THE FUNDAMENTAL FREQUENCY RELATION OF THE SAPTA SVARAS OF KARNATIC VOCAL MUSIC

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To

'Amma & Appa'

- my source of inspiration.
Your love, support and encouragement
has helped me come a long way.

and

'Sridhar'

-for making the sun shine on my cloudy days.
You've enriched my life beyond measure.

CERTIFICATE

This is to certify that the dissertation entitled "THE FUNDAMENTAL FREQUENCY RELATION OF THE SAPTA SVARAS OF KARNATIC VOCAL MUSIC" is a bonafide work in part fulfilment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M9222.

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CERTIFICATE

This is to certify that this dissertation entitled "THE FUNDAMENTAL FREQUENCY RELATION OF THE SAPTA SVARAS OF KARNATIC VOCAL MUSIC" has been prepared under my supervision and guidance and it is a bonafide work of the student with register number M9222.

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DECLARATION

This dissertation entitled "THE FUNDAMENTAL FREQUENCY RELATION OF THE SAPTHASWARAS OF KARNATIC VOCAL MUSIC" is the result of my own study undertaken under the guidance of Mr. C.S. Venkatesh, Lecturer in Speech Sciences, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other Diploma or Degree.

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'Friendships don't just happen
They're special gifts that god sends
Because He knows that life is not
complete without good friends'.

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CONTENTS

"Music is the universal language of mankind." -Longfellow.

INTRODUCTION

"We *accept music, discuss music and musical matters much as we discuss life and all pertaining to it; yet what life is, no one as yet has revealed. Life is a mystery to those who trouble to think about it, but merely a fact to those who do not; the same may be said of music. "*

........*Cyril Scott (1958)*

Communication is a process by which we develop and share meaning (Bradley, 1974). Human communication is a subject of study in so many disciplines because it touches human beings daily. Human communication takes many forms such as morse code, sign language, drawing, singing, writing, etc. The most efficient way of communication is by using the vocal apparatus. Communication using vocal apparatus can be achieved by speech or by singing. Speech is widely used in everyday life. Music serves as a means of entertainment, conveys messages and forms an integral part of human culture.

Music can be divided into folklore and classical music. Folklore originated from the moods of the common man. Classical music in India, on the other hand originated from the vedic chanting. Classical music is highly rule governed and has to be learnt formally.

Indian classical music can be divided into Hindustani and Karnatic music. Hindustan music is widely practised in the northern parts of India, whereas. Karnatic music is practised in the southern states.

Indian classical music is very rich in content and hence provides lot of avenues for experimentation. The intricacy and variety of its composition though widely appreciated for years, is drawing attention of researchers only in the recent past. Instrumental music has been more widely researched than singing. Research on instrumental music has been done by varying tension, length, etc. (Bharatamuni, 200 AD). The Hindustani classical music is being researched at the "Sangeet Research Academy" at Calcutta. Reports of experimental investigations into Kamatic music are scant. Kamatic vocal music has been analyzed only in recent years (Gupta, J. 1984; Ragini, 1989; Sujatha, 1987).

Intonation and rhythm are the basic elements of music. Intonation or raga is determined by the various permutation and combination of notes or svaras - " Sa, Ri, Ga. Ma, Pa, Da, Ni". These notes arc called the 'sapta svaras' as they arc seven in number. These notes, with the exception of 'Sa & Pa' exhibit two varieties and can be sung in three registers or sthayis, namely the 'tara sthayi' or head register 'madhya sthayi' or neck/middle register and 'mandara sthayi' or chest register. Rhythm is determined by the 'tala' which is the temporal aspect of music.

The fact that there exists a specific relation among the sapta svaras is evident from the way the notes are placed along the 'shruti scale' and in the way they are played on any instrument. The relationship between the adjacent notes as quoted by Sambamoorthy (1963) is 1:1.05946. This relation has not been studied with respect to the human voice. Acoustic analysis of the singing voice enables us to study this relation. It is an advantageous method as it is objective.

The present descriptive study aims al studying this relation in Kamatic vocal music. This study aims at addressing the following questions.

1) What is the fundamental frequency relation between the 'svaras' of Karnatic vocal music?
2) Is the relation maintained across all the three registers?
3) Is the relationship between the 'svaras' affected by the presence or absence of the drone note?
4) Do the values of the fundamental frequency of the 'svaras' correspond to the theoretically stated values?

Justification for the study:

This study aims at answering one of the basic questions in singing. It throws light on the intricacy of control of the vocal apparatus. Singing being one the supra normal aspects of voice, understanding it will aid in understanding the normal physiology of the vocal apparatus. There are no studies of this kind available in the literature

REVIEW OF LITERATURE

A) SOME LATENT FEATURES OF MUSIC:

> *"Speech and music we the two most universal, natural andfastest means of communication of knowledge, information, ideas feelings and sentiments among human beings. " -Agarwal (1987)*

Music as is known is one of the fine arts. It appeals to the sense of beauty in the listeners. As it utilizes the medium of sound for its expression, it must obey the physical laws of sound. Music creates its own forms and order, so that it makes a direct appeal to man's aesthetic instincts and enriches him emotionally. So music basically adheres to two sets of laws - the physical laws and the aesthetic ones.

Music is not an isolated art. It actually forms a most necessary link in the great family of arts. Any art aims at the transformation of the material world. Music being the least material of all arts easily surpasses the other arts in this respect and is therefore called the "Art of Arts".

Music systems all over the world can be basically divided into two, namely:

1) melodic system and 2) harmonic system

This classification is based on the pattern of distribution of notes in the system. The melodic system is one in which the music progresses by successions of single notes. Music of the Oriental countries and the Indian classical music are examples of such a system. The music in the harmonical system progresses by successions of groups of notes called chords. The individual notes of the chords are in harmony with each other. The western classical music is an example of such a system.

The basic component of music is sound which is referred to as "nada" by musicologists. The "nada" gives rise to the "shrutis", which give rise to "svaras" and the svaras to the "raga".

The basic notes or svaras, are seven in number. These notes can be sung in three registers i.e. the seven notes are placed in an interval of one octave. The entire octave is divided into 22 microtones or semitones. Each microtone is referred to as a shruti. The various permutations and combinations of the notes results in the different ragas. Ragas constitute the melody of music. They help bring out the emotions the singer wishes to convey. All these concepts are dealt with elaborately in a next section.

B) TERMINOLOGY:

1) **NADA:** The basic component of music is sound or "nada". Nada actually refers to any musical sound. Nada can be basically of any one of the two types, namely:

i) Anahata ii) Ahata

Anhata refers to sounds of nature, i.e. sounds produced without human effort. Sounds produced by body metabolism fall into this realm. Ahata refers to sounds produced by concious effort of man. So it is the ahata that is analyzed. Ahata is further divided into 6 sub types depending on the origin of the sound.

The six subtypes are as follows:

1. Sariraja - Sound emanating from human voice
2. Nakhaja - Sound produced by plucked instruments eg. veena
3. Dhanuraja - Sound produced by bowed instruments eg. violin
4. Vayuja - Sound produced by wind instruments eg. flute
5. Charmaja - Sound produced by skin covered instruments eg. drums
6. Lohaja -Sound produced by metallic instruments eg. cymbals

This study concerns itself only with the "Sariraja".

2) SVARA : Svara refers to any musical note or interval. - Sambamoorthy (1963). The basic notes in Karnatic music are seven in number. These are:

Sa - Shadja

Ri - Rishabha

Ga - Gandhara

Ma - Madhyama

Pa - Panchama

Da - Dhaivata

Ni - Nishada

According to Hindu mythology these notes emanated from animal cries.

"Sa" - is sound produced by peacock at its highest rapture.

"Ri" - is the 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 seven notes are synonymous to the "Do, Re, Mi, Fa, So, La, Si/Ti " of Western classical music. These notes can be sung back and forth in the following order.

1) Sa Ri Ga Ma Pa Da Ni Sa

2) Sa Ni Da Pa Ma Ga Ri Sa

While moving from one "Sa" to another "Sa" in set (1) a range of one octave is covered i.e. the second "Sa" is one octave higher than the first one. The vice versa is true of the second set i.e. there is reduction by one octave while moving from the first "Sa" to the second "Sa". The set (1) is also called "arohana" and the set (2) as the "avarohana".

All the notes with the exception of "Sa" and "Pa" exhibit varieties. "Sa" and "Pa" are hence called "avikrita svara" or fixed svaras. The remaining five notes namely Ri, Ga, Ma, Da, Ni, have a "komal" or low note and a "tivra" or a high note. The varieties of these notes are as follows.

BASIC NOTE	NAME OF VARIETY	DENOTED AS
Ri	Shuddha Rishabha	Rl
	Chatssruti Rishabha	R2
Ga	Sadharna Gandhara	G2
	Antara Gandhara	G3
Ma	Shuddha madhyama	Ml
	Prati madhyama	M2
Da	Shuddha Dhaivata	Dl
	Chatssruti Dhaivata	D2
Ni	Kaisiki Nishadha	N2
	Kakali Nishadha	N3

These 10 varieties along with "Sa" and "Pa" give rise to 12 notes. As can be noted "Gandhara" and "Nishada" do not enlist a Shuddha note. This is actually due to overlap with the immediately preceeding note i. e., Shuddha Gandhara = Chatssruti Rishabha

Shuddha Nishadha = Chatssruti Dhaivata

Shuddha actually refers to the lowest pitched or the earliest variety of each note in the ascending scale.

3) SHRUTI: As has been mentioned earlier the 12 notes lie in the invertal of one octave. The interval between the notes depends upon which scale is chosen. Basically there are three types of scales as has been quoted by Sundberg (1982). These scales are the:

i) Equally tempered scale, ii) Pure scale and iii) Pythagorean scale.

i) The Equally tempered scale: Theoretically it is the simplest scale. In this scale the octave interval is divided into 12 equal intervals. All the intervals have exactly the same frequency ratio $2^{1/12}$: 1. The disadvantages of this scale is that none of the notes, tuned to this scale, except the octave are beat free.

ii) Pure scale: Most musical instruments produce harmonic spectra. If the lowest partials of such spectra arc combined to form pairs, the intervals formed by such pairs give particular type of intervals. This type of interval is called pure. The frequency ratios of these pure intervals can be expressed in small integers. Eg. In all musical instruments except percussion instruments and plucked instruments, the frequencies of partials belonging to a harmonic spectrum with a fundamental of 110 Hz has the following frequencies - 110 Hz, 220 Hz, 330 Hz, 440 Hz, and so on. The frequencies of the partials constitute a so called harmonic series and hence the partials are called harmonics. Between these harmonic partials are found the following musical intervals : octave, fifth, fourth, major third, minor third, a bit smaller minor third and majorsecond. These intervals are called pure or harmonic and theirfrequency ratios expressed in terms of integers 1:2, 2:3. 3:4 and so on.

In the pure scale the beats are avoided. It is formed by piling up of three pure triads - the tonic, the dominant and the subdominant. However the pure scale cannot be applied to instru-ments with fixed fundamental frequency such as piano, organ etc.

iii) Pythagorean scale: This scale is thought to be invented by Pythagoras. In this scale the scale tones are obtained by piling pure fifths on top of each other i.e., by repeatedly multiplying the frequency by 3:2. When the pile is seven steps high all tones in the diatonic scale are included. Then all tones are brought down to the same octave by halving the frequencies a proper number of times. This scale although easy to use does not produce beautiful (small integer) frequency ratios.

When all the three scales were compared, it was found that they agree only for the intervals of the prime and the octave. Apart from this the pure scale and the pythagorean scale agree for the fourth and fifth, while the remaining intervals differ by 22 cents, and the equally tempered scale value occur, somewhere in between this difference Indian classical music follows the scale of equal temparament. The entire (Klave in Indian classical music is divided into 22 parts. Each part is called semitone or microlone or shruti. The 12 notes are distributed along this scale in the following manner:

The number of microtones per note is as follows:

NOTE	NO. OF SHRUT1S
Sa	4
Ri	4
Ga	3
Ma	2
Pa	4
Da	**3**
Ni	2
TOTAL	22

The question arises as to how the notes were assigned positions along this scale.

This 22 point division was proposed by **Bharatamuni (200 A.D.)** in his "Natyashastra". He experimented with veenas. He kept varying the tension of the veena string i.e. from one octave to the next. He found that he could perceive 22 different tones along the octave. He perceived the first four as Sa, next four as Ri and so on. Thus the basic division was arrived at. Specific points were also assigned based on the perceptual analysis. He perceived first note as being Sa, the third note as shuddha rishabha and so on.

An alternate explanation for this has been proposed by **Subba Rao (1962).** He says initially there was only the note Sa. A search for other notes in harmony with this note yielded the notes "Pa" & "Ma", with Pa being more in consonance with Sa than Ma. Then a further search for notes which are as much in consonance with Pa & Ma, as these are with Sa yielded two strings of 11 notes each.

These are as follows:

S	P	R2	D2	G3	N3	M2	R1	D1	G2	N2	Ml
S	Ml	N2	G2	Dl	Rl	M2	N3	G3	D2	R2	P

These two series as can be noted are reciprocal of each other. These explanations throw light on the fact that some relation exists between these notes. It is this relation that the present study aims at quantifying.

4) STHAYI: Sthayi actually refers to the vocal register. In musicology basically five registers are considered. In an ascending scale these are

i) Anu mandara sthayi

ii) Mandara sthayi

iii) Madhya sthayi

iv) Tara sthayi

v) Ati tara slhayi

The first and the last registers are not used. It is the middle three registers that are used. The mandara sthayi corresponds to the chest register, the madhya sthayi corresponds to the neck register or middle register and the tara sthayi to the head register. All the seven notes cannot be sung in all the three registers due to the physiological limitations.

The madhya sthayi is chosen either according to the convenience of the singer or using a drone note as a reference. This drone note is provided by means of instruments such as the tanpura, sthuti box etc. Once the madhya sthayi is decided the other two registers get automatically defined e.g. if the tonic note i.e. "Sa" of madhya sthayi is decided at 100 Hz, the Sa of tara sthayi is at 200 Hz and that of mandara sthayi at 50 Hz. This shows that mandara and madhya sthayi are one octave apart, similarly madhya and tara sthayi are one octave apart.

C) EVOLUTION OF INDIAN MUSIC:

The literature of Indian music dates from the period prior to the beginning of the Christian era. References to music are contained in the Vedas, Upanishads, Ramayana, Mahabharatha and the Puranas, however extensive explanations are available in Samaveda.

It was the cries of birds and animals such as the cooing of cuckoo or the neighing of the horse that first drew the attention of the early artist. The inclusion of rhythm and melody into vedic hymns marked the beginnings of music. These acquired a new dimension when they were modified to express emotions. It was during this period - **second century A.D.** that the oldest and probably the first detailed exposition of 'Theory of Indian Music' was put forth by **'Bharata'** in his **Natyashastra** or Science of Dramaturgy. He gave a clear account of svaras, shrutis, gramas and mruchanas. Based on his experiments with the veena he explained the 22 point shruti scale. There were only two parent scales and 18 Jatis along which all the melodic progressions were classified. This was found to be inadequate for classification and thus gave rise to the ragas which were obtained by splitting the jatis. This was around 400 A.D. The raga system was introduced by Matanga who published his work **'Brhatdesi'** around this time. This shift over from jatis to ragas came very early as is revealed by **Kalidasa's** work **'Shakuntala'** which closely followed rules of art laid down by Bharata. Evidence is again provided by the parady of an ass that poses as a musician in the Panchatantra (5th Century A.D.). Details about music given in this table, compare very favourably with those of Northern School of Indian music of today.

Next authoritive work on music belongs to early thirteenth century by **Sarangdeva (1230 A.D.).** He assigned names to all the 22 shrutis. In his work **'Sangeet Rathnakara'** he has replaced a lot of the old ragas. There is still a lot of controvery whether this work has anything in common with the present day music of either South or North India.

At the close of **13th century,** all the aspects Indian culture, including music were affected due to the Mohammedan invasion. Persian models began to be introduced into Indian music, widening the gap between the Northern and Southern schools. The Northern school adopted a new scale as its base while the Southern School retained the traditional one. This change was pioneered by **Amir Khusrau.** He introduced finer variations in the ragas and introduced new instruments, one of which is the 'sitar' of today.

Many new theories were put forth in the beginning of the **17th century.** Some of these served only to add to the confusion already present whereas some tried to systemize the available views along rational lines. One such work was by **Pandit Ahobala (1700 A.D.)** author of the **"Sangita-Parijata".**

Around the same period **(16th - 17th century A.D.)** many great artists such as **Haridas, Surdas, Tansen, Tulsidas, Jagannatha** Sadarang **and Adharang** unconciously laid down the foundations of the present day classical style.

There were numerous schools and classifications during the early British period. These schools varied widely in their line of thinking. Attempts were made to unify these schools. One such attempt was made by **Raja Pratap Singh - Deva of Jaipur (1779 -1801 A.D.)** as is reflected in his work **'Radha Govind Sangitasara'.** This work according to **Pandit Bhatkande (1910-1923)** does not seem to have understood any school of thought.

A similar work is the **'Naghamat-e-Asafi'** published by **Mohammed Reza** in 1814. The drawback in this work is that it does not state the intervals between the notes of the scale nor are the notes referred to as Shuddha. Pandit Bhatkande (1910-1923) suggests a scheme in which Reza's scale possibly consisted of the following 22 notes.

3 of Sa, 3 of Re, 5 of Ga, 4 of Ma, 1 of Pa, 3 of Dha & 5 of Ni.

Towards the end of the 18th century works in musicology were published by many Englishmen.The study of the theory of music gained momentum only towards the latter half of 19th century. Mathematic measurements such as measurement of length of string, distance between frets etc. were used.

One of the outstanding personality in musicology, who published his work in the early 20lh century was Pandit Bhatkande. He gave a simple pattern of classifying ragas in his book 'Lakshya - Sangita' published in 1910. In 1923 he gave the description of the frequencies of the Hindustani music.

Thus music gradually evolved to its present status from its beginnings as humming of the hymns of vedas.

D) REVIEW OF STUDIES ON CLASSICAL MUSIC:

> *The basic unifying theme in Speech and Music is that both of them provide the oldest, fastest, most common, most efficient and are universal acoustical means for human communication*
>
> *- Datta, Ganguli & Majumdar (1983)*

Both speech and music have a lot of scope for research. Speech has attracted a lot of attention since time immemorial and has been extensively researched. Music has also attracted the attention of the aesthetic ear; as being a channel of expression and entertainment. It has attracted attention of researchers only in the recent years with Western classical gaining much more than Indian classical. Much of the work in Indian classical music is documented based on perceptual studies. The rules of music are based on these perceptual experiments. The physical aspects of these perceptual findings still remain an enigma, waiting to be understood. They, thus hold a lot of promise for a potential researcher.

Studies in musical acoustics have been conducted mainly using musical instruments. Studies on human voice have been highly limited, especially those in which the fundamental frequency has been analyzed. Western classical music has been analyzed more often than Indian classical music.

The earliest systematic work in the theory of Indian music is by **Bharatmuni (200 A.D.). It** was he who in his **'Natyashastra'** gave the 22 point shruli scale. He varied the tension of the veena string and studied **the** perceptual variationsof the tones produced. Sarangadewa (12th -13th century) carried out similar experiments with a 22 string veena. It was he who named thee 22 shrutis.

In 1923 **Bhatkande** gave the frequency values of each of the 12 notes. This work has been quoted by **Chandola (1988).** The exact details of how the values were arrived at are unavailable. Similar values have been quoted by Sambamoorthy **(1963).**

The values given by Bhatkande and Sambamoortliy are in the tabular column below.

NOTES	VALUES ARE GIVEN BY BHATKANDE	SAMBAMOORTHY		
	in Hz.	in Hz.	in Cents.	freq. ratio
S	240	240	0	1
Rl	254-2/17	252.8	90	256/243
R2	270	270	204	9/8
G2	288	288	316	6/5
G3	301-17/43	300	386	5/4
Ml	320	320	498	4/3
M2	328-14/17	337.5	590	45/52
P	360	360	702	3/2
Dl	381	379	792	128/81
D2	405	405	906	27/16
N2	432	432	1018	9/5
N3	452-4/43	450	1088	15/8
S	480	480	1200	2

Rasch (1983) has specified similar values for some notes in western classical music.

Interval	Freq.ratio	Log. value in cents
Octave	2/1	1200
Fifth	3/2	701.955
Fourth	4/3	498.045
Major third	5/4	368.314
Minor third	6/5	315.641
Major sixth	5/3	884.359
Minor sixth	8/5	813.686

Sambamoorthy (1963) also quotes of a study carried on string instruments. This study found that in an equally tempered scale the relation between the adjacent notes is 1:1.05946 and that each point along the scale is 81/80 higher than the previous one. Various aspects of the Fundamental Frequency and Formant frequencies of the human voice have been studied.

Sundberg (1979) studied the role of f l on fo control in male and female singing. He found that fo control is affected when f l is damped out, more so among males than females. He attributed this difference to the difference in coupling between males and females. He says its probably due to a greater damping of fl in female high pitched. **Hagerman & Sundberg (1980)** conducted a study to find out the accuracy with which fundamental frequencies are chosen in Barbershop singing. Barbershop singing is a special type of male quartet singing originating in USA. The four voices in rising pitch order are called - bass, baritone, lead and tenor. The tenor sings in a soft falsetto voice while the lead carries the melody part. All the singers avoid vibrato. They found that the accuracy with which fo's are chosen in Barbershop singing is extremely high and does not depend on the vowel being sung. They found that the lead serves as the reference to which the other singers adjust fo's so as to produce the desired chords.

Sundberg, Rossing & Ternstrom (1984) carried out an acoustic comparison of voice used in solo and choir singing. Their results revealed that the singers sang with more power in the singers formant region (around 2-3.5 KHz in male) in solo mode and in their fo region in the choir mode i.e. their voice had more energy in this region.

Bloothooft & **Plomp (1986)** found that irrespective of the mode of singing the sound level of the singers formant remained constant upto fo = 392 Hz. When fo values crosses 392 Hz a variation in sound level ranging from 9 to 14 dB was found.

Studies have been conducted to determine the relation between vowels and fo. **Bloothooft & Plomp (1985)** found that vowel configurations were similar for male and female singers upto an fo= 220. Beyond this spectral variations were observed. They also found that relation between the average sound level of singers formant and fo to be vowel dependent. **Benolken** & **Swanson (1990)** studied the effect of pitch related changes on the perception of sung vowel. They found that American english sung vowels became increasingly difficult to discriminate as fo is increased. They found that as fo increased the vowel is perceived as one with a higher f l as, the fo of the singer rises more rapidly than the listeners perceptual formant. With a high fo (near 1000 Hz) they found that two different vowels are perceived simultaneously.

Fugisaki (1981) & Sundberg (1982) found that the fo changes in music are best explained when the they used a logarithmic scale rather than a linear scale. The linear scale, according to **Sundberg (1982)** is based on physical laws, so they fail to adequately represent the dynamic characteristics of fo, which is more of a perceptual one. This perceptual aspect, he found is expressed best, when a log scale is used. Both of them found that when a linear scale is used, the expression is crude in the form of integers.

Sundberg (1982) in the same study also found the perceptual octave to be larger than the theoretical one in western classical music. **Datta, Ganguli & Majumdar (1983)** also quote of a similar result. This difference is found to be absent in the Hindustani classical music, wherein the perceptual and theoretical octave coincide exactly.

Nag, Bannerjee, Sengupta & 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 the lower limit to the whole upper limit, there occurs one or two breaks or failure in the continuous sound. This was vowel and sex independent. During the transition from one register to the other the amplitude of the singers formant becomes exceedingly high compared to the region where a particular register is being utilized.

An exploration into the area, has revealed that a study has not been carried out to find the fundamental frequency relation between the svaras using human voice. Similar studies have been conducted using string instruments and reveal the ratios to be complex numbers. The human vocal system may not be able to produce such a complex ratio. The present study aims at unravelling this mystery.

METHODOLOGY

The purpose of the study was to obtain the fundamental frequency relation between the adjacent svaras in Karnatic vocal music. The effect of drone and registers on the ratio were examined.

A. SUBJECTS: 2 male and 3 female trained singers between the ages of 25 and 40 years were chosen for the study. They had either passed the proficiency examination in music or were post graduates in music. All of them had a minimum of 7 years of experience. None of them had any recent history of any ear, nose or throat problem. All of them were familiar with the Mysore style of Karnatic music.

B. INSTRUMENTATION: The dual channel digital tape recorder (Sony DTC 59 ES) with Sony pre-amlifier / mixer (Sony MU-XO51) and Sony cardioid dynamic microphone (F 760) was used to record the samples in a sound treated room of dimension 10x12 feet.

The computer PC-AT 386 with 12 bit ADC and the software "ANALYSIS" and "FOEDIT" developed by Voice and Speech Systems, Bangalore were used for the fundamntal frequency analysis of the sample. The same software was used to plot the fundamental frequency in both linear scale as well as in log scale i.e. in semitone scale.

C. SAMPLE: The singers were asked to sing all the seven notes alongwith its varieties in all the three registers, under two conditions. They were

i) without the drone note   ii) with the drone note

Singing of all the notes in the ascending and descending scale mentioned below were recorded three times each. Each note was produced for atleast 2 seconds. The notes were sung in the following order.

1. P D1 D2 N2 N3 S R1 R2 G2 G3 M1 M2 P D1 D2 N2 N3 S R1 R2 G2 G3 M1 M2 P
2. P M2 M1 G3 G2 R2 R1 S N3 N2 D2 D1 P M2 M1 G3 G2 R2 R1 S N3 N2 D2 D1 P

The set-1 represents the ascending scale and set-2 the descending scale.

D. JUDGE: One professional singer was chosen as a judge. The singing samples were judged by him to ascertain its accuracy. The samples judged as being accurate by listening were taken up for the fundamental frequency analysis. The rest were discarded.

E. PROCEDURE :

Recording of Samples : The written version of the musical notes (Appendix-2) was provided a week in advance to the subjects in order to get familiarize and to practice them.

After a week when the subject arrived to the recording room of Dept. of Speech Sciences, AIISH, he / she was made to sit comfortably in the sound treated recording room. The noise level in the room was well below 35 dB A.

The subject was instructed as follows :

"You are requested to sing all the "swaraws' given to you in the written format in both ascending and descending order. You should sing each "swara" for atleast 2 seconds at a comfortable loudness. Please repeat the same for three times each"

The microphone (Sony F-760) was placed 15 cms from the mouth of the subject for recording oral output. The microphone was connected to pre-amlifier / mixer (Sony MU-XO51) and then to digital audio tape deck (Sony DTC 59ES). The recording was done on a digital audio cassette.

The subjects were asked to sing the notes and the recording was done under two conditions namely i) without drone note ii) with drone note. The drone note was provided using a Philips Stereo Amplideck (AW 739) through hi-fi headphones and its intensity was adjusted according to the subjects convinience. The note provided was of the 'A scale' for males and 'C scale' for females.

Same procedure was repeated for all the subjects.

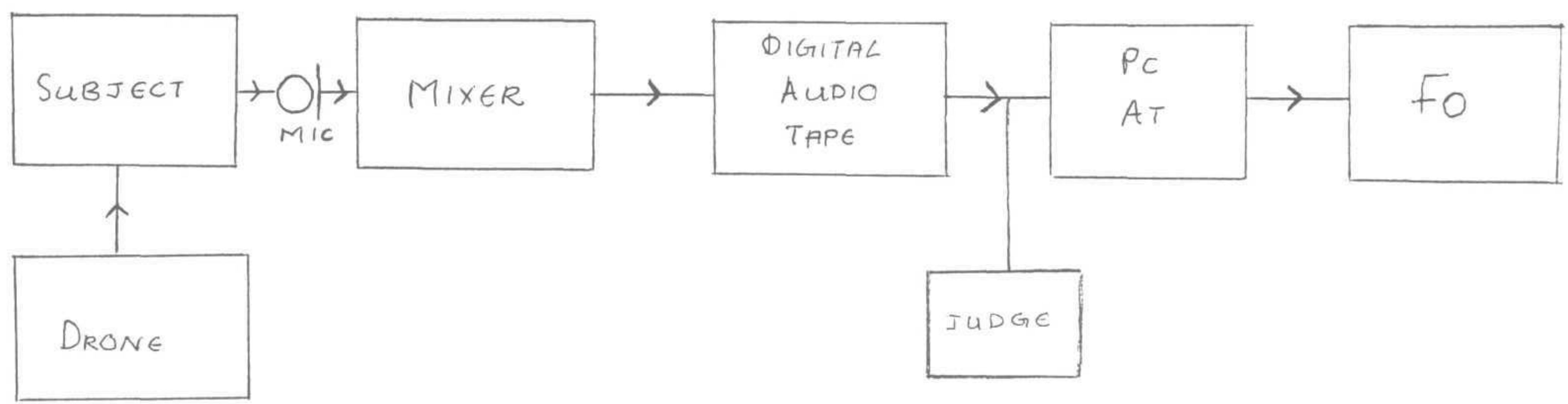
Acoustic Analysis : The recorded voice samples of singing of notes were digitized at 10 k H/ sampling frequency using a 12 bit Analog to Digital converter which is installed in PC-AT 386. Before extracting the fundamental frequency form these singing samples, these were edited using 'DISPLAY" programme developed by VSS, Bangalore. Middle 500 mili seconds of each note was edited and used for further analysis.

The fundamental frequency extacu'on was done using LPC Auto correlation technique. 'ANALYSIS" progamme which was developed by VSS, Banagalore was used for this purpose. A window size of 25 ms and resolution of 5 ms were used for the samples of male singers, while a window size of 15 ms and resolution of 3 ms were used for that of the female singers. Only the middle 500 ms of each note was used for the fundamental frequency analysis.

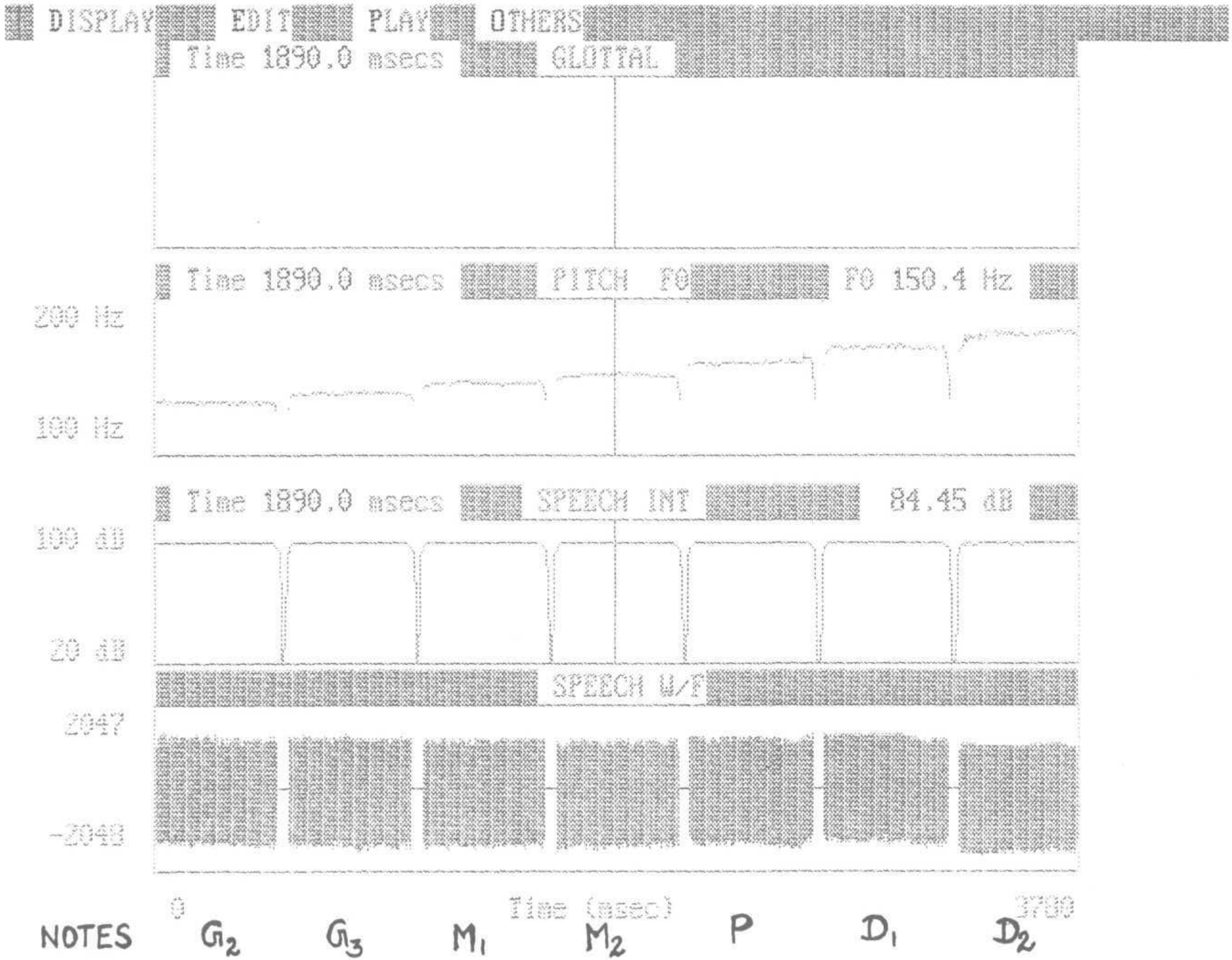
The extracted fo values were plotted on the screen with respect to time usig 'F0EDIT' programme and the values of the fundamental frequency of different svaras were noted down. These values which were in linear scale were converted into 'semitone' values which is in logarithmic scale. These semitone values of sung swaras were also noted down.

Statistical Analysis : Descriptive statistical procedures were used to describe the data. The ratios for individual tokens were found first and then averaged. Significant difference between males and females, with and without drone and among the three registers were examined for using T-test and ANOVA. The practically obtained values of the various notes were compared with the theoretically calculated values.

BLOCK DIAGRAM REPRESENTING RECORDING & F_0 EXTRACTION OF THE VOICE SAMPLE



F_0 & Intensity Display Of The Notes From The Computer



RESULTS & DISCUSSION

The fundamental frequency in Hz and semitones of all the 'swaras' were measured for 'arohana' and 'avarohana' i.e. ascending and descending scales, in the presence and absence of the drone. Graphs of the fundamental frequency for each condition were plotted for each subject.

The graphs revealed differences between males and females. The tracing obtained with and without drone did not overlap for the males whereas an overlap was observed for the females. An overlap between the tracings of arohanas and avarohanas was observed for both males and females and for both the presence and absence of the drone.

The ratios of the fundamental frequency of a 'swara' with its following 'swaras' were calculated. The mean of these ratios is given in Table I and II.

Table I: Mean and standard deviation of the ratios of the fundamental frequency (in Hz)

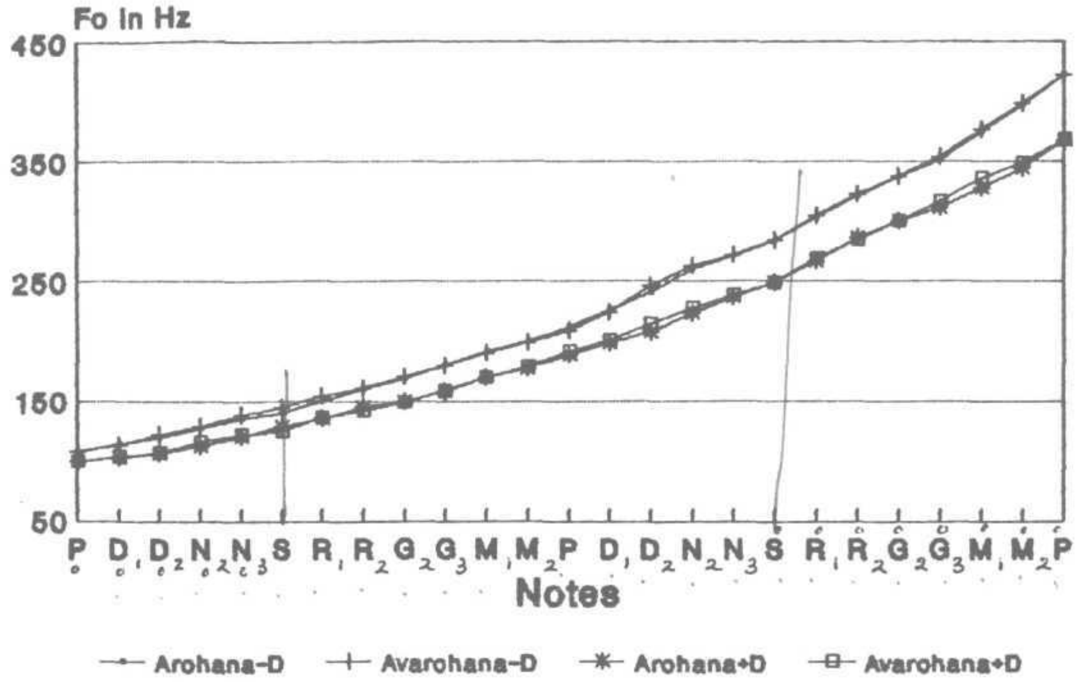
	Without Drone		With Drone	
	Males	Females	Males	Females
Mean	1.057364	1.054923	1.057575	1.056596
Standard Deviation	.002622	.001534	.001807	.001003

Table II: Mean and standard deviation of the ratios of the fundamental frequency (in semitones)

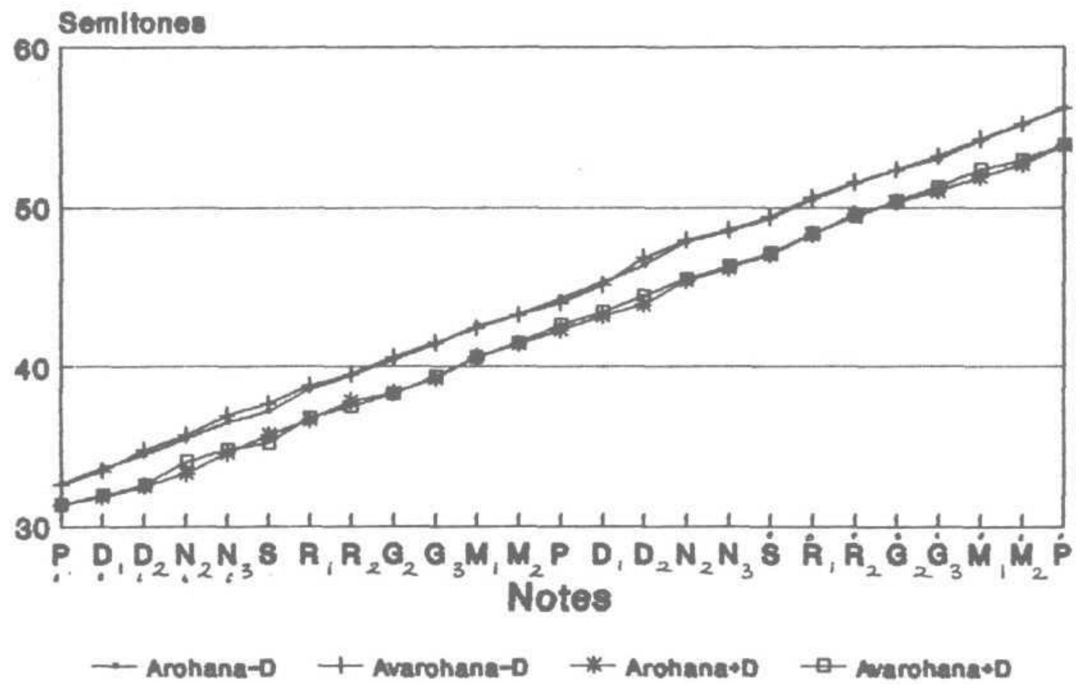
	Without Drone		With Drone	
	Males	Females	Males	Females
Mean	1.026234	1.018933	1.023407	1.0192
Standard deviation	.006455	.000925	.000636	.001068

SM1

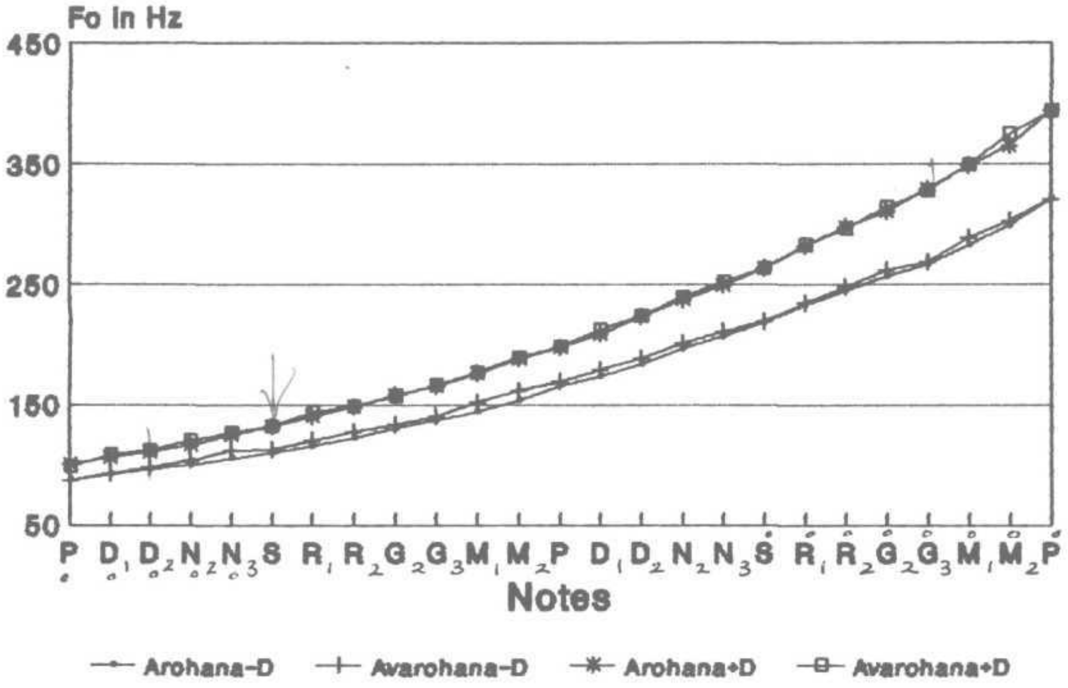
SUBJECT : 1 SEX : MALE



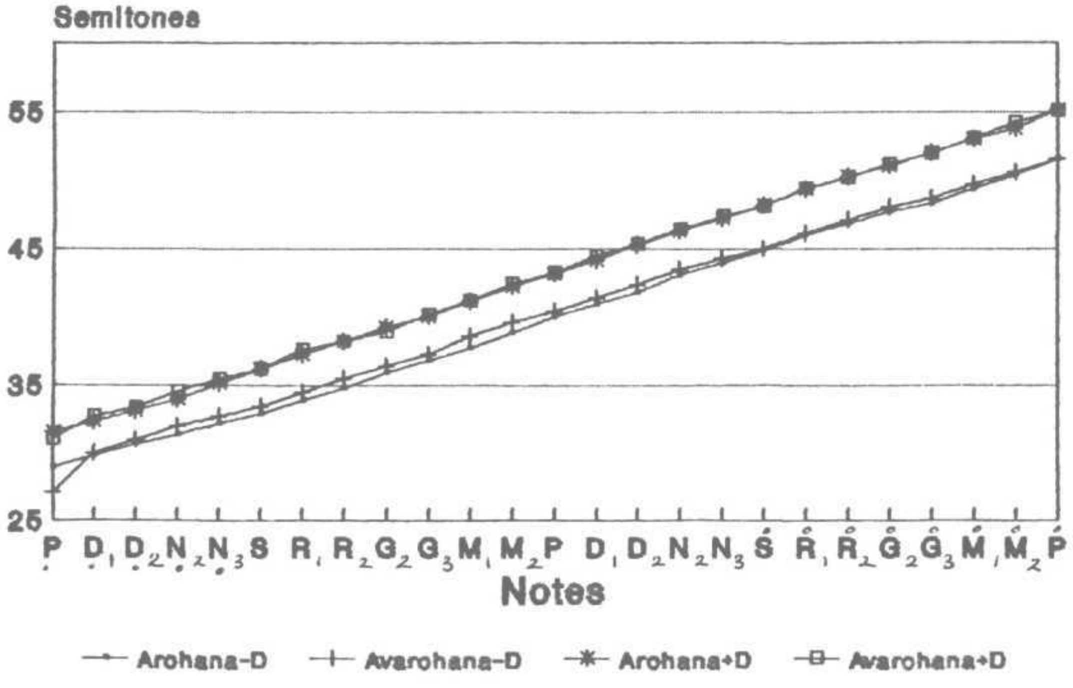
Graph 1 & 2 : showing Fundamenatal frequency of subject 1 with and without drone for 'arohana' and 'avarohana' in Hz and semitones



SUBJECT : 2 SEX : MALE

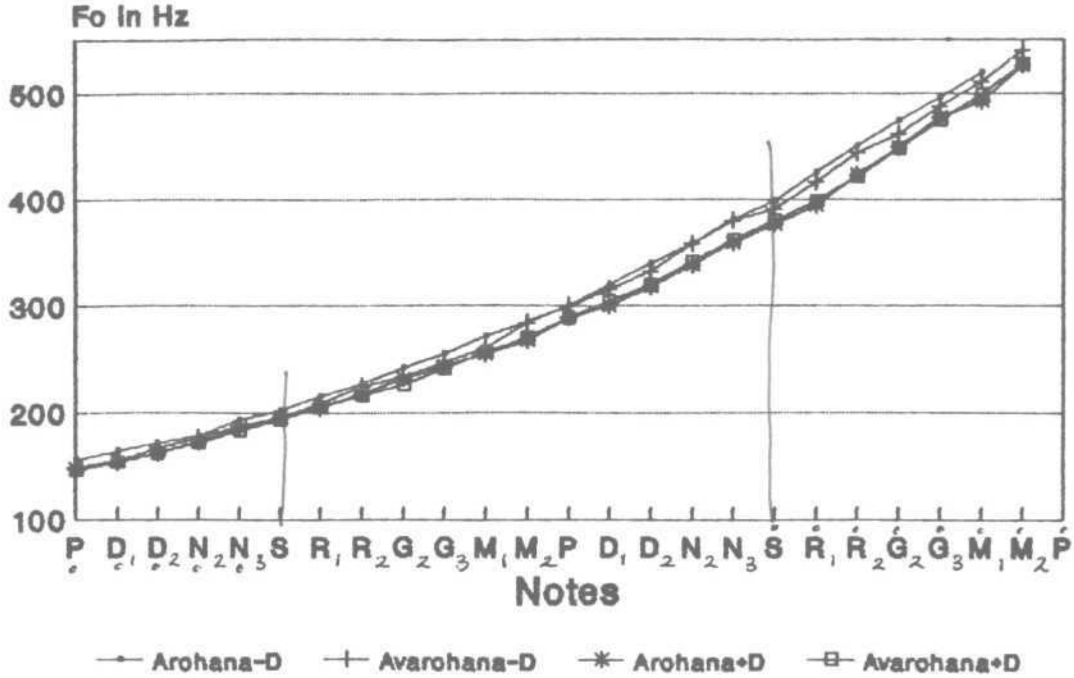


raph 3 & 4 : showing Fundamenatal frequency of subject 2 with and without drone for 'arohana' and 'avarohana' in Hz and semitones

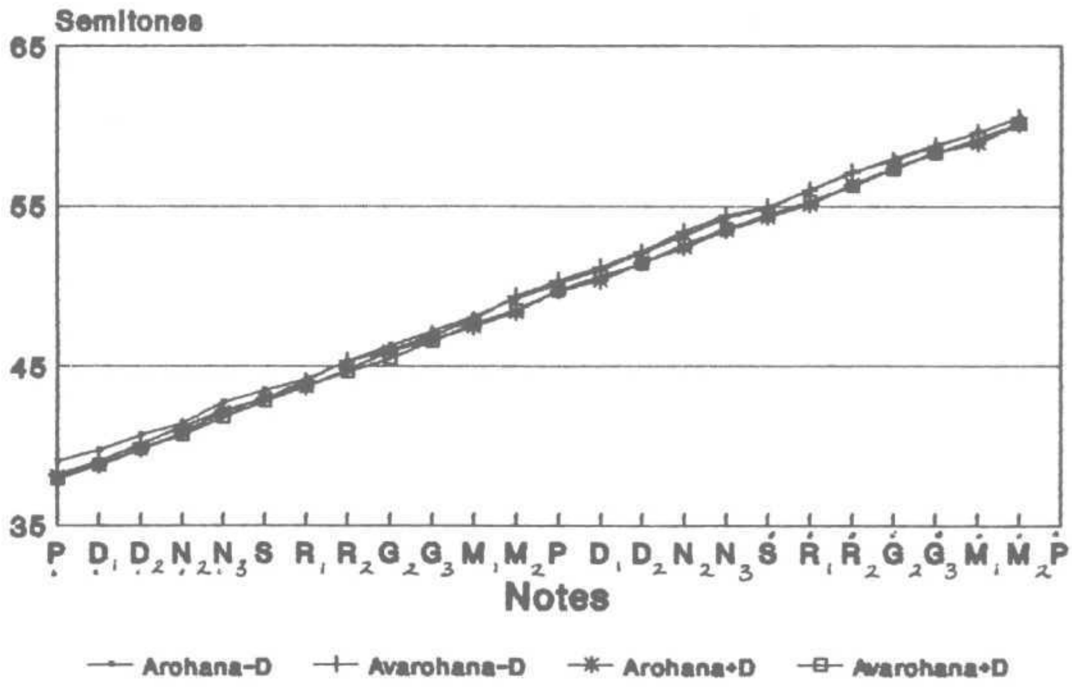


SUBJECT : 3

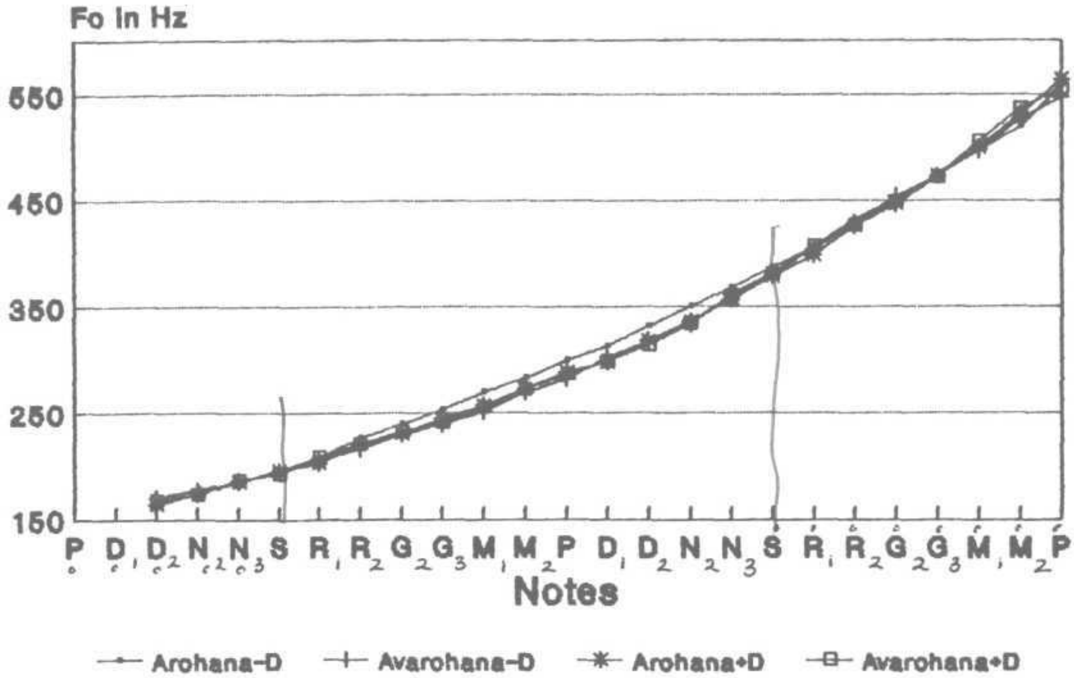
SEX : FEMALE



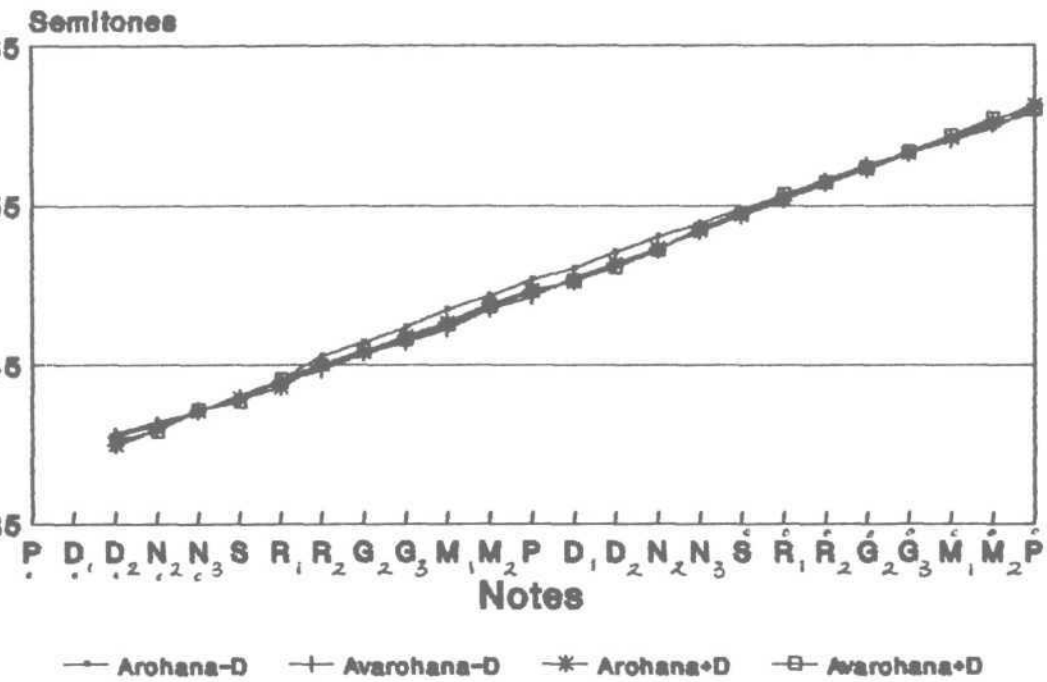
Graph 5 & 6 : showing Fundamenatal frequency of subject 3 with and without drone for 'arohana' and 'avarohana' i Hz and semitones



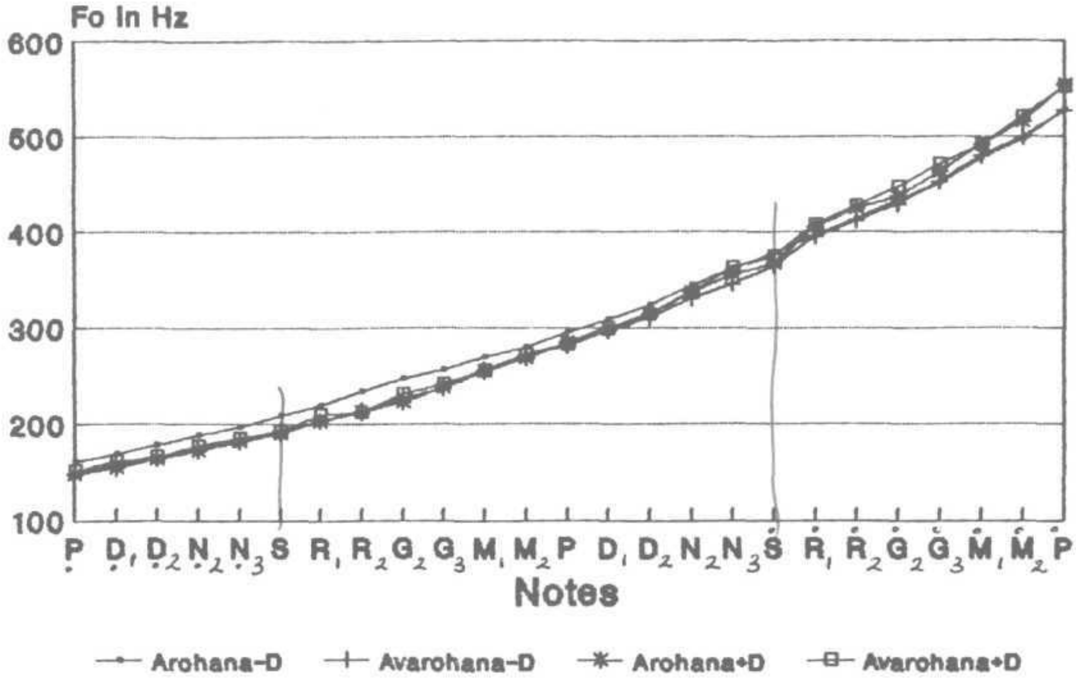
SUBJECT : 4 SEX : FEMALE



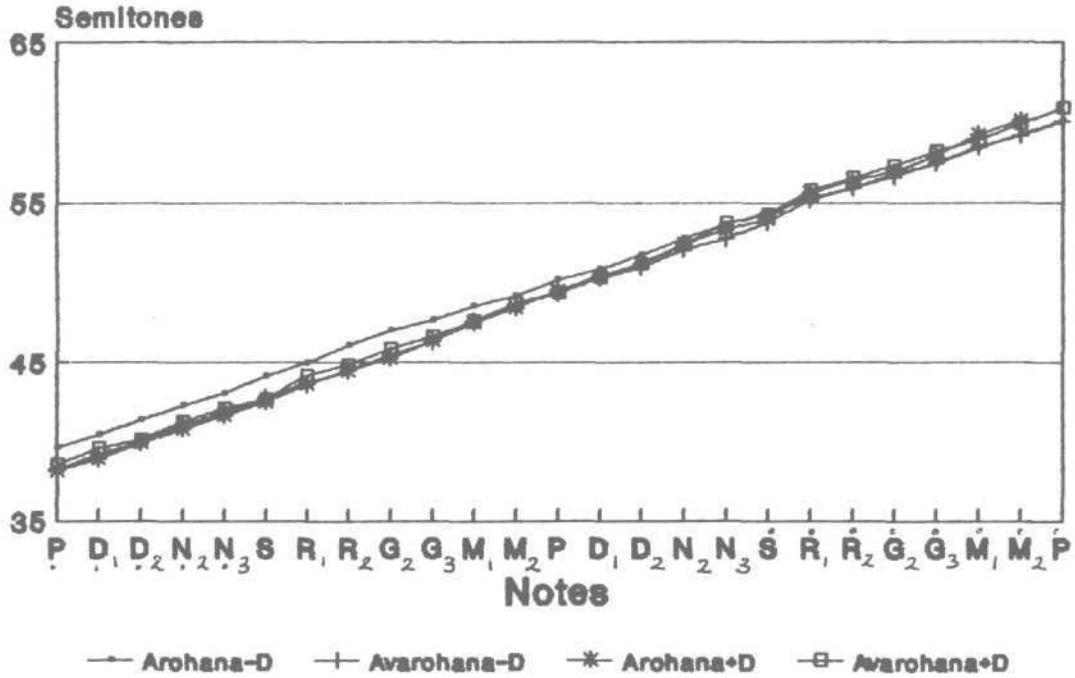
Graph 7 & 8 : showing Fundamenatal frequency of subject 4 with and without drone for 'arohana' and 'avarohana' in Hz and semitones



SUBJECT :5 SEX :FEMALE



Graph 9 & 10: showing Fundamenatal frequency of subject 5 with and without drone for 'arohana' and 'avarohana' in Hz and semitones



The mean of the ratios of the fundamental frequency (in Hz) is approximately equal to the value quoted by Sambamoorthy (1963) and Sundberg (1982). It corresponds to the value obtained in an equally tempered scale namely $2^{1/12}$ or 1.0594631. So these finding supports the fact that Karnatic music follows the equally tempered scale. It also reveals that human beings with training can exercise a high degree of control over their vocal system.

A comparison of the ratios in the presence and absence of the drone revealed no significant differences between them. The mean and standard deviation for the same is given in Table III.

Table III: F-ratio and probability values of the ratios across drone.

Variable	Sex of subject	Fo in Hz		Fo in ST	
		F-Ratio	Probablity	F-Ratio	Probability
Drone	Males	0.04	0.91	1.08	0.375
	Females	0.56	0.86	0.68	0.754

This result reveals that with practice, singers can sing accurately even in the absence of the drone note. This indicates that with training and practice singers acquire an inbuilt reference tone, so the role of the external reference point, i.e., drone is minimized. However the singers reports of an ease in singing in the presence of the drone note.

The effect of vocal register on the ratios was examined. The mean of the ratios across registers is given in the following Table.

Table IV: Mean of ratios across registers.

Register	Mean	
	Fo in Hz	Fo in ST
Low	1.0544	1.0241
Middle	1.0577	1.0217
High	1.0561	1.0176

Analysis using repeated measures of ANOVA revealed the absence of a significant difference among ratios, across registers, when the fundameantal frequency is calculated in Hz. This was true for both male and female subjects. The F-ratio and probability values for the same are given in Table V.

Table V: F-ratio and probability values of the ratios across registers for the fundamental frequency in Hz.

Variable	Sex of subject	F-ratio	Probability
Register	Males	0.59	0.56
	Females	0.46	0.63

A different picture was found to emerge when the fundamental frequency was calculated in semitones. A significant difference was observed across registers. The F-ratios and probability values are given in Table VI.

Table VI: F- ratio and probability values of the ratios across registers for the fundamental frefquency in semitones.

Variable	Sex	F-ratio	Probability
Register	Males	0.59	0.56
	Females	0.46	0.63

The Newman-Keuls comparison test was used for further comparison of the means across registers. It was found that for the male subjects, the ratio of only the low register differed significantly from that of the middle and high register. On the other hand, for the female subjects, the ratios of the low and middle register differed significantly from that of the high register. This could be because the males found it difficult to go to the low register because their fundamental frequency is low whereas the females found it difficult to go to the high register because their fundamental frequency is high. The differences in the results when the fo is calculated in Hz and semitones can be attributed to the differences in scaling. The semitone scale being a logarithmic scale, even small differences are magnified and so a significant difference emerges. These differences could also be attributed to the small sample size.

The effect of sex of the subject on the ratios was also examined. No significant difference was obtained when the fundamental frequency was calculated in Hz, whereas a significant difference was obtained when the fundamental frequency was calculated in semitones. The F-ratios and probability values are given in Table VII.

Table VII: F-ratio and probability values of ratios across sex of the subject.

Condition	Fo in Hz		Fo in St	
	F-ratio	Probability	F-ratio	Probability
Without drone	0.61	0.4272	8.08	0.0118
With drone	2.89	0.1096	176.66	0.0000

This difference can be attributed to the differences in scaling when the fundamental frequency was calculated in Hz and semitones. The semitone scale being a logarithmic scale magnifies small differences making them significant.

A comparison made between the obtained fundamental frequency (in Hz) and the theoretically calculated values for all the notes of the middle register, revealed a close correlation between the two with a maximum difference of plus or minus 5 Hz. This correlation was found to be independent of the drone note.

SUMMARY AND CONCLUSION

Introduction:

The present study was undertaken to determine the fundamental frequency relation between the svaras of Kamatic vocal music. The review of literature on musical acoustics reveals that this relation has been studied only in instruments and not in human voice. The present study aims at calculating this relation and also studying the effect of the vocal register and the drone note on this ratio. For this purpose the fundamental frequency of the seven notes and its varieties was calculated.

Procedure:

Two males and three females in the age range of 25 to 40 years served as subjects. All of them were well trained and had a minimum of 7 years of singing experience. The sample recorded was that of all the notes with its varieties in the three registers, namely low, middle and high, and under two conditions, namely without and with the drone. The sample was analyzed for its fundamental frequency in Hz and semitones. The ratio between the fundamental frequency of adjacent notes was calculated. Repeated measures of ANOVA were used to check for the effect of vocal register and the drone note on the ratio. The Newman-Keul's Comparison Test was used for further comparison when significant differences were obtained.

Conclusions:

The fundamental frequency relation between the adjacent svaras is 1:1.056143 when the fundamental frequency is calculated in Hz, and is 1:1.022583 when it is in semitones. This ratio is unaffected by the presence or absence of the drone note. No significant difference was obtained between males and females when fundamental frequency is in Hz but a significant difference exists when fundamental frequency is in semitones. This ratio was also to be unaffected by the presence or absence of the drone note, or the vocal register when the fundamental frequency is in Hz. When the fundamental frequency is in semitones, the ratios of the low register was found to differ significantly from that of the middle and high register for the males, whereas that of the high register differed significantly from that of the low and middle register for females. A comparison of the practically obtained values of the fundamental frequency of the svaras with the theoretically calculated ones revealed a close correlation between the two. A maximum difference of 5Hz was observed.

Implication:

This study proves that with training the human vocal system is capable of producing notes which bear complex ratios with one another. It also highlights the fact that well trained singers have an inbuilt reference tone which minimizes the need for an external drone note.

Limitation:

1. Sample size is small. 2. Other styles of Karnatic music eg. Tanjore style has not been considered.

Recommendation for further research:

1. The study can be carried out on a large sample.
2. The study can be carried out with the 'alapana' sample of the notes.
3. A similar study can be done using ragas in which all the seven notes are included.
4. The effect of number of years of training on the ratio can be studied.

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APPENDIX-1

FORMAT FOR RECORDING INFORMATION

NAME: AGE: SEX:

EDUCATION: PROFESSIONAL/AMATEUR

AGE AT WHICH FORMAL TRAINING STARTED:

NO. OF YEARS OF TRAINING:

NO. OF HOURS OF PRACTICE A DAY:

H/O VOICE PROBLEM

NATURE OF PROBLEM DURATION OF PROBLEM TREATMENT

MEASUREMENTS:

Fo of /a/ /i/ /u/

APPENDIX - 2

1. P̣ Ḍ1 Ḍ2 Ṇ2 Ṇ3 S R1 R2 G2 G3 M1 M2 P D1 D2 N2 N3 Ṡ Ṙ1 Ṙ2 Ġ2 Ġ3 Ṁ1 Ṁ2 Ṗ
2. Ṗ Ṁ2 Ṁ1 Ġ3 Ġ2 Ṙ2 Ṙ1 Ṡ N3 N2 D2 D1 P M2 M1 G3 G2 R2 R1 S Ṇ3 Ṇ2 Ḍ2 Ḍ1 P̣

1. ಪ ಧ1 ಧ2 ನಿ2 ನಿ3 ಸ ರಿ1 ರಿ2 ಗ2 ಗ3 ಮ1 ಮ2 ಪ ದ1 ದ2 ನಿ2 ನಿ3 ಸ ರಿ1 ರಿ2 ಗ2 ಗ3 ಮ1 ಮ2 ಪ
2. ಪ ಮ2 ಮ1 ಗ3 ಗ2 ರಿ2 ರಿ1 ಸ ನಿ3 ನಿ2 ದ2 ದ1 ಪ. ಮ2 ಮ1 ಗ3 ಗ2 ರಿ2 ರಿ1 ಸ ನಿ3 ನಿ2 ಧ2 ಧ1 ಪ