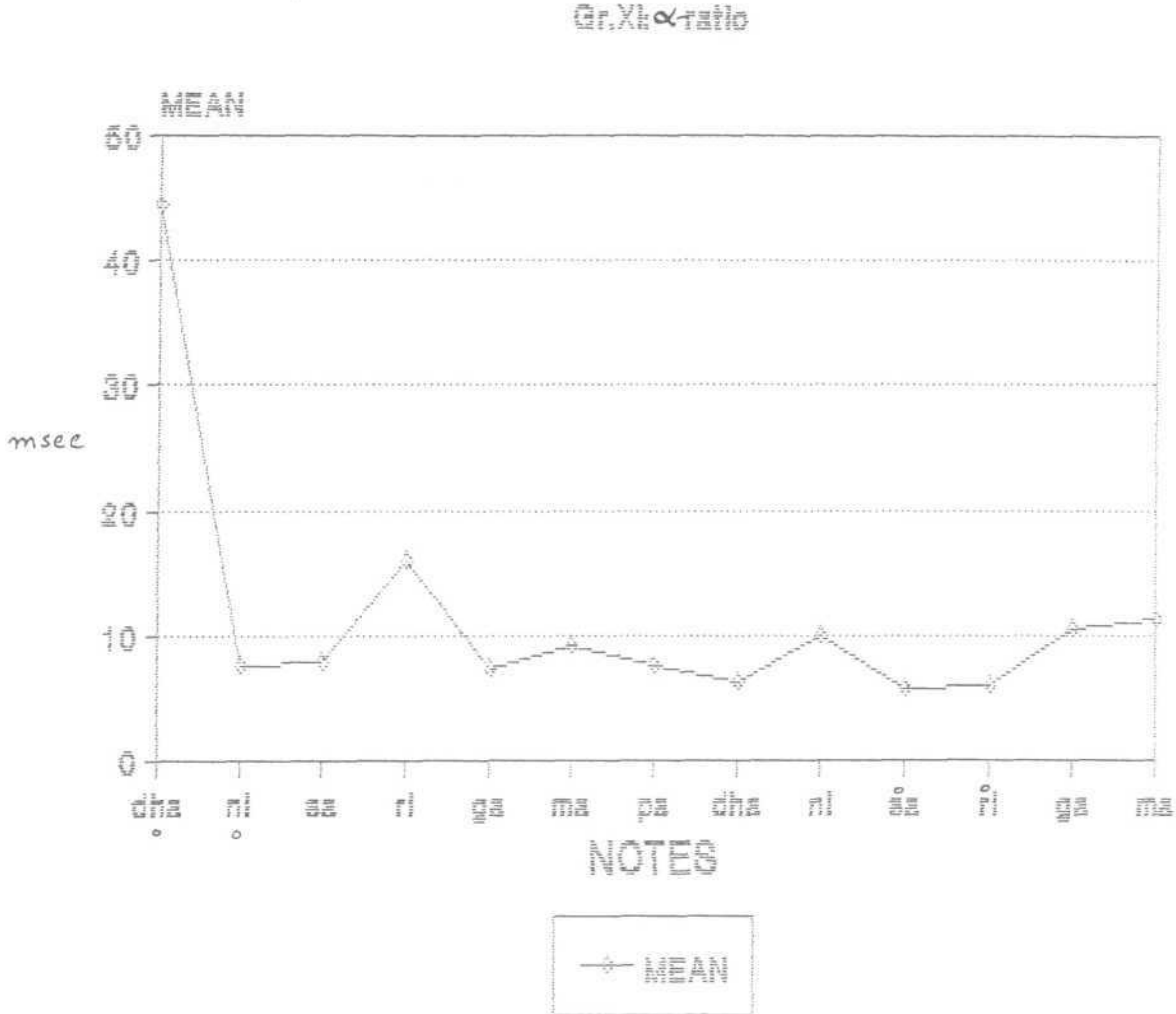
Long-term average spectrum provides data regarding the spectral energy with frequency plotted against amplitude. It provides information regarding the formants and harmonics also.

XI α ratio - $0\frac{0-1}{1-5}KHz$

Within registers

In 'mandhra' sthayi, there are significant differences between dha and ni. Similarly, in the 'madhya' sthayi, there is a significant difference between adjacent notes again may be attributable to the singer's formant. However, in the 'tara' sthayi, there is no significant difference between sa to ri and ri to ga, but a significant difference is noted between ga to ma.

At the transition point from ni to sa of 'mandhra' to 'madhya' there is no significant difference found. But, it is not so at the transition point from 'madhya' to 'tara' sthayis. The results are shown in Table XIA and Graph XI.


Gr.XI: α-ratio
MEAN
60
40
30
20
10
0
msec
dha
ni
sa
ri
ga
ma
pa
dha
ni
sa
ri
ga
ma
NOTES
MEAN

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	44.39	43.42	61.41	P
2	ni-m	7.54	8.53	17.83	A
3	sa-M	7.82	5.42	13.65	P
4	ri-M	16.02	10.66	26.15	P
5	ga-M	7.46	4.17	10.82	P
6	ma-M	9.17	3.13	8.37	P
7	pa-M	7.64	4.18	8.87	P
8	dha-M	6.22	3.98	10.04	P
9	ni-M	10.58	15.17	38.62	P
10	sa-T	5.7	2.56	6.08	A
11	ri-T	5.99	3.23	7.4	A
12	ga-T	10.43	13.23	31.83	P
13	ma-T	11.35	11.05	15.62	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table XIA: Table for significance values for notes within registers with respect to α ratio.

Across registers

At the level of higher notes of 'tara' sthayi in comparison with the corresponding notes of 'madhya' sthayi there is no significant difference but otherwise, there is a significant difference between corresponding notes across registers. This may be due to the changes being subtle at higher pitches.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	44.39 6.22	43.42 3.98	75.09 21.94	P
2	ni-m ni-M	7.54 10.58	8.53 15.17	20.29 42.24	P
3	sa-M sa-T	7.82 5.7	5.42 2.56	17.07 8.84	P
4	ri-M ri-T	16.07 5.99	10.66 3.23	32.9 9.48	P
5	ga-M ga-T	7.46 10.43	4.17 13.23	13.51 32.89	A
6	ma-M ma-T	9.17 11.35	3.13 11.05	13.72 19.16	A

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table X I B : Table of significance across registers with respect to α ratio for adjacent notes.

XII β ratio $\frac{0\text{-}2}{2\text{-}8}$ KHz

Within registers

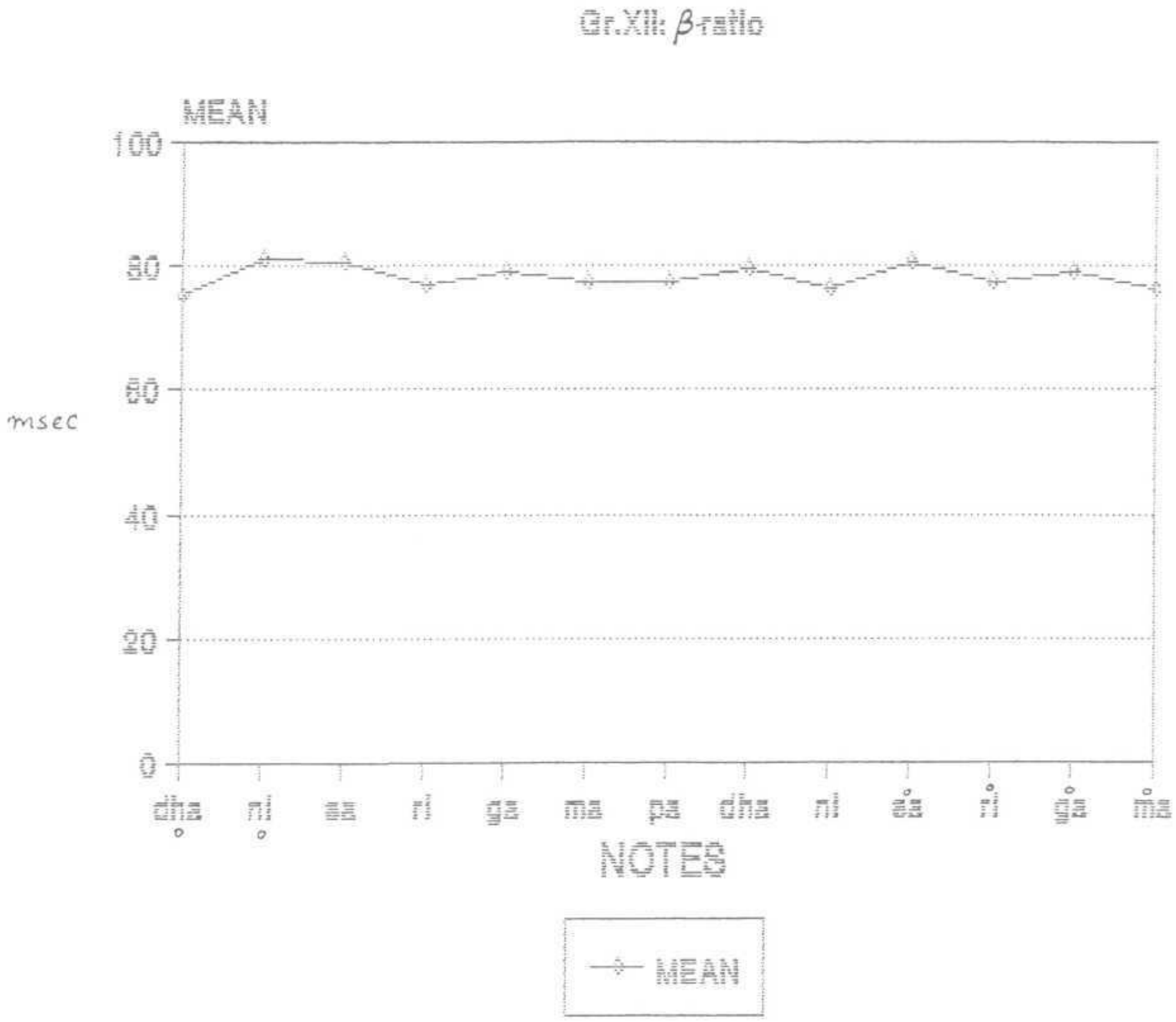
There are significant differences between adjacent notes in the 'mandhra' sthayi. But, there are no significant differnces between adjacent notes ri to ga in both 'madhya' and 'tara' sthayi.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	75.47	4.79	6.77	P
2	ni-m	81.27	6.1	13.11	P
3	sa-M	80.46	2.87	6.82	P
4	ri-M	77.14	3.03	6.88	A
5	ga-M	79.22	3.68	10.05	P
6	ma-M	77.45	2.93	5.89	A
7	pa-M	77.62	2.52	6.82	P
8	dha-M	79.47	4.93	11.8	P
9	ni-M	76.24	4.15	10.87	P
10	sa-T	80.54	3.53	8.67	P
11	ri-T	77.64	6.68	14.05	A
12	ga-T	79.15	7.89	19.38	A
13	ma-T	76.19	5.38	7.61	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table XIIA: Table of significance within registers for β-ratio.

There are also no significant differences between ma and pa in the 'madhya' sthayi and ga and ma in the 'tara' sthayi due to inter-subject variation. However, there are significant differences at the transition point from 'mandhra' to 'madhya' sthayi and 'madhya' to 'tara' sthayis also. The results are indicated in Table XIIA and Graph XII.



Across-registers

There are only significant differences between corresponding notes dha and ni of 'mandhra' and 'madhya' sthayis. Further, no significant difference is obtained between the corresponding notes in 'madhya' and 'tara' sthayis as the pitch increases.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	75.49	4.79	6.77	P
	dha-M	79.47	4.93	11.8	
2	ni-m	81.27	6.1	13.11	P
	ni-M	76.24	4.15	10.87	
3	sa-M	80.46	2.87	6.82	A
	sa-T	80.54	3.53	8.69	
4	ri-M	77.14	3.03	6.88	A
	ri-T	77.64	6.68	14.05	
5	ga-M	79.22	3.68	10.05	A
	ga-T	79.15	7.89	19.38	
6	ma-M	77.45	2.93	5.89	A
	ma-T	76.19	5.38	7.61	

m-mandhra; M-madhyaa; T-tara; P-present; A-not present

Table XIIB: Table of significance across registers in β-ratio for corresponding notes.

XIII γ-ratio $\frac{1-5}{5-8}$ K Hz

Within register

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m	74.81	70.28	99.39	
					P
2	ni-m	13.99	15.58	33.46	
					P
3	sa-M	41.45	50.36	123.26	
					P
4	ri-M	46.65	27.69	6.06	
					A
5	ga-M	39.26	37.78	99.03	
					P
6	ma-M	16.67	35.05	60.31	
					A
7	pa-M	55.93	48.23	116.36	
					P
8	dha-M	78.02	75.47	159.57	
					P
9	ni-M	115.88	111.73	269.63	
					P
10	sa-T	48.2	56.04	123.91	
					P
11	ri-T	88.66	153.72	356.26	
					A
12	ga-T	183.15	339.17	780.81	
					P
13	ma-T	112.86	132.72	168.68	

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table XIIIA: Table showing significance of difference within registers for γ ratio between adjacent notes within registers.

Across registers

There is a significant difference between notes dha and ni; in the 'mandhra' sthayi. However, in the 'madhya' sthayis, there are no significant differences between the notes ri to ga; ma to pa; and in the 'tara' sthayi, sa to ri.

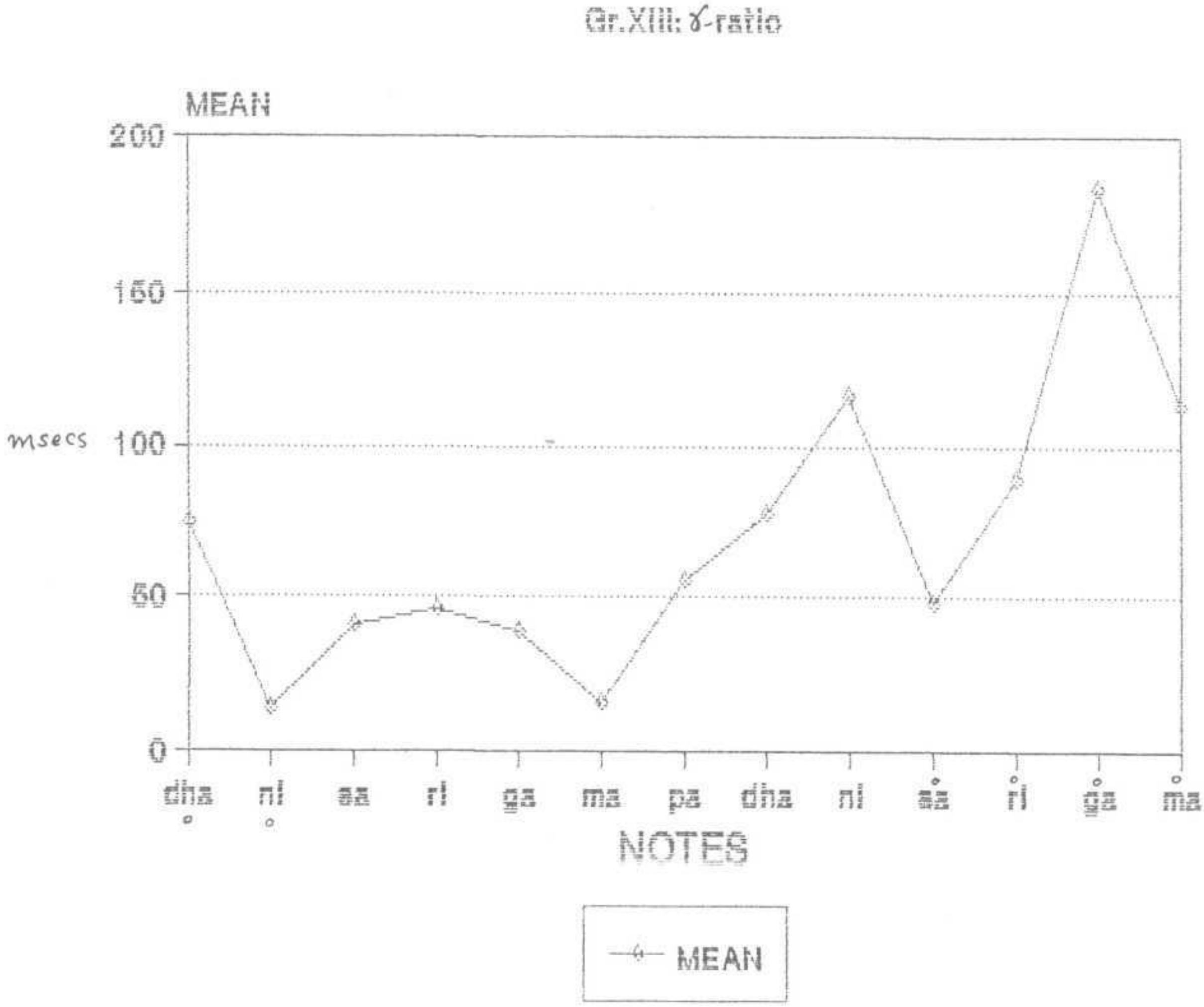
Further, there are significant differences at the transition points between registers, i.e., from 'mandhra' to 'madhya' sthayis and 'madhya' to 'tara' sthayis.

Sl.No.	Notes	Mean	SD	Range	Significance of difference
1	dha-m dha-M	74.81 78.02	70.28 75.47	99.39 159.57	A
2	ni-m ni-M	13.99 115.88	15.58 111.73	33.36 269.91	P
3	sa-M sa-T	41.45 48.2	50.36 56.04	123.26 123.91	A
4	ri-M ri-T	46.65 88.66	27.69 153.72	6.06 356.26	P
5	ga-M ga-T	39.26 183.15	37.78 339.17	99.03 780.81	A
6	ma-M ma-T	16.15 112.86	35.54 132.73	60.31 168.68	A

m-mandhra; M-madhya; T-tara; P-present; A-not present

Table XIIIB: Table showing significance of difference for corresponding notes across registers for γ-ratio.

There are no significant differences between dha, sa, ga, ma as well, the pattern being inconsistent. And, there are significant differences between corresponding notes ni, and ri. Hence, it can be concluded the the γ-ratio does not vary either with the notes or with change in the register also.



DISCUSSION

Sl.No.	Parameters	Within Registers	Across Registers
1	Open Time	SD	SD
2	Closed Time	NSD	SD
3	Opening Time	NSD	SD
4	Closing Time	NSD	SD
5	Open Phase	SD	SD
6	Closed Phase	SD	SD
7	Open Quotient	SD	NSD
8	Speed Quotient	NSD	SD
9	Total Period	SD	SD
10	Speed Index	NSD	SD
11	α-Ratio	SD	SD
12	β-Ratio	SD	NSD
13	γ Ratio	SD	NSD

SD-significant difference present; NSD-no significant difference present

Table XIV: Table shoving the summary of significance of difference, for different electroglottographic and spectral parameters at different musical notes within and across registers

It is known that the basic notes or swaras in music are seven in number, which can be sung in three registers mainly;

i.e., seven notes are placed at an interval of one octave each- the 'mandhra', the 'madhya', and the 'tara' sthayis, in Karnatic vocal music. But, due to physiological limitations, all the notes cannot be sung in all the registers.

Many singers and teachers of singing have encountered the most baffling phenomenon of register break, in the voice, which may be the result of maladjustment, rather than a natural physiological function. This would be manifested by noticeable changes in the glottal mechanism.

Register in singing concerns itself, mainly with an interruption of the pitch line-Victor (1973). He has listed the determinants of vocal pitch as density, thickness, width and longitudinal tension, i.e., those factors that affect the firmness or elasticity of the glottal margins. Hence, there appears to be differences in different glottal parameters as well as spectral parameters while singing at different registers.

The frequency composition of the glottal wave does vary in different registers. A number of partials are also seen exhibiting significant energy in the modal register than in the falsetto register.

In the present study, significant differences in terms of α, β and γ ratios in the lower register as compared to the higher ones are noticed which can be attributed to the energies at low frequencies. The presence of a remarkable band of energy between 1-5KHz, specifically at 1.5-2.7KHz region, i.e., the region in which the 'singer's formant' has been said to be present, has brought significant differences in the intensity parameters corresponding to that area, i.e. α, β and γ ratios.

One of the parameters of the 'singer's formant' includes differences in body height and length of vocal tract. Acoustically, the different registers show differences of the glottal wave shape, which can result in a different frequency composition (Gerritt et. al.,1992). In the current study, there has been a concentration of energy at low frequencies, which reduced as the pitch was moved from low to high registers.

Results of the electroglottographic analysis, as reported by other investigators, can be summarised as follows (Gauffin and Sundberg 1989).

Feature	Modal Voice	Vocal Fry	Falsetto
Open Quotient	Medium	Low	High
Closure sharpness factor	Low	Low	High

The glottal closure period involved in different registers has also been different, according to the present study also. It is for a longer period in the lower register as compared to the higher ones. In the present study, it is indicated by the increased mean values of 'closing time' in the 'mandhra' sthayi, with a gradual decrease as the pitch moved towards the 'tara' sthayi. But, 'closed time' didnot vary significantly, as pitch moved from lower to higher registers. Similar results have been found with reference to 'opening time' also.

Further, in the present study, the 'open phase' seems to increase gradually as pitch changed from 'mandhra; to 'tara' sthayis. It may be noted that the 'open phase' is influenced by the 'opening time' also. Similar results are also observed for 'closed phase'.

'Open quotient' is lower in low registers, as compared to high registers as reported in literature. But, in the current study, no significant differences were noticed with reference to this parameter.

On the whole, there have been significant differences across registers in terms of open time, closed time, opening time, closing time, open phase, closed phase, speed quotient, total period, speed index, α-ratio; and not for open quotient, β -ratio and γ-ratio. Significant differences have been noted for notes within registers for open time, open phase, closed phase, open quotient, total period of the glottal cycle, along with α -ratio, β-ratio, γ-ratio; and not for closed time, opening and closing time, speed quotient and speed index.

A change in pitch from low to high is seen with the change from lower to the higher registers (mandhra to tara sthayi) as expected. This change in pitch also leads to changes in glottal parameters as evidenced in the current study.

Hence, the hypothesis stating that,

1) no significanct differences in terms of the glottal parameters is rejected as the majority of the parameters (nine out of ten) are showing statistically significant differences across the corresponding notes across registers.

2) no significant differences in terms of the glottal parameters for adjacent notes within registers is neutral as the number of parameters rejected as well as acepted is equal to each other.

3) no significant differences in terms of the spectral parameters for corresponding notes across registers is accepted as majority of the parameters (two out of three) do not show statistically significant differences.

4) no significant differences in terms of the spectral parameters for adjacent notes within registers is rejected as majority of the parameters (three out of three) show statistically significant differences.

5.1

SUMMARY AND CONCLUSIONS

It is known that registration is observed both in speaking as well as singing. A register is a physical, acoustic event which results fromØ an energetic change within muscular coordination of vocal cords. There has been changes in the terminologies as well as the numbers used to designate these registers from the past to the present. Similarly, the effect of the parameters, the acoustical correlates,the physiological correlates, the presence of special features like the 'singer's formant' for the vocal analylsis in the different registers also has been studied, the results of which have been presented in the previous chapters.

Indian music also has been researched from times immemorable, which includes the work done by Bharatamuni, Ahobala, Bhatkande, Brhatdesi, Chandola and others even prior to the 17th century, Guppta(1984), Sujatha (1987), Ragini (1989) Vijaya (1990).

The present study was undertaken to find out the efficiency of electroglottographic parameters and long term average spectral parameters in trying to differentiate musical notes within and across the three registers in

Karnatic vocal music viz. Mandhra (low) sthayi, Madhya sthayi (mid), tara sthayi (high).

Five trained female singers in Karnatic style of music with minimum of five years of musical training were taken as subjects. They were asked to sing the individual notes from lowest to highest of their vocal range in raga Shankarabharan sustaining each note for 1-2 seconds. Simultaneously, signal from electroglottographic and acoustic output were recorded, and the corresponding parameter values were obtained for the same. The notes and registers were subjectively verified again.

Further the data obtained was subjected to statistical analysis. The non-parametric Wilcoxon test for related samples was used and measures of significance of differences were obtained for different parameters.

5.3 Conclusions

The following conclusions were drawn :

The electroglottographic parameters viz. the open time, closed time, opening time, closing time, open phase, closed phase, open quotient, speed quotient, speed index, total period showed statistically significant differences across the notes and registers.

There were statistically significant differences between corresponding notes across registers due to the marked change in the glottal parameters across frequencies of glottal vibration.

The parameters of long term average spectrum viz. the α -ratio; β-ratio; γ-ratio; showed significant differences across registers. But within registers only α-ratio showed statistically significant differences and majority of the notes did not show significant differences for the other two parameters, viz., β-ratio and γ-ratio.

Evidence of greater spectral energy in the region between 2-4K Hz, correspondingly showing significant differences in intensity between the same region may be attributed to the presence of the special phenomenon of the 'SINGERS FORMANT'.

Implications of this study:

1. This study helps in determiniong the role of various glottal parameters and spectral parameters by an efficiently used voice in the notes within and across the registers.

2. This would provide the teachers of singing to make appropriate adjustments in the vocal folds and respiratory mechanism for efficient use of vocal range without any vocal breaks or change in the perpceived quality.

3. The study provides data regarding the efficiency of the singer to use compensatory techniques to obscure the transition points between registers like covering.

4. The current study also indicates the fact that the special phenomenon observed in a Western singers, like that of 'singer's formant'is observed in Karnatic vocal music also.

Limitations

1. The number of subjects is limited to five only.

2. This study is only limited to Electroglottography and long term average spectrum.

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