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EMOTION COGNITION BASED CATEGORIZATION AND LEARNING OF INDIAN CLASSICAL MUSIC (*GURU SISHYA PARAMPARA* ONLINE) USING NOVEL NON-LINEAR COMPUTING TECHNIQUE

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Music, when soft voices die,
Vibrates in the memory— Shelley

Preface:

This research project is focused to characterize the emotion (Rasas) of Indian Classical music including dance using rigorous scientific techniques of 21st century based on chaos formalism. The topic is huge and multi-dimensional covering the basic aspects of acoustical and neuro-cognitive features. This novel research is expected to deliver new interesting findings about emotions from acoustical and cognitive standpoint. The results will be useful to scholastic persons in global context interested in bringing out relationship between emotions and brain functions from deepest level of scientific exploration. In brief, this is an attempt to extend our conventional wisdom of scientific application to entire canvas of art, culture and science which is a need of the day.

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"There are thousands of ragas, and they are all connected with different times of the day, like sunrise or night or sunset. It is all based on 72 of what we call 'mela' or scales. And we have principally nine moods, ranging from peacefulness to praying, or the feeling of emptiness you get by sitting by the ocean."

Ravi Shankar

"The fact that the colors in the flower have evolved in order to attract insects to pollinate it is interesting; that means insects can see the colors. That adds a question: does this aesthetic sense we have also exist in lower forms of life?"

......Richard P. Feynmann

Prelude:

Humans have engaged in artistic and aesthetic activities since the appearance of our species. Our ancestors have decorated their bodies, tools, and utensils for over 100,000 years. The expression of meaning using color, line, sound, rhythm, or movement, among other means, constitutes a fundamental aspect of our species' biological and cultural heritage. Art and aesthetics, therefore, contribute to our species identity and distinguish it from its living and extinct relatives. Science is faced with the challenge of explaining the natural foundations of such a unique trait, and the way cultural processes nurture it into magnificent expressions, historically and ethnically unique. How does the human brain bring about these sorts of behaviors? What neural processes underlie the appreciation of speech, music, drama and dance? How does training modulate these processes? How are they impaired by brain lesions and neurodegenerative diseases? How did such neural underpinnings evolve? Are humans the only species capable of aesthetic appreciation, or are other species endowed with the rudiments of this capacity? In Natyashastra, a classical treatise by Bharata, a famous saying by Bharata needs mentioning here "that which can be relished – like the taste of food – is rasa (emotions)": "Rasyate anena iti rasaha (asvadayatva). The concept of rasa is unique to Indian poetics and dramatics and is essentially a creation of the Indian genius—Bharata. With his organized presentation, Bharata carved a niche rasa-sutra in the annals of poetics and dramaturgy. He presented rasa formula in context to natya in his Natyasastra. Later on the rasasutra became the touchstone for all the poetics. The aim of a dramatic performance is to evoke sentiment or rasa in the mind of the learned audience. The ultimate goal, purpose of writing, presenting and viewing a play is to experience rasa realization. It has been found that no one word or phrase is adequate to convey the total meaning of rasa. Rasa is actually the impression created on the mind of the sympathetic audience by the expression of emotions and is an experience the individual is subjected to on account of this expression. Emotion identification has recently been considered as a key element in advanced human-computer interaction. In seventeenth century, Descartes considered emotion to mediate between stimulus and response. Though self report measures form the cornerstone of emotion recognition research, recently, other physiological measures have gained importance in identifying high arousal levels.Human beings embody express, process, inhibit, function, act, and feel. All the verbs I just listed, along with many more, have as their sources the essential parts of what constitutes a human: body, mind, emotion, and behavior. Kemp states that cognitive science acknowledges the central role of the body and enables a better understanding of understand the relationship between thought and expression (p. 20). Acting, on the other hand, does not explain the bodymind-soul relationship, but rather provides the richest material for exploration of and experimentation with human emotions. A recent discovery in the brains of primates, mirror neurons is special neurons that show activity both when a subject performs an action and when it observes the same action performed by another. Some scientists consider mirror neurons one of the most important findings in neuroscience in the last decade, in part because they are thought to be responsible for the empathic response in humans. In particular, these neurons allow a person to empathize with someone who is having a traumatic experience. How does this adaptation come into play for an actor? Actors must draw on various sources—memory, imagination, observation—to elicit their own deep emotional responses. This emotional activity must have a level of authenticity, on a physiological and even a neurological level, in order to provoke empathy in the observer, whether it's another actor or a member of the audience. Drawing on the perspectives of neuroscience, drama therapy, kinesiology and acting technique, the mirror neuron theory is expected to explain the mechanisms that allow the actor to move an audience emotionally. In the context of aesthetics in both arts and science it is very important to appreciate the following: Symmetry and asymmetry are at the heart of our aesthetic experience in music, dance, drama and art. Also, symmetry and search for broken symmetry guide us in understanding of all Laws in Physics..

Time has come to study contemporary view of space-time and cosmology from the view point of symmetry and we may use learning strategy from the art to develop a deeper understanding of the reality which is beyond our sensory perception and which is described by mathematics. More precisely, chaos based scientific techniques are attempted to decipher symmetry in terms of fractals. Fractals are known for their aesthetic appeal

The term “fractal” coined by Mendelbrot describes a shape or pattern with a greater pattern of which it is a scaling piece identical to the greater pattern and in which are reproduced an infinite number of patterns or fragments which are also identical to it, thus, identical to whole in all scale. In the ongoing project, “Emotion cognition based categorization and learning of Indian Classical Music (guru-shishya parampara) using novel nonlinear techniques” as Tagore National Scholar, a new and novel method was proposed and developed based on rigorous chaos based scientific approach and in a way readily accessible to musicians in general. In the pilot study, pedagogy is presented as a scientific supplement with the existing guru-shishya parampara technique. The preliminary study is encouraging. Since emotion characterization is a difficult task remembering extensive shades of emotions rendered in different ragas as well as even in one raga, extensive research is needed. This approach is new in the global scenario so far as music teaching and learning is concerned. The Indian guru-shishya parampara can be sustained using modern techniques of science and technology. Based on the initial study in music, we propose to extend this methodology in case of emotion elicitation in dance and drama. In case of drama, both audio and video data will be analyzed with the same chaos based non linear computation techniques. So far as human response is concerned, we would use both self-reporting of audience as well as biosensors like Electroencephalogram (EEG).

EEG signal will also be analyzed with nonlinear chaos based techniques yielding a quantitative parameter. Dance is one of the most expressive types of affective body language. Yet, few of us can imagine dance without the accompaniment of one of the other grand art forms: music. Music often potentiates the experience of affect expressed in movement; and in theatre and cinema alike, directors use music to great effect in order to regulate the audience's emotions. Psychological research has provided ample evidence to confirm that our affective perception of an emotional stimulus presented to one sensory modality (e.g., visual) is altered by the emotional information presented to another modality (e.g., auditory), even when participants are asked to ignore the latter. This effect is called the cross-modal bias, and was first described in the purely perceptual domain, showing that visual perception (e.g., intensity) is enhanced by simultaneous auditory stimuli. In case of drama, a recent neuro-cognitive study indicates that special type of neurons known as "mirror neurons" are fired during witnessing drama. That mirror neurons can be studied with EEG using a special EEG frequency range called mu-wave. It is highly interesting to mention that the oldest treatise of drama "Abhinay Darpan" by Nandikeshwar contained the name "Mirror of Gesture". This association of ancient wisdom with modern science is our motivation of this study and a pioneer work is proposed in global scenario which will deal with Indian age old heritage of music, dance and drama.

Chapter ONE

"Music - Sound and Beyond"

What is Music?

Can music be defined ? "You are the music while the music lasts"—music is so defined by T.S. Eliot. Music is on of the oldest entities of human culture, played a very important role in the evolutionary process. There is no culture which has no language; there is no culture which has no music. Tagore in his famous conversation with Einstein says "In India, the measure of a singer's freedom is in his own creative personality. He can sing the composer' song as his own, if he has the power creativity to assert himself in his interpretation of the general law of the melody which he is given to interpret". The conversation which took place almost a century ago it still very much relevant in the present context. Still today most people in the Indian subcontinent see music as a thing of art and craft, something in diametrically opposite poles to Science.

Indian Classical Music

In Indian classical music (ICM) each Raga has a well defined structure consisting of a series of a series of four/five or more musical notes upon which its melody is constructed the way the notes are approached and rendered in musical phrases and the mood they convey are more important in defining a Raga then the notes themselves. Every performer of this genre is essentially a composer as well as an artist because the performers of ICM visualize every Raga as a living existence.

Raga

The word Raga is derived from the Sanskrit word "Ranj" which literally means to delight or please and gratify. The goal of a performer is to convey the musical structure and expression so that the audience gets pleasantness. For every Raga, the tonic 'Sa' is the most important note as each Raga can be identified uniquely from appropriate establishment of 'Sa'.

Indian Classical Music (ICM) - Singing Style

Indian Classical Music is divided into two genres according to singing style—Hindustani Music (Originated in the northern parts of Indian) and Carnatic Music (popular in southern parts of India) The vocal presentation of Raga in Hindustani music style can be divided into two categories—Khayal and Dhrupad. Khayal singing usually starts with a short Alap or Aochar while in case of Dhrupad singing or instrumental performances.

Alap is sung/played for a much longer time period. The Alap is the opening section of a typical Hindustani Music (HM) performance. In the alap part, the raga is introduced and the paths of its development are revealed briefly using all the notes used in that particular raga and allowed transitions between them with proper distribution over time. Alap is usually accompanied by the tanpura drone only and sung/played at a slow tempo or sometimes without tempo.

Then comes the vilambit bandish part(in case of vocal music) where the lyrics and taal are introduced. Bandish is a song i.e. a fixed, melodic composition in Hindustani vocal or instrumental music, set in a specific raga, performed with rhythmic accompaniment by a tabla or pakhawaj, a steady drone, and melodic accompaniment by asarangi, harmonium etc. (Neuman, 1990).

Vilambit is a type of bandish which is sung at a very slow tempo, (laya) or 10-40 beats per minute. Madhyalaya or drut bandish are sung usually at a much higher timpo. Along with the bandishes the performers sing vistara (melodic and rhythmic variations or improvisations of the lyrical contents of the bandish, which help is convey the meaning of the lyrics more elaborately to the listeners) and taan (melodic and rhythmic improvisations of the phrases of a raga, mostly sung without lyrics).

Dhrupads are simpler forms of Khayal having higher emphasis on Meends and lesser emphasis on Alangkars. In case of instrumental representation of a Raga, after the completion of alap. Gat, Jor and Jhala are played sequentially. In ICM, the existing phrases are stretched or compressed, and the same may happen to motives from the phrases; further motives may be prefixed, infixed and suffixed. Phrases may be broken up or telescoped with others, and motives or phrases may be sequenced through different registers (Neuman, 1990). Thus, during a performance, a singer steadily loosens the strangle hold of the rules of music in a subtle way. He does not flout them, he merely interprets them in a new way, which is the beauty of Hindustani classical music and there comes the wisdom and Raga and its grammar are only means and not ends in themselves. The way in which a performer interprets raga during each specific performance is unique and is the very essence of improvisation in Hindustani music (HM). Unlike symphony or a concerto, Raga is unpredictable; it is eternally blooming, blossoming out into new and vivid forms during each and every performance which is the essence of “improvisation” (McNeil, 2007).

Tagore during his discussion with Einstein emphasized that is Indian Classical music. There duality prescribed grammar and freedom of expression of performer.

Music and Emotion

Emotion is a subjective experience characterized by psycho-physiological expressions, biological reactions, and mental states. An emotion is a complex psychological state that involves three distinct components: a subjective experience, a physiological response, and a behavioral or expressive response. The hundreds of colours present in the universe can be generated by using combinations of a few basic colours all human emotions are generated from a few basic emotions brain scientists and psychology experts have proposed different emotional models. An American Psychologist Paul Ekman as part of his valuable legacy established the foundations for measuring emotions. During his research, he discovered that basic emotions exists and are culturally independent. These basic emotions can be read literally from people's facial expressions. He found that six different facial expressions (angry, sad, disgust, happy, fearful and surprise) were categorically recognized by humans from distinct cultures using a standardized stimulus set. In other words, these facial expressions were stable over age brackets, and were consistent even in people blind by birth. Another American Psychologist James presented his two-dimensional model of affect, including pleasure-displeasure and arousal-sleep as the two dimensions. The model itself is based on the internal representation of affect of the people tested, i.e., their cognitive structure of the interpretation of emotions and not a description of their current affective state. It is believe that the result is a universal and easily transferable metric for describing emotions. The Greek philosopher Aristotle thought of emotion as a stimulus that evaluates experiences based on the potential for gain or pleasure. If someone smiling and shouting "Shut up" at someone it does not have the same meaning as saying it while aggressively shouting "SHUT UP". In literature these are a number of empirical investigations that attempt to disentangle the contributions of universal and culture-specific associations between music and emotion.

Ragas and Rasas

Music in the Indian subcontinent has been a source of aesthetic delight from time immemorial. From the time of Bharata's Natyashastra there have been a number of treatises which speak in favor of the various rasas meaning emotional experiences. The consolidation and evocation of rasa represent the function of all the fine arts including music. This is the central conception in Indian since Bharats's Natyashastra first expounded the doctrine of rasa with its eight categories, viz., Love or Romance (Sngara), Gaiety or Humor (Hasya), Compassion (Karunya), Fury (Raudra), Valor (Veera), Terrible (bhayankara), Loathesomeness (bibhatsa), and Wonder (adbhuta). Later fourth century onwards Silence or Tranquillity (shanta) was added as the ninth category and considered as the supreme. The aim of any or musical performance is to emote in the minds of audience a particular kind of aesthetic experience, which is described as "Rasa". The concept of "Rasa" is said to be the most important and significant contribution of the Indian mind to aesthetics.

The study of aesthetics deals with the realization of beauty in art, but till date science had nothing to do with the aesthetic experiences corresponding to a particular performance and was kept as a separate entity. Recently scientists began to understand the huge potential of systematic research that Indian Classical Music (ICM) has to offer in the advancement of cognitive science as well as psychological research. A number of studies have revealed unlike Western Music pieces the emotions evoked by Indian Classical Music pieces are often more ambiguous and far more subdued. Earlier few musicologists believed that a particular emotion can be assigned to a particular Raga but recent studies clearly revealed that different phrases of a particular Raga is capable of evoking emotions among the listeners.

The different sets of ragas form the backbone of Indian Classical Music and there are several questions which need to be answered to :

•How do the ragas induce emotion in the audience? What are the acoustic features involved which modulates the emotional responses corresponding to a certain raga ?

•What are the cognitive attributes during the listening of an emotional raga? Are there specific brain regions which are activated when a person is listening to the raga of a particular emotion or there exists some universality in regards to brain response ?

It is essential to assess the effect of emotions induced by Hindustani Classical music in human brain using latest state of the art non-linear tools. The ambiguous nature of emotions portrayed by Hindustani ragas have also been subjected to robust analysis and it has been established that there is nothing called discrete emotion in Hindustani music, emotions conveyed by a raga are all superposition of two or more emotional states.

The use of pauses (or silence) in Hindustani music and how the distribution of pauses change the emotional expression of a raga need to be studied in detail.

Guru-Shishya parampara

One of the most unique and exclusive feature which is incorporated in the teaching of Indian Classical Music is the “Guru-Shishya” tradition. In recent times, the education of Indian Classical Music is the imparted in several institutions, schools, colleges and universities. The Gharana comes into existence through the confluence of the “Guru” and the “Shishya”. A wise “Guru” through his intelligence, aptitude and shear practice creates a sense of uniqueness and exclusivity and thereby inculcates a special eminence into his form of music. These attributes and traits are amicably transferred into the talented “Shishya” and the particular form of the performing arts thus becomes a traditions. The Guru acts as the instrument through which the importance, the intricacies, and the sound of the music as well as the thinking behind the music are transferred to the student. Alberto Neuman stats that “The Guru enculturates the Shishya into musical life. He transmits two elements, neither of which is available through any other medium of instruction: a body of knowledge which is both secret and esoteric, and the way a musician must lead his life. He transmits two elements, neither of which is available through any other medium of instruction: a body of knowledge which is both secret and esoteric, and the way a musician must lead his life. This totally musical life provides important evidence that social relations between musicians are indeed systematic. It comprehends a subculture in Indian which cuts across the boundaries of sex, religion, age, caste, territory, language, as well as time, yet includes all these as internal categorical distinctions”. The Guru acts as the guide on the path towards the higher consciousness, to the deepest level of sound through music.

In the 21st century, due to advancement of communication technology Guru –Shishya parampara has become subject of interest.

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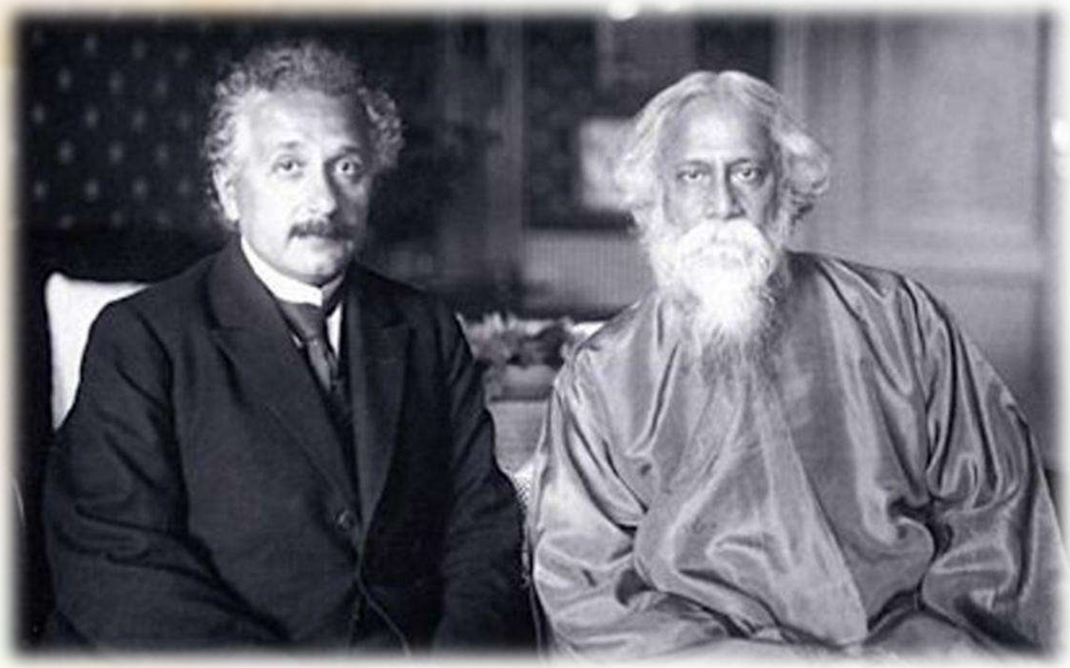


Chapter TWO

"World of Ragas"

EMOTIONAL CHARACTERIZATION

Enough study has been done about musical structure of different ragas…
I do not think more study is important in this domain..
What is important that scientists should endeavor to find the reasons why different musical structures evoke different emotions????

….Rabindranath Tagore, 1881

स्वरवर्णविशेषेण ध्वनिभेदेन वा पुनः ।
रज्यते येन यः कश्चित् सः रागः सम्मतः सताम् ॥

The Raga is, as the wise declare,
the sequence of musical notes
and the play of sound
which delights the hearts of men.

- **The purpose of Indian music is not to create a fine singer, or artist, or performer, but a new type of person**
- With the singer, who has attained ***Swara***, music grows and opens into new dimensions.
- He steadily **loosens the strangle hold** of the rules of music in a subtle way.
- He does not flout them; he merely **interprets** them in a new way.

•Suddenly, the tension of having to look out for transgressions of our music's pervading grammar is gently removed and in its place a wondrous bliss takes over.

• **There comes the wisdom that Raga and its grammar are only means and not ends in themselves.**

•Some scholars believe that the real name of our music is not '**Sangeet**', which is a general label that includes dance, drama and music, but '**Raga Vidya**' or the knowledge of Raga.

• The Raga is the costume of the **Swara**

• **From the notes of the scale the Swara can be dressed and decorated with several thousand Ragas which are, technically speaking, permutations and combinations of the notes of the scale**.

•*We are often asked how many Ragas are there in our music*.

• There is no true answer to this question.

• The most simplistic answer is of course the mathematical one, which in fact is not an answer at all

• From a **single scale** it is possible to have **4840** Ragas. Thus, from **72** scales we can have **34840** Ragas.

• To this, if we add Vakras, meends, different Shrutis, Vadis and Samvadis we can have several millions Ragas

THIS IS OF COURSE ABSURD

LIST OF IMPORTANT *RAGAS* IN HINDUSTANI MUSIC:

In the next few pages we have tried to present an exhaustive list of all the *ragas* present in Hindustani classical music:

Alhaiya Bilaval	Bihagara	Jog	Pilu
Amritvarshini	Bilaskhani Todi	Jogiya	Puriya
Asa	Bilaval	Kafi	Puriya Dhanashree
Asavari	Brindabani Sarang	Kalavati	Purvi
Ahir Bhairav	Darbari Kanada	Kalyani	Rageshree
Bageshri	Deepak (Poorvi Thaat)	Kedar	Ramkali
Bahar	Desh	Khamaj	Sahana
Bairagi	Desi	Kirwani	Sarpada
Bairarika Sargam	Dhanashree	Lalit	Shankara
Barwa	Durga	Madhukali	Shivaranjani
Bhairav	Gauri	Madhuvanti	Shree
Bhairavi	Gond	Malgunji	Sindhu Bhairavi
Bhatiyar	Gurjari	Malhar	Sohni
Bhimpalasi	Hameer	Malkaush	Sorath
Bhinnashadaja	Hem Bihag	Marva	Suhi
Bhoopeshwari	Hindol	Megh	Todi
Bhopali	Jaijaivanti	Megh Malhar	Vasant
Bhupal Todi	Jaitsri	Multani	Yaman
Bibhas	Jaunpuri	Nat Bhairav	Yaman Kalyan
Bihag	Jhinjhoti	Patdeep	Zeelaf

LIST OF OTHER *RAGAS*:

Aarabi	Bhavsakh	Deosakh	Gunjikauns	Jogwanti
Abheri Todi	Bhawani Bahar	Desh Malhar	Gurjari todi[1]	Joun Bhairav
Abhogi Kanada	Bhawani	Deshi Tilang	Guru Kalyan	Kabir Bhairav 1
Achob	Bhilalu	Deshkar (Purvi aang)	Gyankali	Kabir Bhairav 2
Adambari Kedar	Bhim (Kafi thaat)	Deshkar[1]	Hamir Bahar	Kafi Bahar
Adana Bahar	Bhinna Bhairav	Dev Gandhar (Jogia aang	Hamir Kalyan	Kafi Kanada
Adana Malhar	Bhinna Kauns	Dev Gandhar	Hamir Kedar	Kafi Malhar
Adbhut Kalyan	Bhinna Lalat	Devaranjani	Hamir[1]	Kalahans
Adbhut Ranjani	Bhinna Rageshri	Devata Bhairav	Hamiri Bilawal	Kalaranjani
Ahimohini	Bhinna Shadaja[1]	Devgiri Bilawal	Hansanarayani (Purvi thaat)	Kalashree
Ahir Kanada	Bhoopal (Bhairavi thaat)	Devkauns	Hanskinkini	Kalawati[1]
Ahir Lalat	Bhoopal Todi[1]	Dhan Basanti	Hansvinod	Kalingada[1]
Ahiri Malhar	Bhup Bilawal	Dhanakoni Kalyan	Harikauns	Kamal Shree
Ahiri Todi	Bhup Nat	Dhanashri (Bhairavi aan	Haripriya	Kamalaranjani
Alahiya Bilawal	Bhupawali	Dhanashri (Kafi aang)	Hem Bihag	Kameshwari
Alamgiri	Bhupkali	Dhanashri (Khamaj aang	Hem Kalyan	Kamod Nat
Amba Manohari	Bhuplai	Dhanawarchi Kalyan	Hem Lalat	Kamod[1]
Ambika Sarang	Bibhas (Marwa aang)	Dhani[1]	Hem Nat	Kamodwanti
Ananda Bhairav	Bibhas (Purvi aang)	Dhanikauns	Hemant	Kanada Bahar
Ananda Malhar	Bihagada (with N)	Dhanya Dhaivat	Hijaj Bhairav	Kapar Gauri
Anandi kedar	Bihagada (with n, N)	Dhulia Malhar	Hindol Bahar	Kedar Bahar
Anandi	Bihari	Dhulia Sarang	Hindol Basant	Kedar Bhairav
Anjani Kalyan	Bilaskhani Todi[1]	Dinka Shankara	Hindol Hem	Kedar Bhankar
Anjani Todi	Bilawal Malhar	Dinki Puriya	Hindol Kalyan	Kedar Mand
Anuranjani	Bilawali	Durga (Khamaj thaat)	Hindol Pancham	Kedar Nand
Araj	Birju ki Malhar	Durga Kedar	Hindolita	Kesari Kalyan
Arun Malhar	Chaiti Bhup	Durgeshwari 1	Hussaini Kanada 1	Khamaj Bahar
Asa Bhairav	Chakradhar	Durgeshwari 2	Hussaini Kanada 2	Khambavati
Asa Mand	Chalnat	Enayatkhani Kanada	Hussaini Kanada 2	Khammaji Bhatiyar
Asa Todi	Champak bilawal	Gagan Vihang	Hussani Bhairavi	Khat Dhanashree
Averi Bhairavi	Champak	Gandhari 1	Imratkauns	Khat Todi
Badhamsa Sarang	Champakali	Gandhari 2	Indumati	Khat
Bageshri Bahar	Chanchalsas Malhar	Gandhari 3	Jaijaiwanti[1]	Khem Kalyan
Bageshri Kanada	Chandani Bihag	Gandhi Malhar	Jaij Bilawal	Khemb
Bahaduri Todi	Chandani Kalyan	Ganeshwari	Jait Kalyan	Khemdhwan
Bairagi Bhairav	Chandani Kedar[1]	Gara Bageshri	Jait	Khokar
Bairagi Todi	Chandra Bhairav	Gara Kanada	Jaladhar Basanti	Kiranranjani
Bakul Bhairav	Chandra Bhankar	Gara[1]	Jaladhar Desa	Klawanti
Bangal Bhairav	Chandrakauns (Agra Gharana)	Gaud Bahar	Jaladhar Kedar	Komal Bageshri
Bangal Bilawal	Chandrakauns (Bageshree aang)	Gaud Bilawal	Janasammohini	Lachari Todi
Barari (Marwa aang)	Chandrakauns[1]	Gaud Malhar	Jangla Purvi	Lachchasakh
Barari (Purvi aang)	Chandramouli	Gaud Sarang	Jangula (Asavari aang)	Lagan Gandhar
Barathi Todi	Chandranandan	Gaudgiri Bahar	Jaunkali	Lajwanti
Barhams Sarang	Chandraprabha	Gaudi Lalat	Jaunpuri Bahar	Lakshmi Todi
Basant Bahar	Charju ki Malhar	Gauri (Bhairav thaat)	Jaunpuri Todi	Lalat Bahar
Basanta Mukhari[1]	Charukauns	Gauri (Kalingada aang) (	Jayajawanti (Desh aang)	Lalat Pancham
Basanti Kanada	Charukeshi	Gauri (Marwa aang)	Jayajawanti Kanada	Lalat[1]
Basanti Kauns	Chhaya bihag	Gauri Basant	Jayajawanti Todi	Lalit Bhatiyar
Basanti Kedar	Chhaya Gaud Sarang	Gavati	Jayajawanti	Lalit Bilas
Bayati	Chhaya Hindol	Gawati	Jayet	Lalita Gauri (Bhairava aang)
Beehad Bhairav	Chhaya Kalyan	Gopika Basant	Jetashree	Lalita Sohani
Bhairav Bahar	Chhaya Tilak	Gorakh Kalyan	Jhanjh Malhar	Lalitdhwani
Bhairav Bhatiyar	Chhaya	Govardhani Todi	Jog Bahar	Lalitkali
Bhankhar	Chhayanat	Gujari Todi	Jogeshwari	Lankeshri 1
Bhankhari	Dagori	Guna Kalyan	Jogi Bhairavi	Lankeshri 2
Bhaskali	Dayabati	Gunakali (Bilawal thaat)	Jogi Mand	Lankeshri Kanada
Bhatiyar (Marwa aang)	Deepak (Bilawal Thaat)	Gunakali Jogia	Jogia Kalingada	Lankeshwari
Bhatiyar (Purvi aang)	Deepak Kedar	Gunakree	Jogia	Lom
Bhatiyari Bhairav	Deepawali	Gunaranjani	Jogiya Asavari	Madha Kalyan
Bhavmat Bhairav	Deepranjani	Gunji Kanada	Jogkauns	Madhasuraja

Madhu Basant	Mudrika Kanada	Ramdasi Malhar	Shuddha Kalyan
Madhu Kalyan	Multani dhanashree	Ramsakh	Shuddha Kedar
Madhu Malhar	Nagaswaravali	Rangeshwari	Shuddha Lalat
Madhu Sarang	Nanad	Rasia	Shuddha Malhar (Bilawal thaat)
Madhu Saraswati	Nanak Malhar	Rasranjani Rasavati	Shuddha Malu
Madhukauns	Nand Basant	Rati Bhairav	Shuddha Nat
Madhumadh Sarang	Nand Kauns	Rayasa Kanada	Shuddha Sarang
Madhumalati	Nand[1]	Rewa (Purvi aang)	Shuddha Shyam
Madhuranjani	Narayani	Rupawati Kalyan	Shukla Bilawal
Madhusurawali	Nat Bihag	Rupkali	Shyam Kalyan
Madhyamad Sarang	Nat Bilawal	Rupmanjari Malhar	Shyam Kalyan
Malagunji	Nat Kamod	Sagera	Shyam Kalyan
Malashree	Nat Kedar	Sagunaranjani	Shyam Kauns
Malati Basant	Nat nagari	Saheli todi	Shyam Kedar
Malati Bihag	Natachandra	Saindhavi	Shyam Sarang
Malati	Natahams	Sajan	Shyam Shree
Malava	Natnarayani 1	Salagvarali	Simhendramadhyam
Malavi (Marwa thaat)	Natnarayani 2	Salang Sarang	Sindhura Bahar
Malavi (Purvi thaat)	Nayaki Kanada	Samanta Sarang	Sindhura Kafi
Malawa Bihag	Neelambari	Sampurna Bageshri	Sindhura
Malawati	Nindiyari	Sampurna Hindol	Sohani Bhatiyar
Malayalam	Niranjani Todi	Sampurna Kedar	Sohani Pancham
Maligaura (d)	Pahadi	Sampurna Malkauns	Sorath Malhar
Maligaura (d, D)	Palas Kafi	Sandhya Shree	Sourashtra
Malini Basant	Palasi	Sanjani	Shuddha Bahar
Malkauns Bahar	Pancham (Basant aang)	Sanjh Barari	Sugandh
Malkauns Pancham[1]	Pancham (Hindol aang)	Sanjh Sarawali	Sugharai
Maluha Bihag	Pancham Malkauns	Sanjh Tarini	Suha Adana
Maluha Kalyan	Pancham se Gara	Sanjh	Suha Kanada
Maluha Kedar	Pancham	Santuri Todi	Suha Malhar
Maluha Mand	Paraj Basant	Sar Nat	Suha Sughrai
Manavi	Paraj Kalingada	Sarang Kauns	Suha Todi
Mand Bhairav	Paraj	Saraswati Kalyan	Suha
Mand Bhatiyar	Parameshwari	Saraswati	Sujani Malhar
Mand[1]	Pat Bihag	Savani 1	Sukhiya Bilawal
Mangal Bhairav 1	Pat Kafi	Savani 2	Sukul Bilawal
Mangal Bhairav 2	Pat Ranjani	Savani Barwa	Sur Malhar
Mangal Todi	Patdeepak	Savani Bhatiyar	Swanandi
Mangaldhwani	Patmanjari 2	Savani Bihag	Swarparda
Mangalgujari	Patmanjari 3 (Talwandi Gharana)	Savani Bilawal	Tanseni Madhuwanti
Mangiya Bhusan	Phulashree	Savani Kalyan	Tilak Bihag
Manjari Bihag	Poorbya	Savani Nat	Tilak Des
Manjari	Prabhakali	Saveri Todi	Tilak Kedar
Marga Bihag	Prabhat Bhairav	Sazgiri	Tilak Shyam
Maru Basant	Prabhateshwari	Sehra by Sultan Khan	Tirbhukti
Maru Bihag	Pradeepaki	Shahana Bahar	Triveni Gauri
Maru Kalyan	Pratapvarali	Shamvati	Triveni
Maru Khamaj	Priya Kalyan	Shankara Bihag	Utari Gunakali
Maru Sarang	Purabi Kalyan	Shankara Kalyan	Vasanta Carnatic
Marwa Shree	Purva (Purvi thaat)	Sharada	Vibhas[1]
Medhavi	Purva Kalyan	Shiv Abhogi	Vibhavari
Meghranji	Purvi Bihag	Shiv Kauns	Vihang
Mehkali	Rageshri Bahar	Shivmat Bhairav	Vijayaranjani
Mirabai ki Malhar	Rageshri Kanada	Shivranjani	Vikram bhairav
Miyan ki Malhar	Rageshri Kauns	Shobhavari	Vinod
Miyan ki Todi	Rahi	Shree Kalyan 1	Virat Bhairav
Mohankauns	Raja Kalyan	Shree Kalyan 2	Viyogvarali
Motaki	Rajani Kalyan	Shreetanki	Vrindavani Sarang
MotakiTodi	Ram Gauri	Shuddha Barari	Vyjayanti
Mrig Savani	Ram Kalyan	Shuddha Basant	Yamani Basant
Shuddha Dhanashree	Shuddha Bihag	Shuddha Bhairavi	Yamani Bilawal

RAGAS AND *RASAS:* AN OVERVIEW

Music in the Indian subcontinent has been a source of aesthetic delight from time immemorial. From the time of Bharata's Natyashastra (Ghosh, 2002), there have been a number of treatises which speak in favor of the various *rasas* (emotional experiences) that are conveyed by the different forms of musical performances. The consolidation and evocation of *rasa* represent the function of all the fine arts. This is the central conception in India since Bharata's Natyashastra first expounded the doctrine of rasa with its eight categories, viz., Love or Romance (Śṛngāra), Gaiety or Humor (Hāsya), Compassion (*Kāruṇya*), Fury (*Raudra*), Valor (*Veera*), Terrible (*bhayankara*), Loathesomeness (*bibhatsa*), and Wonder (*adbhuta*). From the third or fourth century onwards Silence or Tranquillity (*shanta*) was not only added as the ninth category but considered as the supreme (Mukherjee, 1965). The aim of any dramatic performance is to emote in the minds of audience a particular kind of aesthetic experience, which is described as *"Rasa"*. The concept of *"Rasa"* is said to be the most important and significant contribution of the Indian mind to aesthetics. The study of aesthetics deals with the realization of beauty in art, its relish or enjoyment, and the awareness of joy that accompanies an experience of beauty; but till date science had nothing to do with the aesthetic experiences corresponding to a particular performance and was kept as a separate entity.

It is only from the last two decades of the 20th century that scientists began to understand the huge potential of systematic research that Indian Classical Music (ICM) has to offer in the advancement of cognitive science as well as psychological research. A number of works tried to harvest this immense potential by studying objectively the emotional experiences attributed to the different *ragas* of Indian Classical Music (Balkwill & Thompson, 1999; Chordia & Rae, 2007; Wieczorkowska et.al, 2010; Mathur et.al, 2015). The studies have revealed unlike Western Music pieces the emotions evoked by Indian Classical Music pieces are often more ambiguous and far more subdued. Earlier few musicologists believed that a particular emotion can be assigned to a particular *Raga* but recent studies (Wieczorkowska et.al, 2010) clearly revealed that different phrases of a particular *Raga* is capable of evoking emotions among the listeners.

The different sets of *ragas* form the backbone of Indian Classical Music and there are several questions which need to be answered to:

1. How do the ragas induce emotions in the audience? What are the acoustic features involved which modulates the emotional responses corresponding to a certain *raga?*

2. What are the cognitive attributes during the listening of an emotional *raga?* Are there specific brain regions which are activated when a person is listening to the *raga* of a particular emotion or there exists some universality in regards to brain response?

Music and Emotional Response: A review of conventional wisdom

Basic emotions in vocal communication can be identified across different culturesLikewise, emotions expressed in music can be basic emotions that are cross-culturally similar, and complex emotions. Research on effects of music on emotion has revealed that music generates two types of emotion – that which is experienced and vicarious emotion. Listening to music that is perceived as sad evokes pleasant emotions in the listener. The mechanisms underlying emotion induction are multiple and beyond cognitive appraisal.

There are a number of empirical studies which deal with the psychological aspects of music cognition taking statistical studies of listener's response as parameter for categorization of emotional appraisal. Listeners are highly sensitive to the emotional aspects of music, and they have broadly convergent emotional interpretations of music. Results from a wide range of investigations over the past century suggest that the various attributes of music, such as intensity (loudness), tempo, dissonance, and pitch height, are strongly associated with emotional expressions. In particular, changes in any of these attributes are correlated with changes in emotional interpretation (Ilie and Thompson 2006) and affective experience (Husain, Thompson, and Schellenberg, 2002; Ilie and Thompson 2011; Thompson et al. 2001). Such attributes contribute to an emotional code that may be employed by composers and performers to communicate emotions in music, or by speakers when they communicate emotions in their tone of voice (Juslin and Laukka 2003).

Balkwill and Thompson (1999) asked Western listeners to judge the emotional content of field recordings of Hindustani *ragas*, and to rate structural attributes in the music. Hindustani *ragas* were performed with the explicit intention to evoke specific emotions. Although listeners were unfamiliar with Hindustani music, they were able to decode emotional intentions. *Ragas* intended to convey joy/hasya were assigned high ratings of joy; *ragas* intended to convey sadness/karuna were assigned high ratings of sadness; and *ragas* intended to convey anger/raudra were assigned high ratings of anger. Judgments of emotion correlated with perceptions of musical attributes. For example, joy was associated with perceptions of fast tempo and sadness was associated with perceptions of slow tempo.

Recently, Mathur et al. (2015) tested the hypothesis that *ragas* elicit distinct emotional feelings. Using 3-min compositions of 12 *ragas*, presented in the form of an online survey, participants rated these *ragas* on the degree to which they elicited different emotions. All *ragas* were composed by a professional musician and rendered on *sarod*, an Indian stringed instrument. Mathur et al. exploited the structure of a raga composition and presented each of the 12 *ragas* in both *alaap* and *gat*. Participants were instructed to rate each excerpt on eight distinct emotions on a 0–4 Likert scale (with 0 being “not at all felt” to 4 being “felt the most”) for each of the following emotion labels: happy, romantic, devotional, calm/soothed, angry, longing/yearning, tensed/restless, and sad. The study did not use a forced choice task but instead sought each *raga* to be rated for each of the eight emotions, sensitive to the fact that a single musical composition can elicit multiple moods. Specifically the study sought to determine if participant responses (1) differed between the emotions experienced by *alaap* and *gat* for various ragas (2) whether the psychophysical variables of rhythm and tonality influenced the emotions experienced.

The first finding of Mathur et al.'s study was that distinct ragas are associated with distinct emotional elicitations. This was similar to the findings reported by Balkwill and Thompson (1999) which showed that even western listeners who were unfamiliar with the tonal system of NICM perceived the intended emotion in *ragas*. However Balkwill and Thompson used ragas only in the *alaap* mode and implemented forced choice task. Participants in that study were required to indicate which of the four target emotions was dominant for the raga. Mathur et al. on the other hand asked each participant to rate the extent to which each of the emotions were *experienced* during the listening of the *raga*. Mathur et al. also found that that when the raga was presented in "*alaap*," participants ratings were either calm (positive) or sad (negative) emotion. However, when presented in the *gat* condition, a finer discrimination of emotions were elicited (happy, romantic, calm) and (sad, longing, tension). This was the first experimental verification of the hypothesis that distinct emotions are associated with *alaap* and *gat* of a *raga*. Further, since Mathur et al. also used acoustic analysis to extract estimates of rhythmic regularity and tempo, they correlated acoustic features with behavioral ratings of emotional elicitation and were able to demonstrate that high arousal emotions like happy/tensed were associated with *gat*. As elaborated earlier the *gat* follows faster sequences of notes and provides an explicit rhythmic structure. A comparison of these results with those from the study conducted by Balkwill and Thompson showed that tempo and melodic complexity had some predictive power. However this was found only for some differences. Balkwill and Thompson (1999) used psychophysical ratings of tempo and melodic complexity and found that a combination of the two, predicted emotions primarily joy and sadness. Similar results were also reported by Gabrielsson and Juslin (1996) who showed that faster tempo were associated with positive emotions while slower tempo with negative emotions.

What was novel in Mathur et al.'s study was the finding that there is a change in the level of arousal between *alaap* and *gat* for the same raga. Since the tonal structure of the *raga* is preserved between *alaap*and *gat,* only the tempo is changed and the finding that high arousal emotions are associated with gat points to the fact that the *raga* structure is an optimal stimulus to dissociate the effects of tempo and tonality: tonality is controlled for between *alaap* and *gat*, while rhythm and tempo are manipulated. This result from Mathur et al. (2015), illustrated that this unique structure of NICM that enables the isolation of the effect of rhythm on emotion elicitationrenders it as a useful experimental stimulus.

Of greater interest was the second primary finding of Mathur et al. (2015) study which showed that specific tonic intervals were robust predictors of elicited emotions. Major intervals were found to be associated with positive emotions and minor intervals to be associated with negative emotions. An analysis of tonal intervals of *ragas,* revealed that *ragas* rated as positive (such as “calm” and “happy”) had a greater mean frequency of occurrence of major intervals (*shuddh swaras*) whereas *ragas* with negative emotion (e.g., sad or tensed) were characterized by an increased frequency of minor intervals (*Komal swaras*). **Figure 1** shows a distribution of mean frequency of occurrence of tonic intervals for the 12 *ragas* used in the study. Red bars represent the mean frequency of occurrence of *shuddh swaras* whereas that of *komal swaras* is represented with blue bars for each *raga*. To the best of our knowledge this finding for ragas is novel and has not been reported earlier.

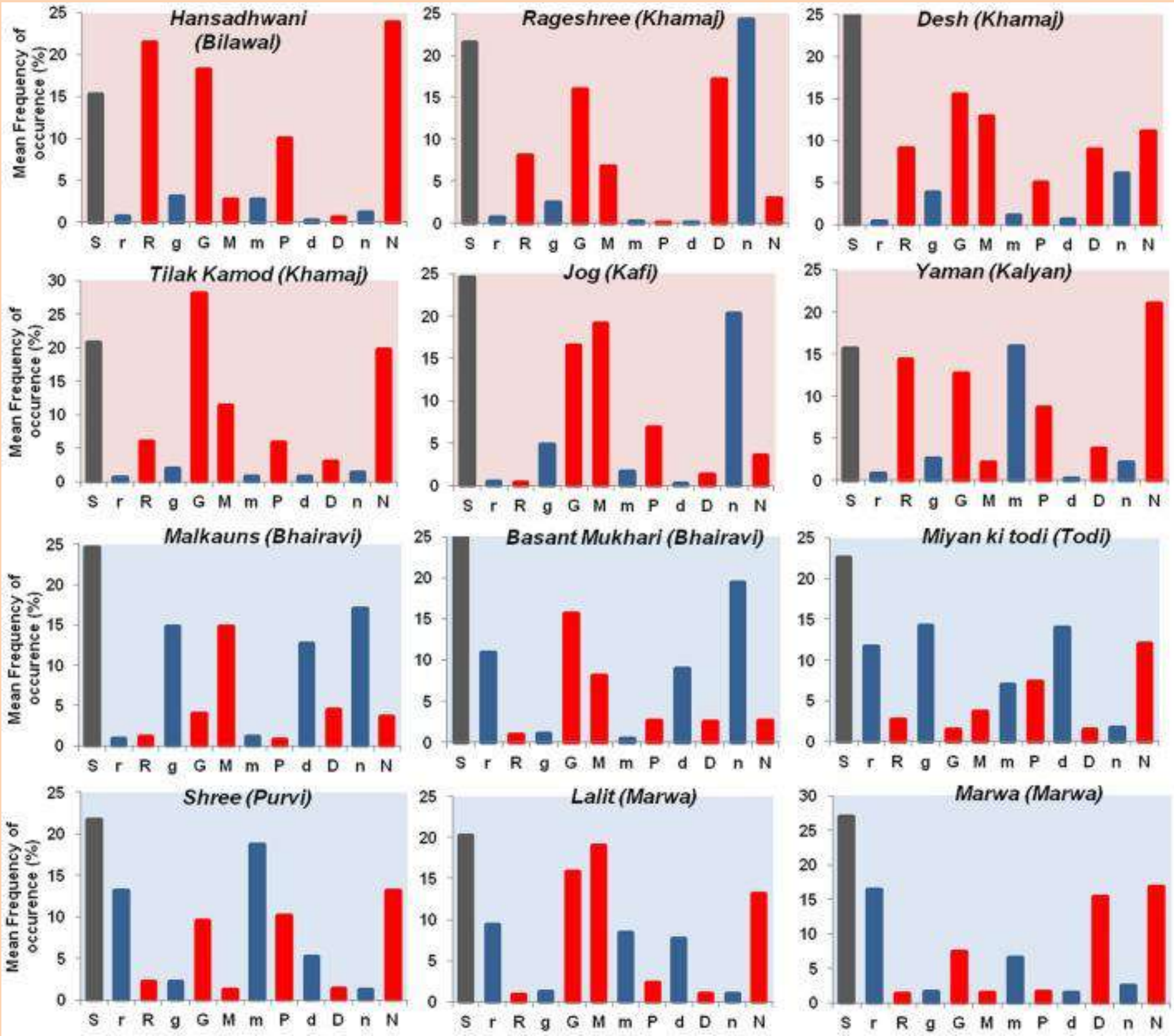


Figure 1 Tonality for ragas. The above figure represents the tonic interval distribution for the 12 ragas used in the study (Mathur et al., 2015). The tonal distribution of ragas rated as “calm” is represented with red background color panel whereas the tonal distribution of ragas rated as “sad” is represented with blue background color panel. Within each panel the mean frequency of occurrence of shuddh swaras [S (Sa), R (Re), G (Ga), M (Ma), P (Pa), D (Dha), N (Ni)] is depicted with red bars whereas the mean frequency of occurrence of komal swaras [r(re), g(ga), m(ma), d(dha), n(ni)] is depicted with blue bars.

The results revealed that pulse clarity (estimate of rhythmic regularity) and note density (estimate of tempo) differ among ragas with different experienced emotions, where high arousal emotions (happy/tensed) are associated with a faster rhythm. In addition, tonality significantly influenced the emotion experienced as the increase in mean frequency of occurrence of minor intervals was associated with ‘tensed’ emotion whereas increase in mean frequency of occurrence of major intervals was associated with ‘happy’ emotion (refer to **Figure 2**). Thus, our results indicated that the tonal distribution patterns determine the underlying mood (rasa) of a raga and the presence of rhythm changes the level of arousal of emotions experienced.

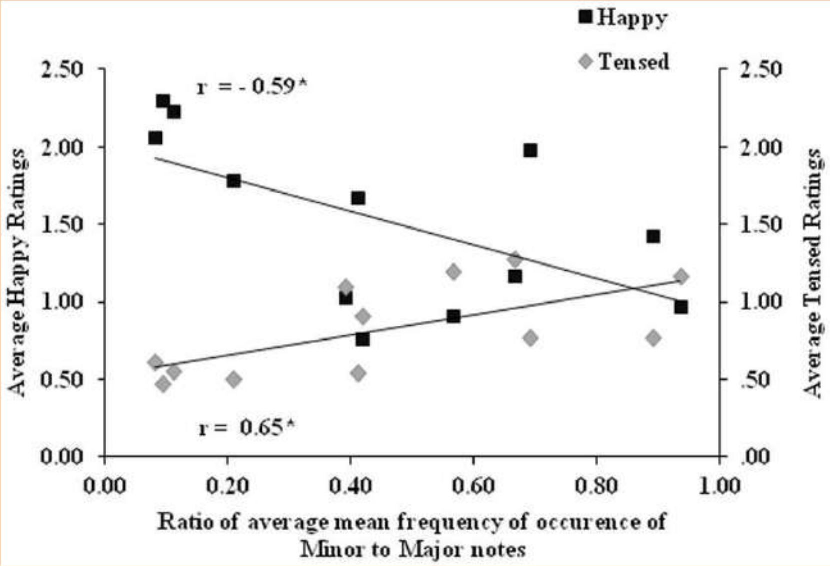


Fig. 2: Correlation plot between the ratio of mean frequency of occurrence of minor to major tonic intervals and average happy and tensed ratings across gat of ragas. The correlation coefficients (r) marked with asterisk (∗) are significant at $p < 0.05$.

Tonality analysis of *ragas* revealed that *ragas* with positive valence (for e.g., calm and happy) have a greater mean frequency of occurrence of major intervals (*shuddh swaras*) where as *ragas* with negative valence (for e.g., sad or tensed) are characterized by an increased frequency of minor intervals (*Komal swaras*; Figure 3).

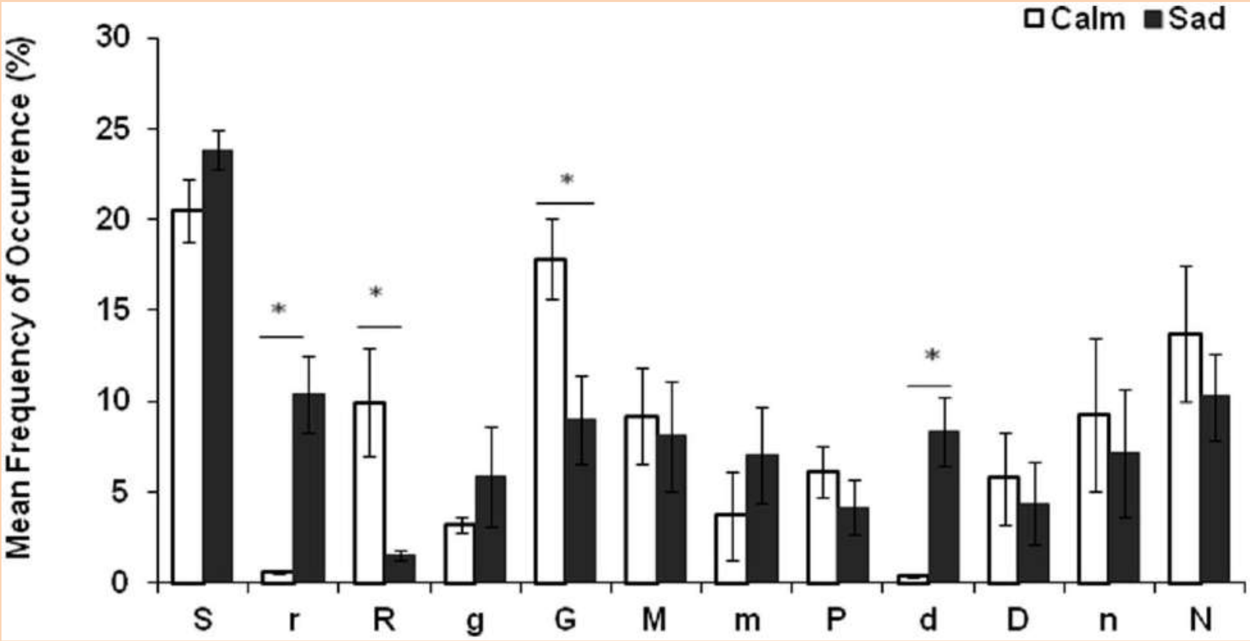


FIGURE 3. The tonic intervals of ragas. The percent mean frequency of occurrence of tonic intervals averaged across alaap of ragas for which experienced emotion was 'calm' and 'sad.' Note: Two-tailed Mann Whitney U-test showed that percent mean frequency of occurrence of komal re and komal dha were significantly higher for ragas with 'sad' emotional response at $p < 0.05$ (marked with an asterisk (∗)). In addition, percent mean frequency of occurrence of shuddh Re and shuddh Ga were significantly higher for ragas with 'calm' emotional response at $p < 0.05$ (marked with an asterisk (∗)).

Within the subset of *ragas* used in this study, there was a significant difference in the mean frequency of occurrence of minor second (*komal re*), major second (*shuddh Re*), major third (*shuddh Ga*), and minor sixth (*komal dha*; refer to **Figure 3**). The mean frequency of occurrence of minor second shows significant negative correlation with'happy,' 'romantic,' and 'calm' experienced emotions which suggests that its absence plays an important role in the rating of a *raga* as positive. On the other hand, it shows significant positive correlation with 'sad' and 'tensed' experienced emotions (**refer to Table 1**).

	Happy	Romantic	Calm	Longing	Tensed	Sad
Sa	0.17	0.20	0.30	0.11	0.01	−0.12
re	−0.79**	−0.83**	−0.88**	0.60*	0.91**	0.74**
Re	0.66*	0.66*	0.59*	−0.65*	−0.67*	−0.69*
ga	0.05	−0.00	0.07	0.08	0.04	−0.06
Ga	0.49	0.52	0.45	−0.47	−0.57	−0.42
Ma	0.00	0.15	0.18	0.22	−0.14	0.16
ma	−0.47	−0.51	−0.66*	0.20	0.47	0.35
Pa	0.25	0.08	−0.06	−0.22	0.14	−0.23
dha	−0.74**	−0.67*	−0.41	0.89**	0.61*	0.80**
Dha	−0.13	−0.10	−0.12	−0.15	−0.00	0.04
ni	0.05	0.01	0. 20	0.16	−0.11	−0.03
Ni	0.08	0.05	−0.08	−0.39	−0.06	−0.19

The correlation coefficients (β) marked with a single (*) and a double asterisk (**) are significant correlations at $p < 0.05$ and $p < 0.001$ respectively.

Table 1. The table lists the correlation coefficients of correlations between the average emotion ratings and mean frequency of occurrence of each tonic interval across the 12 ragas.

In addition, the minor second appears as a significant positive predictor of 'tensed' emotion for *gat* of *ragas* and explains 89% of variance in ratings of 'tensed' emotion (refer to Table 2).

Happy	Romantic	Calm	Longing	Tensed	Sad
re, $\beta = -0.79$*	*re*, $\beta = -0.83$**	*re*, $\beta = -0.88$**	*dha*, $\beta = 0.89$**	*re*, $\beta = 0.91$**	*dha*, $\beta = 0.80$*
$R^2 = 0.58$	$R^2 = 0.66$	$R^2 = 0.75$	$R^2 = 0.78$	$R^2 = 0.89$	$R^2 = 0.60$
$F(1,10) = 16.48$, $p < 0.05$	$F(1,10) = 22.19$, $p = 0.001$	$F(1,10) = 330.61$, $p < 0.001$	$F(1,10) = 39.22$, $p < 0.001$	$F(1,10) = 44.46$, $p < 0.001$	$F(1,10) = 17.23$, $p < 0.05$

The results of the first predictive model with values of adjusted R^2, standardized coefficient (β) and F ratio of ANOVA results are reported in the table. The correlation coefficients (β) marked with a single (*) and a double asterisk (**) are significant correlations at $p < 0.05$ and $p < 0.001$ respectively.

TABLE 2. Results of Stepwise multiple linear regressions performed in order to determine the variance of the emotional responses explained by the tonic intervals in gat of ragas.

Tonality, by definition, creates a hierarchical system in which the 'minor second' is a significant 'pointer' to the tonic, a 'leading note.' In tonal music therefore, the minor second holds a position as an 'upper leading note' (Moore, 2014). However, it is a dissonant interval, since the semitone overtone relationship is 16/15 (**Table 3**).

Interval name	Abbreviation used	Western scale (Interval name)	Frequency ratio	Just intonation (Cents)	12-TET (Cents)
Shadja	*Sa*	Perfect unison	1	0	0
Komal Rhishabha	*re*	Minor second	16/15	112	100
Shuddha Rhishabha	*Re*	Major second	10/9	183	200
Komal Gandhara	*ga*	Minor third	6/5	316	300
Shuddha Gandhara	*Ga*	Major third	5/4	386	400
Madhyama	*Ma*	Perfect fourth	4/3	498	500
Tivra Madhyama	*ma*	Tritone	45/32	590	600
Panchama	*Pa*	Perfect fifth	3/2	702	700
Komal Dhaivata	*dha*	Minor sixth	8/5	814	800
Shuddha Dhaivata	*Dha*	Major sixth	5/3	884	900
Komal Nishada	*ni*	Minor seventh	9/5	1018	1000
Shuddha Nishada	*Ni*	Major seventh	15/8	1088	1100
Shadja	*Sa'*	Perfect octave	2	1200	1200

Each interval is a tone defined by the ratio of its fundamental frequency to the tonic (Sa). Interval names, abbreviations used, frequency ratios and sizes in cents in Just intonation and 12-TET tunings are given in table. The corresponding interval name in the Western chromatic scale is also given. In the notation used the seven Shuddha swaras are denoted by capital letters (Sa, Re, Ga, Ma, Pa, Dha, Ni), four komal swaras, and one tivra swara are denoted by small letters (re, ga, ma, dha, ni).

TABLE 3. Music intervals in Hindustani classical music.

By definition, for a consonant interval, the interval between two notes is a simple numerical ratio of frequencies in terms of the harmonic overtone series (Plomp and Levelt, 1965). Based on structure and composition, all *ragas* are tonal and the tonic is the reference point. As suggested by Moore, the 'minor second' with its tension and high 'yearning' toward the tonic, may build a narrative of hope or fear, the resolution of which brings associations of tension, yearning and a release of energy. The results of this study encourage us to hypothesize that minor second in Hindustani classical music plays an important role in conveying tension and further studies should attempt to investigate its role in detail.

A study by Wieczorkowska et.al (2012) deal with the emotions elicited by *alap* part of professional *khayal* performances. The database for the experiments consists of short segments extracted from *khayal* performances from eleven most emotive ragas selected from the archives of ITCSRA. The first part of the study consists of identifying significant emotions evoked by the aforesaid segments in western listeners as well as native Indian listeners and the cross-cultural differences, if any. This also includes examination of to what extent the raga–rasa relationship indicated in treatises matches with the observed data. The second part consists of the extraction of the distinctive note-sequences in these segments. The signal processing part performed here includes extraction of pitch contour, and segmentation of it into sequences of notes. Thirty seconds long music segments were used in the experiments, to check what specific emotion(s) they elicit. The listening tests showed that different segments from the same raga do not generally correspond to the emotions prescribed in Indian treaties.

Indian musicological treaties since Bharata hold that even notes bear the potential of producing emotional effects. Tembe listed eight of them (**Table 4**). However no rational or scientific scrutiny was provided. It seems that the list was drawn from the proposals presented in Natyashastra.

Notes	Emotional attribute
Shadja	like a *yogi* beyond any attachment
Rishabha (komala)	rather sluggish
Rishabha (shuddha)	reminding of indolence of a person waking up from sleep
Gandhara (komala)	bewildered, helpless and pitiable
Gandhara (shuddha)	fresh and pleasant
Madhyama (shuddha)	grave, noble and powerful
Madhyama (tivra)	sensitive, luxurious
Panchama	brilliant, self composing
Dhaivata (komala)	grief, pathos
Dhaivata (shuddha)	robust, lustful
Nishada (komala)	gentle, happy, affectionate
Nishada (shuddha)	piercing appeal

Table 4 Emotional attributes of notes according to G.S. Tembe

However, he agrees that only four rasas, namely Karuna, Shanta, Shringara and Vira may actually be experienced from a single note. He further proposes that when Shuddha madhyama dominates a melody, it creates a serene and sublime atmosphere, while a dominant Panchama creates an invigorating and erotic feeling. Pandit V.N. Bhatkhande in his work suggested the inadequacy of vadi svara (i.e. the main melodic tone of the raga) in determining the rasa of ragas. However, he mentions that Ragas employing Shuddha (Rishabha, Dhaivata and Gandhara) emote Shringara rasa, and those employing Komala (Dhaivata and Nishad) emote Vira rasa. This view is contradicted by Ratanjankar. According to him, individual notes cannot produce emotion, and they may do so only in a specific context. This implies that expression is born by the melodic content. Konishi et.al reported that listeners can correctly decode emotions like anger, fear, happiness, and sadness from single notes from vibrato effect in Western music. Having noted all these, it appears that the notion of a single note conveying emotion in general may be somewhat contrived particularly in Indian music. In Indian music, a note does not have a specific frequency. It is related to the scale where the base note Sa can be assigned any arbitrary frequency. Kamani noticed inconsistency between the rasa of a raga traditionally prescribed and experienced. He holds that since a raga represents a complex set of feelings, a simple relationship between a raga and rasa is unlikely.

In Hindustani music, ragas are said to be associated with different rasas (emotions). However, one particular raga is not necessarily associated with one emotion. Moreover, opinion varies; a comprehensive summary is available in Semiosis in Hindusthani Music [18]. For the present study we have selected 11 ragas (**Table 5**) to represent different rasas/emotions residing therein. Of the eight emotions listed in the opinion score sheets, only six represent rasas. These are Heroic (Vira), Anger (Raudra), Serenity (Santa), Devotion (Bhakti), Sorrow (Karuna), Romantic (Sringara). Other two emotions namely Joy and Anxiety have been considered additionally.

Name of the Raga	*Rasas*
Adana	Vira
Bhairav	Raudra, Santa, Bhakti, Karuna
Chayanat	Sringara
Darbari Kannada	Santa
Hindol	Vira, Raudra
Jayjayvanti	Sringara
Jogiya	Karuna, Sringara, Bhakti
Kedar	Santa
Mian-ki-Malhar	Karuna
Mian-ki-Todi	Bhakti, Srigara, Karuna
Shree	Santa

Table 5. Selected ragas and corresponding *rasas*

The results of the experiments described in this experiment can be summarized as follows.

1) An oral music segment of length 3 seconds (a few notes) elicit specific emotion, (refer **Table 6**)

Note Sequence	Major emotional Response
mSN	Anger, Devotion, Anxiety
RgM	Heroic, Anxiety
SgR	Heroic, Romantic
GMmP	Romantic, Serenity, Anxiety
Pmd	Heroic, Anxiety, Sorrow
SND	Anger, Devotion
DPmP	Romantic, Serenity
rGrS	Heroic, Devotion, Anxiety
GMR	Devotion
MGR	Devotion
NDP	Heroic, Anxiety, Sorrow
NDm	Anger
mPmG	Heroic, Devotion, Anxiety
mGr	Heroic, Devotion, Anxiety
dPMG	Heroic, Anxiety, Sorrow
grS	Heroic, Devotion
PmG	Heroic, Devotion, Anxiety
RGM	Devotion
gRS	Romantic, Serenity
GMP	Anxiety
DPm	Romantic, Serenity
MdP	Heroic, Anxiety, Sorrow
MPdP	Heroic, Anxiety, Sorrow
GrS	Heroic, Devotion, Anxiety
PMGM	Anxiety
MPd	Heroic, Anxiety, Sorrow
NSR	Devotion
PMG	Devotion
dPM	Anxiety

Table 6. Relationship between note sequences and emotion

2) The elicited emotion can be assigned into prescribed categories,

3) The elicited emotion from different segments from the same raga has some specificity, i.e. the segments of a raga have shown a specific emotion; it might be that four segments from the same raga show different emotions,

4) The emotional response from the segments of a raga does not generally correspond to those prescribed in Indian treaties,

5) The cross-cultural similarity of the elicited response is significant,

6) The melodic sequence (sequence of musical notes) vaguely relate with emotional response.

NON LINEAR EMOTION BASED CHARACTERIZATION OF HINDUSTANI CLASSICAL MUSIC: A SAMPLE STUDY

The main focus is to make use of the acoustic features of different musical instruments to classify the emotional manifestations of different *ragas.* Whether there exists a certain threshold beyond which the emotional context of a particular *raga* changes to other in respect of acoustic parameters. In this context, the ambiguous clips also play an important factor acting as a bridge between two clips of contrast emotions and hence the parameter extracted from them will be an interesting one in the quest for quantification of music induced emotions. We chose 3 min *alap* portion of six conventional *ragas* of Hindustani classical music namely, "*Darbari Kanada", "Yaman", "Mian ki malhar", "Durga", "Jayjayanti" and "Hamsadhwani"* played in three different musical instruments. The first three *ragas* correspond to the negative dimension of the Russell's emotional sphere (Posner, Russell & Peterson, 2005; Russell, 1991), while the last three belong to the positive dimension (conventionally). The music signals were analyzed with the help of latest non linear analysis technique called Multifractal Detrended Fluctuation Analysis (MFDFA) which determines the complexity parameters associated with each *raga* clips. The MFDFA technique is superior to other conventional techniques due to the fact that it accounts both the small and large variations present in the music signal by varying the q-order moments. This technique has been successfully applied in the past to detect complexity parameters associated with music clips (Jafari, Pedram & Hedayatifar, 2007; Telesca & Lovallo, 2011; Banerjee et. al, 2017; Bhaduri & Ghosh, 2016; Sanyal et.al, 2016) and further to classify music clips based on this parameter. With the help of this technique, we have computed the multifractal spectral width (or the complexity) associated with each *raga* clip and further to classify them on the basis of their emotional attribute. The complexity values give clear indication in the direction of categorization of emotions attributed to Hindustani classical music. It is observed that the *ragas* which belong to the positive valence normally possess lower values of complexity, while those belonging to the negative valence have comparatively higher values of complexity. Also, specific cues are obtained for each of the musical instruments used in this study, which makes each of the inherent ambiguities present in the *ragas* of Hindustani classical music beautifully reflected in the results. The complexity value corresponding to different parts of a particular raga becomes almost similar to the values corresponding to parts of a different *raga*. This implies acoustic similarities in these parts and hence the emotional attributes of these parts are bound to be similar.

In this way, we have tried to develop automated algorithm with which we can classify and quantify emotional arousal corresponding to different *ragas* of Hindustani music. The study can be developed further with a wide variety of signals including vocal music which will lead to the generation of an automated algorithm with which we can conclusively identify and quantify emotional cues corresponding to a particular music clip originating from a characteristic source.

EXPERIMENTAL DETAILS

Choice of three pairs of *ragas*

Six different *raga* clips of Hindustani Classical music played in traditional flute, *sitar* and *sarod* were taken for our analysis (**Table 7**). The *ragas* were chosen by an experienced musician such that they belong to the positive and negative valence of the 2D emotional sphere illustrated in **Fig. 4** (Russell, 1991).

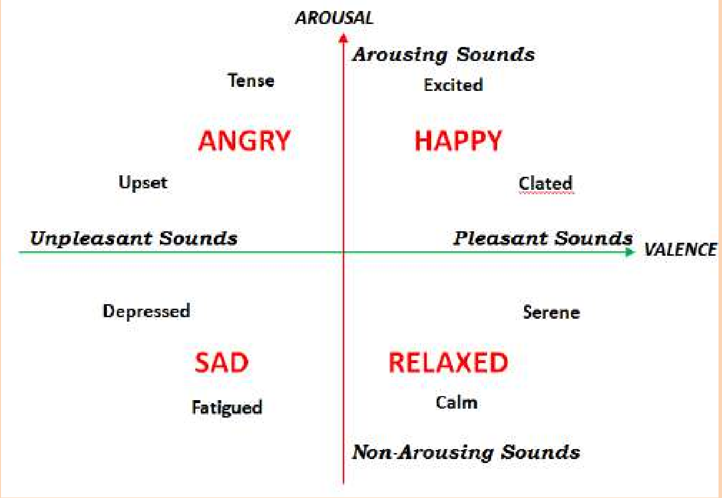


Fig. 4 Russell's 2D circumplex model of emotion

The three pairs of *ragas* were chosen in a way that half of them belong to the positive valence while the other three belong to the negative valence as corroborated from a listening test conducted beforehand and also in ancient treatises (Ghosh, 2002) of Hindustani music. In this way we want to have an acoustic as well as neuro-cognitive categorization of emotional appraisal from *ragas* of Hindustani music. We chose 3 min *alap* portion of six conventional *ragas* of Hindustani classical music namely, "*Darbari Kanada", "Yaman", "Mian ki malhar", "Durga", "Jayjayanti" and "Hamsadhwani"* played in three different musical instruments. The following table gives the details of the artistes and their respective instruments which we have used for our analysis.

Table 7: Details of artists chosen

Artistes	Instruments Used
Ustad Ali Akbar Khan (Artist 1)	Sarod
Pt. Hariprasad Chaurasia (Artist 2)	Flute
Pt. Nikhil Banerjee (Artist 3)	Sitar

The averaged values for each raga clips have been given in the following table (**Table 8**) and the corresponding fig (**Fig. 5**) shows the values for each artist. The SD values have also been computed for the rendition of each *raga* by an Artist.

Table 8: Variation of multifractal width corresponding to *ragas* by different artistes

	Hamsadhwani	Darbari	Jayjayanti	Mia ki Malhar	Durga	Yaman
Artist 1(Sarod)	0.62± 0.04	0.80± 0.02	0.67± 0.04	0.58± 0.03	0.81± 0.06	0.72±0.03
Artist 2(Flute)	1.07± 0.06	0.44± 0.04	0.67± 0.06	0.42± 0.07	0.54± 0.04	0.44± 0.04
Artist 3(Sitar)	0.42± 0.03	0.64± 0.06	0.40± 0.02	0.61± 0.02	0.56± 0.02	0.45± 0.04

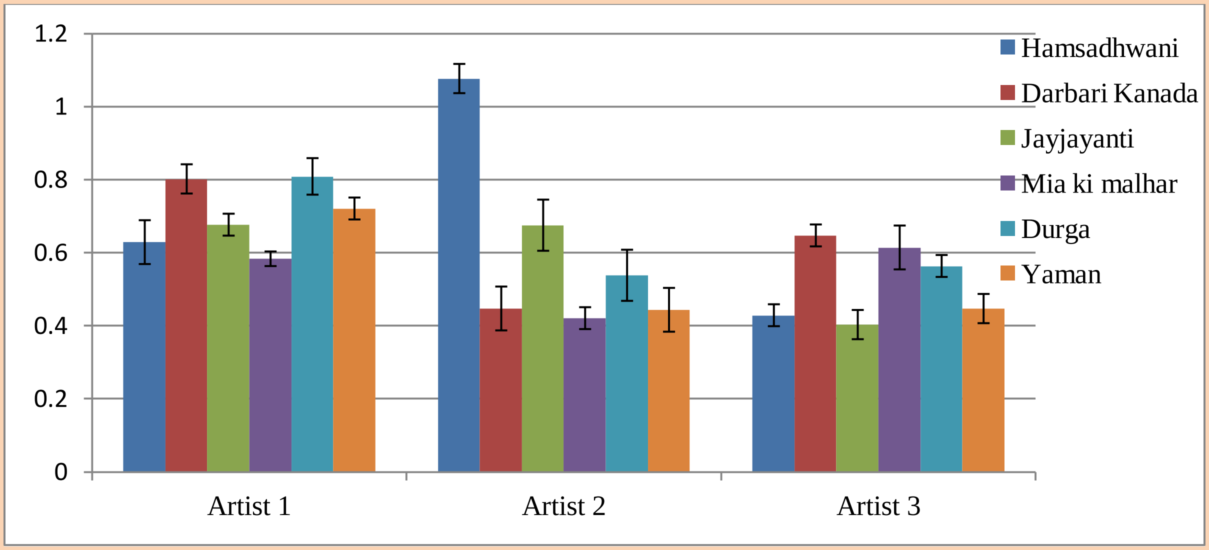


Fig. 5: Clustering of multifractal widths for each artist corresponding to each *raga*

From the above figure it is clear that there is distinct categorization of emotional responses corresponding to each *raga* clip. In case of *sarod* and *sitar*, we find that *raga Hamsadhwani* (corresponding to happy emotion) has a lower value of complexity as opposed to the *flute* clip where the complexity value is significantly high. The complexity values corresponding to *raga Darbari* (depicting sad emotion) are consistently high for *sarod* and *sitar* while that is significantly low for *flute* clip. In case of the other pair *Jayjayanti* (happy clip) and *Mia ki malhar* (sorrow clip), we see that there is similarity in response for *sarod* and *flute*, i.e.

complexity values on the higher side for happy clip while it is lower for sad clip; the response is vice-versa for *sitar* clip. In case of the other pair, i.e. raga *Durga* (mainly on the happier side but is mixed with other emotions like romance, serene etc.) and *raga Yaman* (mainly on the negative side of Russel's emotional sphere but is mixed with other emotions like devotion etc.) there was considerable ambiguity even when it comes to human response psychological data. The same has been reflected in our results where the average difference in complexity of these two *ragas* is not so significant as compared to the other two pairs. Our study thus points in the direction of timbre specific categorization of emotion in respect to *Hindustani raga* music. We see that the emotion classification works the best for *flute* where the difference in complexity for the happy and sad clips is the maximum; while the difference is minimum for *sarod*, thus it is difficult to categorize emotions from acoustic *sarod* clips.

CONCLUDING REMARKS:

This study presents a first-of-its kind data in regard to categorization and quantification of emotional arousal based responses to Hindustani classical music. The inherent ambiguities said to be present in Hindustani classical music is also reflected beautifully in the results. That a particular *raga* can portray an amalgamation of a number of perceived emotions can now be tagged with the rise or fall of multifractal width or complexity values associated with that *raga*. The study presents the following interesting conclusions which have been listed below:

1. For the first time, an association has been made with the timbre of a particular instrument with the variety of emotions that it conveys. Thus for effective emotional classification, timbre of the instrument will play a very important role in future studies.
2. The multifractal spectral width has been used as a timbral parameter to quantify and categorize emotional arousal corresponding to a particular clip played in a specific instrument.
3. We try to develop a threshold value for a particular instrument using multifractal spectral width, beyond which emotions will change.

The following figures (**6**) summarize the results:

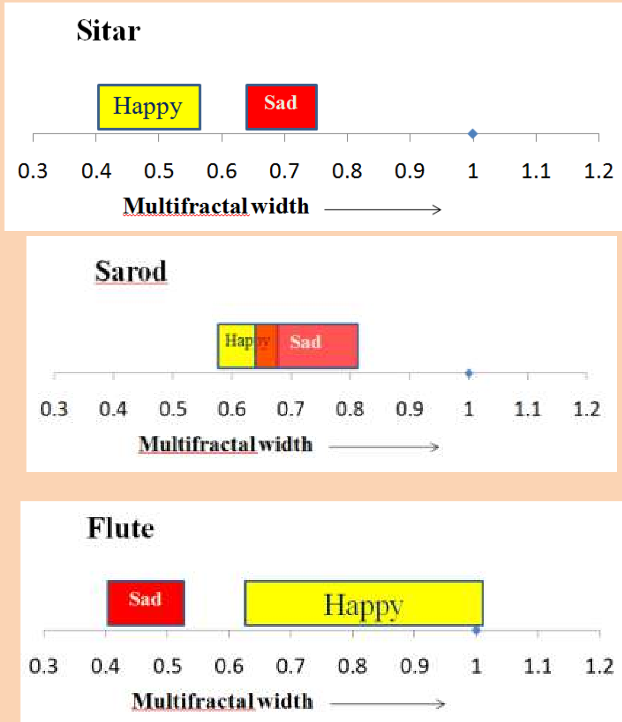


Fig. 6: Use of multifractal width as a tool to categorize emotions in different instruments

(i) From the plot it is clear that emotional classification can be best done with the help of *flute* where the complexity values of happy and sad clips are distinctly different from one another.
(ii) There is an overlap in case of *sarod* clips between happy and sad complexity values. This can be attributed to the inherent ambiguity present in the clips of Hindustani classical music, i.e there cannot be anything as complete joy or complete sorrow, there remains always states which are between joy and sorrow, which is beautifully reflected in the overlap part of the two emotions. In conclusion, this study provides a novel tool and a robust algorithm with which future studies in the direction of emotion categorization using music clips can be carried out keeping in mind the timbral properties of the sound being used. Improvisation – a term which involves a whole lot of features is something which gives Hindustani music its worldwide fame.

FUTURE WORKS:

1) **Non linear emotion based characterization of other *ragas (*using vocal signals of different artistes*).***
2) **Non linear emotion based characterization of other *ragas (*using instrumental signals as for e.g. *sitar, sarod,* flute etc for different artistes*).***
3) **Development of appropriate software for online assessment of emotions of different music samples**

There is
geometry
in the humming
of the strings,
there is
music
in the spacing
of the spheres.

Pythagoras

Chapter THREE

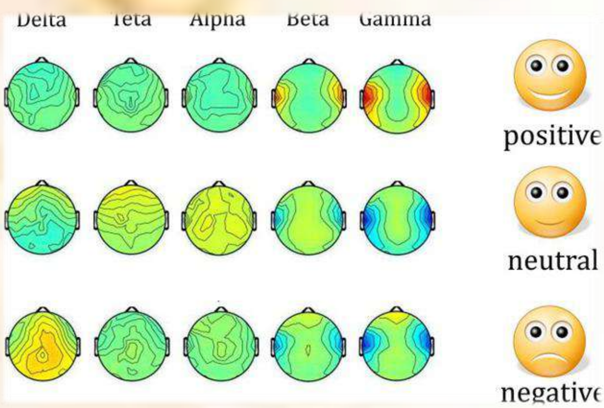
"Scientific Exploration of Indian Classical Music"

It is only from the last two decades of the twentieth century that scientists began to understand the huge potential of systematic research that Indian Classical Music has to offer in the advancement of cognitive science as well as psychological research. The aim of any dramatic performance is to emote in the minds of audience a particular kind of aesthetic experience, which is described as “Rasa”. The concept of “Rasa” or emotion is said to be the most important and significant contribution of the Indian mind to aesthetics. It is essential to seam together these two parallel domains of art and science. This can be done with the help of another fascinating concept of the last century—the Chaos. The Chaos theory is said to be the new link between human and nature; where apparently random, disordered processes are characterized with some inherent order. What happens inside the performer’s brain when he is performing and composing a particular musical piece? What happens inside the listener’s brain when he is listening to a particular musical piece?

Are there some specific regions in brain which are activated when an artist is creating or imaging a musical piece in his brain? Do the regions remain the same when the artist is listening to the same piece sung by him? These are the questions that perplexed neuroscientists for a long time. The endeavor to obtain insights to brain processes that take place during listening as well as composing music has been attempted several times by musicologists and psychologists. Prof. Ghosh perceived that this can be verified scientifically with the advent of bio sensors like EEG (Electroencephalogram), fMRI (functional Magnetic Resonance Imaging) etc which can reflect some light in the domain.

The brain is said to be the most complex structure found in human body and the EEG signals generated from brain are essentially non-stationery and scale varying in nature. Neuroscientists believe the frontal lobe of our brain is usually associated with reasoning, cognitive processing and expressive language; the temporal lobe is important for interpreting sounds and the language we hear while the occipital lobe is important for interpreting visual stimuli and information processing. Generally, there is strong evidence that perception and imagination of music share common processes in the brain.
We identified three different lobes of the brain namely frontal, temporal and occipital whose functions mostly concur with our work. Hence, we chose electrodes from these lobes (frontal, temporal and occipital) to study the brain electrical response of the artist while he is creating as well as listening to a raga of his choice.

The non stationary time signals of EEG generated from different electrodes are best analyzed with the nonlinear technique which helps us to quantify the arousal based effects in each of the chosen lobes during musical imagery and perception. Next, the signals from the two different groups of electrodes are analyzed to assess the inter lobe as well as intra lobe cross correlation from EEG recordings of the same person during creating and perceiving music. EEG signals obtained from two different lobes of brain were separated into alpha and theta frequency rhythms and again analyzed with the help of same technique. The resultant correlation exponent gives the degree or the amount by which the two signals are correlated.



With this background, we tried to develop "EMOTION COGNITION BASED CATEGORIZATION AND LEARNING OF INDIAN CLASSICAL MUSIC (GURU SHISHYA PARAMPARA ONLINE) USING NOVEL NON-LINEAR COMPUTING TECHNIQUE"). This lend support from Tagore's view on Indian Classical Music, where he categorically mentioned that "enough was done in regard to rigour of following the exact notes in a particular raga—most important is to know why different structure of notes in Indian classical music elicits different emotions – why "*Raga Jayjayanti*" elicit happiness where as "*Raga Darbari*" elicit pathos. Still, why do we want to listen to more '*Darbari*. These questions were not tackled at all scientifically. Frontiers of physics, neuroscience and computing techniques based on chaos can be used to answer all these questions.

This is for the first time a scientific project is undertaken where Emotion elicited by Indian classical music will be studied with state of the art scientific technique. This includes acoustic analysis as well as neuro-cognitive analysis using biosensors like EEG (Electroencephalogram), EMG (Electromyogram) and ECG (Electrocardiogram). This study aims at neuro-cognitive quantification of emotions elicited by Indian Classic Music which eventually can be used as cognitive music therapy.

Besides, this approach using non-linear neuro-cognition based characterization of classical rages will be helpful in music learning using on-line mode in *Gure Sishya parampara* format.

The project is further aimed at better understanding of the intimate relationship between music and the emotional experience and its biological parameter, which in turn can be a guide to use proper music as an effective therapeutic agent.

यथो हस्त तथो दृष्टि

Wherever your hands go, your eyes will follow

यथो दृष्टि तथो मनः

Wherever your eyes go, your mind will follow

यथो मनः तथो भाव

Wherever your mind goes, there will be expression of inner feeling

यथो भाव तथो रस

Where there is expression shown, there will be sentiment evoked

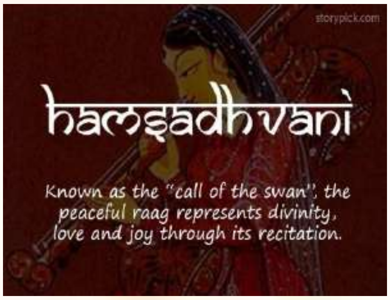
– नाट्य शास्त्र

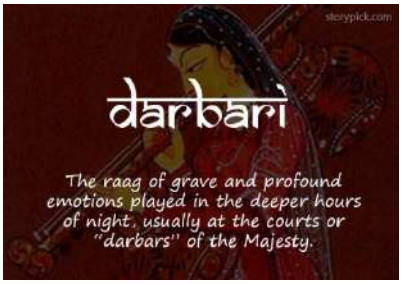
(Natya Shastra)

Ever noticed what invokes emotion deep inside you, whilst attending any sort of performance art? Be it dancing, singing, drama or even a movie for that matter; what connects it to the core of your soul is the way the story is expressed. And that is what exactly the above-mentioned verse, famously taken from Natya Shastra

Indian classical music is as deep as the universe itself and every scale has been composed taking different human emotions in mind.

A few ragas with emotions





Time Preferences of a few ragas

Time	Modes of Music
4:00 a.m. to 7:00 a.m.	1. Hindola, 2. Bhairava, 3. Ahira Bhairava, 4.Bhairavi, 5. Siddha Bhairavi, 6. Ramakali, 7. Gunakali
7:00 a.m. to 10:00 a.m.	1. Jaunapuri, 2. Asavari, 3. Todi, 4. Gurjara Todi, 5. Ahilya Bilavala
10:00 a.m. to 1:00 p.m.	1. Megha Malhara, 2. Buddha Saranga, 3. Sura Malhara
1:00 p.m. to 4:00 p.m.	1. Madhuvanti, 2. Multani
4:00 p.m. to 7:00 p.m.	1. Patamanjari, 2. Makha, 3 Ragasri, 4. Kalavati, 5. Puriya Dhanasri
7:00 p.m. to 10:00 p.m.	1. Yamana Kalyana, 2. Kalyana, 3. Puriya, 4. Sivaranjani, 5. Yamana, 6. Suddha Kalyana, 7. Maruvihaga, 8. Kedara, 9. Sama Kalyana, 10. Priya Kalyana,
10:00 p.m. to 1:00 a.m.	1. Darabari, 2. Kanada, 3. Nayaki Kanaka, 4. Malakaumsa, 5. Dipaka, 6. Bhagyasri, 7. Candrakaumsa, 8. Kaumsi Kanada, 9. Jayajayavanti
1:00 a.m. to 4:00 a.m.	1. Lalita, 2. Nara Bhairava, 3. Sohani, 4. Vasanta, 5. Vasanta Bahara

Main Protocol

The procedure to characterize and quantify emotion scientifically is essentially as follows:

A performer (vocalist or instrumentalist) will perform a raga, say "Jaya Jwanti" and a person is listening. The song will be recorded and a sound signal will be analyzed using the latest techniques of physics of complex systems (based on chaos). This analysis will provide a quantitative parameter namely – Fractal Dimension, which is a measure of complexity of sound signal of that particular raga and in the deepest sense, this parameter delivers information about degree of symmetry scaling embedded in the acoustic signal.

Next, the listeners brain response will be recorded with the help of a biosensor, namely EEG (Electroencephalogram) which provides in detail how brain is responding in terms of electric signal generated from different parts of the human brain manifested as variation of electric potentials in digitized format. This digitized data will be analyzed again with the methods of physics of complex systems applied to acoustic signals to get information quantitatively about the response of the brain due to the acoustic signal of the specified ragas. It is to be mentioned that the conventional data analysis of EEG signals used by medical experts are incapable for revealing this information.

Thus, one can characterize the acoustic signal of “Jay Jwanti” quantitatively with a number and in a similar way response of the brain (due to input of raga “Jay Jwanti”) can be characterized with another number. In this way all ragas (for which emotions have been labelled with conventional wisdom) can be characterized emotion wise with a scientific parameter.

This is the essence of the experiment, which is new and uses novel technique in scientific perspective and can be used for learning Indian Classical music giving stress on emotions not attempted so far in scientific domain.

Following the protocol described in preceding section, a pilot study is performed, the detail of which follows:

1. **Notes of Ragas**
2. **"Alaap" segment of different ragas**
3. **Neurocognitive study of audio signal of music (Indian Classical) with biosensor (EEG)**
4. **Neurocognitive studies of visual stimuli of dance performance (Indian Classical) with biosensor (EEG)**

Appendix

1

Notes of Ragas

The Notes in an Octave

- In Indian classical music, one divides an octave into 12 notes. On a movable scale, the starting point is the tonic (called "sa" and denoted by "S").
- All the other notes are defined in relation to sa.
- For notation purposes, each of the 12 notes in an octave has a unique identity, given by S, r, R, g, G, m, M, P, d, D, n, N.

Different Kinds of Ragas

There are ways to group notes to form ragas, not just in terms of the number of notes, but also based on musical phrasing, or by combining two ragas to get a new raga, and so on. It is interesting to learn something about the traditionally prescribed time for performing or enjoying a raga and the mood (*rasa*) or emotional content (*bhāva*) associated with it. A short description for each raga, mainly based on the mood traditionally assigned to the raga and also on the number of notes they use is given in the next section.

Raag Marwa (hexatonic)

•It is one of the major ragas in Hindustani classical music

•Raag Marwa is sung during the late afternoon hours up to sunset.

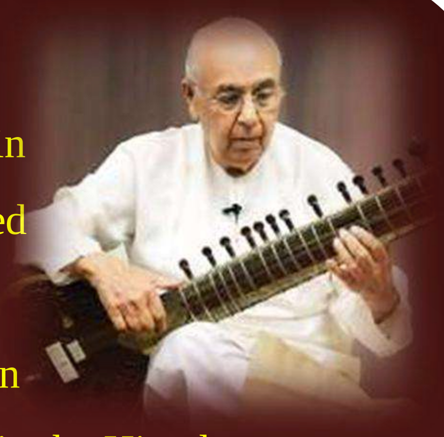
•One of the interesting things about Raag Marwa is that it de-emphasizes the tonic (sa) and excludes the perfect fifth (pa) which makes it a very unsettling raga, mainly evoking dark moods of foreboding and anxiety.

•It can also portray compassion or resignation in the face of some inner struggle.

Raag Bhairav (heptatonic)

•It is a morning raga, and solemn peacefulness is its ideal mood.

•It is very easy, however, for this scale to deteriorate from peaceful to melodramatic, and artists must watch out for that.



•Ustad Vilayat Khan described Raag Bhairav as the music in the mind of Lord Shiva as he meditated in the Himalayas.

•Picture Shiva-the-terrible, absorbed in the deepest meditation in a dark cave in the Himalayas.

•Everything is still, except for the occasional dripping of a stalagtite.

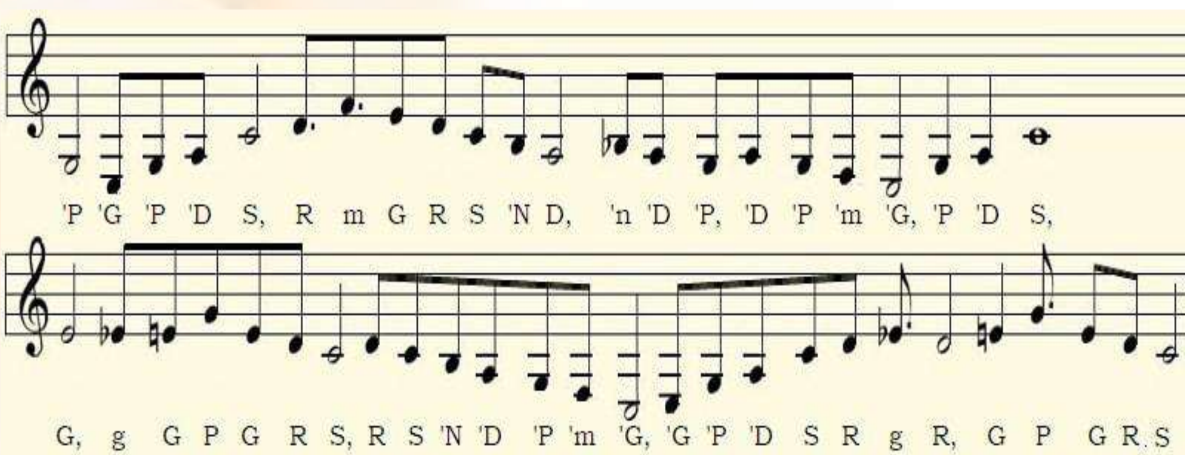
•Then dawn breaks and the first rays of sunlight penetrate into the cave.

Raag Pahadi

•Pahadi is an evening raga that combines both playful and pensive aspects.

•It has a very charming, folksy flavor.

•The notes S R G P D form the backbone of Raag Pahadi, which makes it a very close cousin of the pentatonic Raag Bhupali.



Raag Bhairavi

•Raag Bhairavi is a very important raga in both classical and semi-classical music.

• Any note in the octave can be used in Raag Bhairavi, but its main structure comprises the notes S, r, g, m, P, d, and n.

•This gives the raga a very gentle quality.

• A small composition in Raag Bhairavi is often sung at the end of a long performance as a way of winding down.

Raag Yaman

•Yaman is an evening raga, sung from sunset to late evening.

•It is full of grace and beauty, and the main mood it creates is one of devotion and dedication.

• It is a raga that suggests unconditional offering of everything one has at the altar of whatever one's calling may be, asking nothing in return.

Raag Bhimpalasi

•An afternoon raga, sung from late afternoon to sunset, Bhimpalasi is poignant and passionate, filled with yearning.

Raag Kaunsi-Kanada

•The late night Raag Kaunsi-Kanada is a delectable combination of Raag Malkauns and Raag Kanada, and is an example of the kind of compound raga in which the identities of both the constituent ragas are retained and weave in and out.

Raag Megh

•Raag Megh (also called Megh Malhar) is a combination of Raag Madmaad Sarang and the Malhar group of rain ragas, is an example of the second kind of compound raga.

•Below, Sushree Savani Shende shows how Raag Megh expresses the Malhar (rain) ragas using the notes of Raag Madmaad Sarang.

Raag Kedar

•Kedar is sung from late evening to midnight and is said to create a mood of peacefulness.

•However, that this raga and its circular note combinations are beautifully suited also for creating a very playful mood.

Raag Jaunpuri

•Raag Jaunpuri is a very pretty, if somewhat plaintive, raga.

•Compared with its cousin, Raag Darbari, it has a distinctly feminine quality to it.

•It needs to be treated with a light touch and uses predominantly light ornamentation.

•This raga is sung in the late morning hours, up to noon or so.

Raag Darbari-Kanada

•Raag Darbari-Kanada is one of the most stately ragas in the Hindustani tradition.

•The first part of its name, Darbari, comes from the word *darbar* (the king's court), and the second part, Kanada, indicates that it is originally a Carnatic (south Indian) raga.

•Grave and majestic, this raga is best sung in a heavy bass voice during the late evening hours, and sometimes deep into night.

•It is characterized by its extensive use of powerful percussive ornamentation (*gamak*) and a slow lower-side oscillation on the g (minor third) and d (minor sixth) notes.

Raag Bahar

•*Bahar* means spring, and Raag Bahar is filled with the lightness and joyous celebration of springtime.

•It is sung throughout the spring season during the early afternoon hours and lends itself best to a lively tempo.

Raag Miya-Ki-Malhar

•Miya-Ki-Malhar is probably one of the most famous Indian ragas.

•"Malhar" means "cleanser of impurities" (indicating the rains) and all ragas that contain the word Malhar in their names are rain ragas.

•Miyan-Ki-Malhar can depict the joy and relief of the first rains, but on a dramatically contrasting note, it can also depict restless longing in separation and unnamed fears.

•Ornamentations are used to great effect in this raga to suggest the wind blowing, the thunder rumbling, and lightning cracking.

•The fragrance that rises as the first raindrops touch the scorched earth is indescribable, peacocks start to dance.

•That is when the Malhar ragas are sung.

SCIENTIFIC ANALYSIS

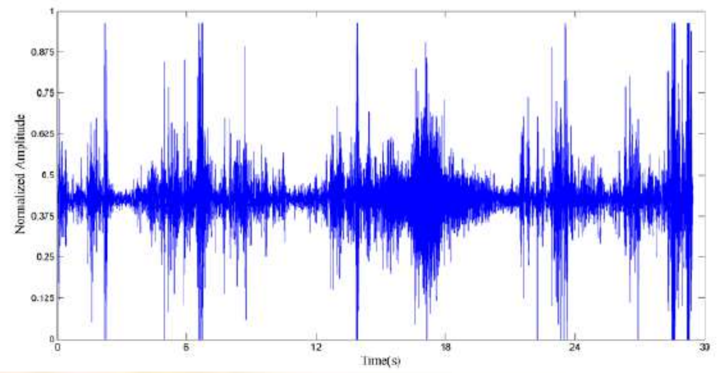
Non linear analysis of note structure of ragas

The detailed methodology is given in Annexu**re**

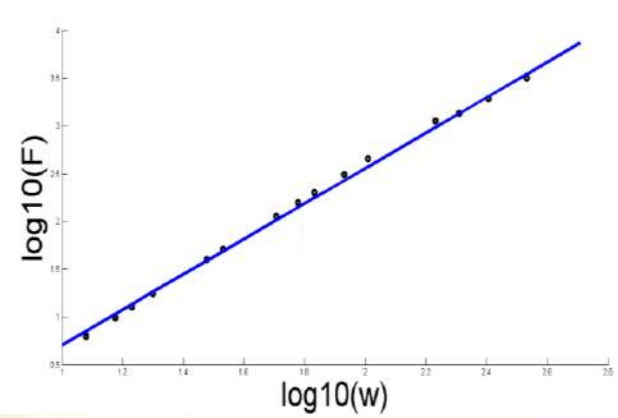
Fractal Dimension corresponding to note structure of a raga

Raga Bhairav

Note structure of Raga Bhairav



Acoustic Waveform of Raga Bhairav



Non linear analysis for characterization of acoustic signal of notes of Raga Bhairavi to obtain the quantitative parameter – **Fractal dimension**

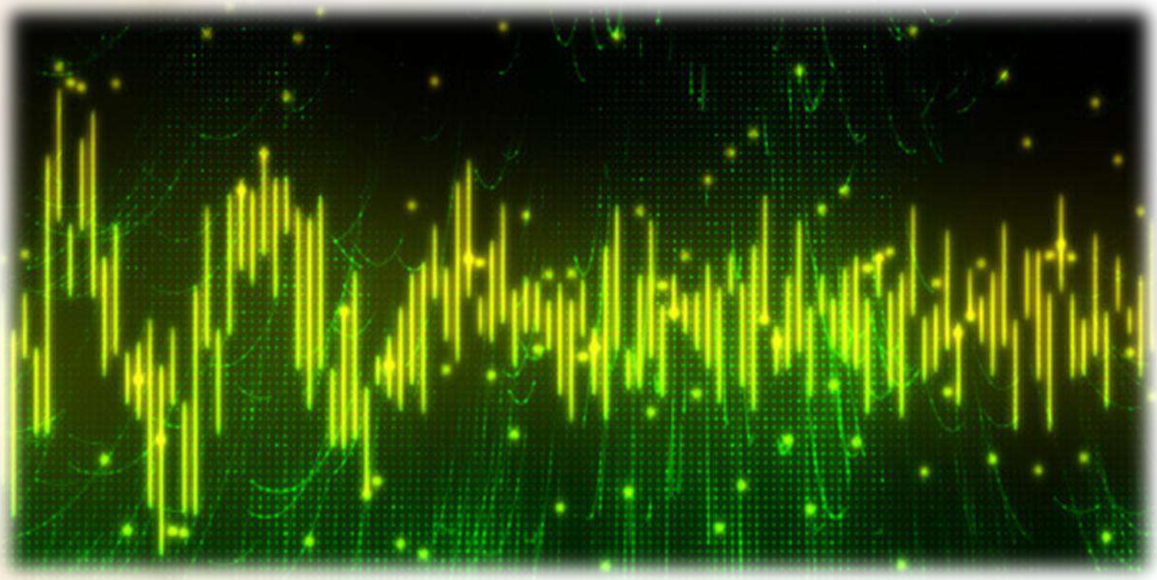
Raga Bhairavi **Fractal Dimension= 1.53**

The table below gives the summary of results of scientific analysis of 9 ragas using the note sequence – Table includes names of ragas, time of rendition, conventional emotion/mood portrayed and degree of symmetry scaling (in terms of Fractal dimension)

Name of Raga	Time of rendition	Emotions/ Mood Conveyed	Fractal dimension (degree of symmetry scaling)
Bhairav	Morning	Peaceful	1.53
Yaman	Evening	Devotion and Dedication	1.76
Bhimpalashi	Afternoon	Passionate yearning	1.67
Bhupali	Evening	Pensive	1.67
Durga	Late evening to midnight	Brightness, innocence	1.73
Hamswadhani	Evening	Positive energy and sense of well being	1.53
Kaunsi Kanada	Late night	Mixed emotion	1.62
Kedar	Late evening to midnight	Peaceful	1.59
Malkauns	Early morning	Majestic, solemn mood	1.66

2

"Alaap" segment of different ragas



Alap ordinarily constitutes the first section of the performance of a raga. Vocal or instrumental, it is accompanied by a drone (sustained-tone) instrument and often also by a melodic instrument that repeats the soloist's phrases after a lag of a few seconds.

The performer of the *alapa* gradually introduces the essential notes and melodic turns of the raga to be performed. Only when the soloist is satisfied that he has set forth the full range of melodic possibilities of the raga and has established its unique mood and personality will he proceed, without interruption, to the metrically organized section of the piece.

SCIENTIFIC ANALYSIS

NON LINEAR ANALYSIS OF EMOTION IN ALAAP SEGMENT OF RAGAS OF INDIAN CLASSICAL MUSIC

The detailed methodology is given in Annexure

•**Data Extracted**: A trained Sitar exponent played the alap part of eight Ragas in Hindustani music.

•**Sets**: Jhinjhoti, Yaman, Chayanat, Basant, Suddh Sarang, Lalit, Multani, and Gurjari Todi. Each Raga is divided into subsets of five.

•**Brief Description:**

•Direct digital recording done in noise proof studio having reverberation time of 0.1 s via standard sound card in P IV PC (2.4GHz.).

•The recordings were listened by 3 musicians who opined that the Ragas are perfectly played and the associated emotions are present in each signal.

•The digitization of the signal was done at (16 bits/sample).

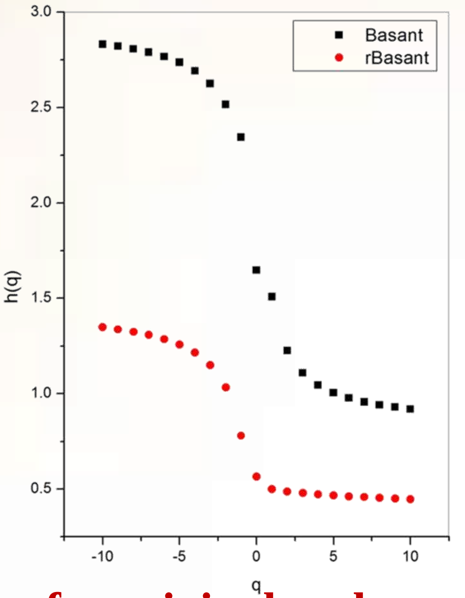
•Pitch periods were extracted by using standard software package Wavesurfer developed by KTH, Stockholm.

•Each data file constitutes the average pitch computed at 10ms interval consecutively for the entire signal.

Origin of multifractility:

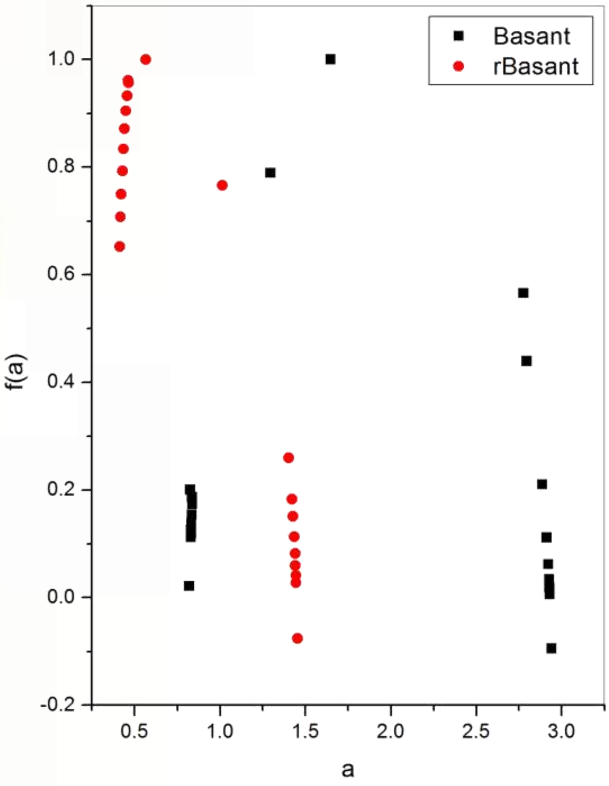
Plot of h(q) vs. q for original and shuffled series for Raga Basant

The degree of multifractality for the shuffled series is less than the original series for Raga Basant



Multifractal spectrum f(α) vs. α for original and shuffled series for Raga Basant

The Fig shows the shuffled series to exhibit weaker multifractility indicating that that the origin of multifractality is due to both long range correlations and broad probability distribution.



Raga	W	γ	Raga	W	γ
Jhinjhoti 1	2.26 ± 0.16	-0.39 ± 0.01	Suddh Sarang 1	2.14 ± 0.14	-0.37 ± 0.006
Jhinjhoti 2	2.28 ± 0.18	-0.42 ± 0.009	Suddh Sarang 2	2.16 ± 0.12	-0.31 ± 0.007
Jhinjhoti 3	2.39 ± 0.188	-0.33 ± 0.01	Suddh Sarang 3	1.83 ± 0.13	-0.35 ± 0.008
Jhinjhoti 4	2.32 ± 0.17	-0.27 ± 0.01	Suddh Sarang 4	2.029 ± 0.12	-0.27 ± 0.008
Jhinjhoti 5	2.49 ± 0.13	-0.32 ± 0.01	Suddh Sarang 5	2.30 ± 0.17	-0.23 ± 0.01
Yaman 1	1.83 ± 0.11	-0.50 ± 0.007	Lalit 1	1.93 ± 0.10	-0.27 ± 0.006
Yaman 2	1.71 ± 0.11	-0.46 ± 0.007	Lalit 2	1.89 ± 0.14	-0.41 ± 0.006
Yaman 3	1.69 ± 0.11	-0.53 ± 0.008	Lalit 3	2.03 ± 0.10	-0.31 ± 0.006
Yaman 4	1.81 ± 0.10	-0.42 ± 0.01	Lalit 4	1.93 ± 0.10	-0.37 ± 0.006
Yaman 5	1.90 ± 0.11	-0.33 ± 0.01	Lalit 5	1.91 ± 0.08	-0.27 ± 0.008
Chayanat 1	2.14 ± 0.19	-0.40 ± 0.011	Multani 1	1.98 ± 0.11	-0.29 ± 0.007
Chayanat 2	2.38 ± 0.11	-0.40 ± 0.012	Multani 2	1.91 ± 0.11	-0.21 ± 0.007
Chayanat 3	2.34 ± 0.12	-0.36 ± 0.012	Multani 3	1.86 ± 0.14	-0.39 ± 0.006
Chayanat 4	2.42 ± 0.12	-0.37 ± 0.014	Multani 4	1.87 ± 0.11	-0.27 ± 0.008
Chayanat 5	2.37 ± 0.12	-0.33 ± 0.015	Multani 5	2.03 ± 0.09	-0.25 ± 0.008
Basant 1	1.93 ± 0.16	-0.46 ± 0.01	Gurjari Todi 1	1.85 ± 0.12	-0.40 ± 0.008
Basant 2	2.15 ± 0.31	-0.44 ± 0.01	Gurjari Todi 2	1.81 ± 0.17	-0.39 ± 0.007
Basant 3	1.92 ± 0.12	-0.55 ± 0.01	Gurjari Todi 3	1.86 ± 0.11	-0.35 ± 0.007
Basant 4	2.16 ± 0.14	-0.49 ± 0.01	Gurjari Todi 4	1.87 ± 0.12	-0.41 ± 0.007
Basant 5	2.19 ± 0.11	-0.45 ± 0.01	Gurjari Todi 5	2.06 ± 0.10	-0.31 ± 0.008

•The table shows different segments of alap of a particular Raga possess different values of multifractal width w and auto-correlation coefficient γ.

•Thus it indicates that even different segments of alap of a particular Raga elicits different emotions as evident from different values of w and γ.

•There are segments of the alap of a particular Raga possess close values of w, the interpretation of which is straight forward that in those segments elicitation of emotion remains more or less same.

•The present study offers new and novel method using latest state of the art of exploring complex musical signal which can provide a hint for quantification of emotion elicited by music.

•All the Ragas show different multifractal width w & the correlation γ is also different for all sets of Ragas.

•Auto-correlation γ seems to be the least in Raga Multani.

Conclusion

•Result of this pilot study indicates that each Raga has a characteristic fractal structure of different multifractal width w and different degree of correlation γ.

•For different Music signals (conventionally labeled as Raga) eliciting different emotions possess different mean values of complexit (w).

•The signals can be differentiated from one another on basis of multifractal width w and the auto-correlation coefficient γ.

•**Major findings of this pilot study is**

• Different segments of alap of a particular Raga also elicits different emotions as evident from different values of w and γ,

•Even alap segment, contains different emotions contrary to common belief.

3

Neurocognitive study of audio signal of music (Indian Classical) with biosensor (EEG)

DEVELOPMENT OF METHODOLOGY FOR CATEGORIZATION OF EMOTIONS FROM AUDITORY STIMULI: A NEUROCOGNITIVE APPROACH

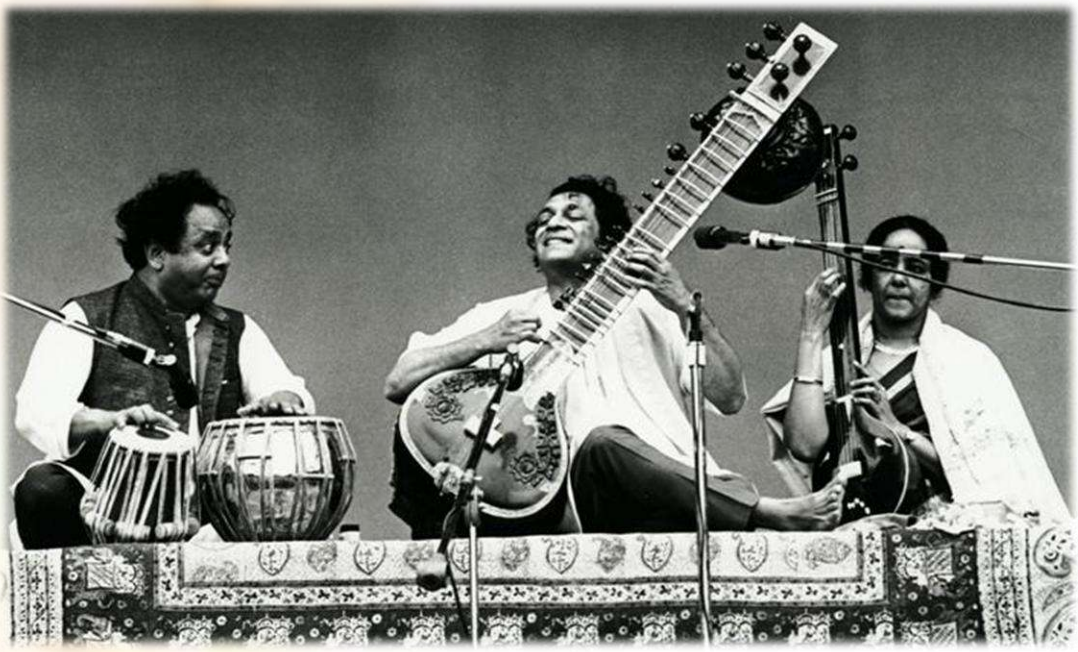
EMOTIONS COGNITION

- Emotion can be reflected through non-physiological signals such as words, voice intonation, facial expression, and body language, many studies on emotion recognition based on these non-physiological signals have been reported in recent decades.
- Signals obtained by recording voltage changes occurring on skull surface as a result of electrical activity of active neurons in the brain are called EEG.
- From the clinical point of view, EEG is the mostly used brain-activity-measuring technique for emotion recognition.
- Furthermore EEG-based BCI systems provide a new communication channel by detecting the variation in the underlying pattern of brain activities while performing different tasks.
- However, BCI systems have not reached the desired level to interpret people's emotions.
- Does the intensity of emotional arousal remain the same or does it change?
- We look to answer such questions in this work with the help of state of the art mathematical tools to assess bio-sensor data.

Hindustani Classical Music and Emotions:

Music in the Indian subcontinent has been a source of aesthetic delight from time immemorial. From the time of Bharata's Natyashastra (Ghosh, 2002), there have been a number of treatises which speak in favor of the various *rasas* (emotional experiences) that are conveyed by the different forms of musical performances. The aim of any dramatic performance is to emote in the minds of audience a particular kind of aesthetic experience, which is described as "Rasa". The concept of "Rasa" is said to be the most important and significant contribution of the Indian mind to aesthetics. The study of aesthetics deals with the realization of beauty in art, its relish or enjoyment, and the awareness of joy that accompanies an experience of beauty; but till date science had nothing to do with the aesthetic experiences corresponding to a particular performance and was kept as a separate entity.

It is only from the last two decades of the 20th century that scientists began to understand the huge potential of systematic research that Hindustani Music (HM) has to offer in the advancement of cognitive science as well as psychological research. A number of works tried to harvest this immense potential by studying objectively the emotional experiences attributed to the different *ragas* of Hindustani classical music (Balkwill & Thompson, 1999; Martinez, 2001; Wieczorkowska et.al, 2010). The *raga* is a sequence of musical notes and the play of sound which delights the hearts of people. The word Raga is derived from the Sanskrit word "Ranj" which literally means to delight or please and gratify (Brahaspati, 2002). Although there are a number of definitions attributed to a Raga, it is basically a tonal multifarious module.



In HM the existing phrases are stretched or compressed, and the same may happen to motives from the phrases; further motives may be prefixed, infixed and suffixed. Phrases may be broken up or telescoped with others, and motives or phrases may be sequenced through different registers (Neuman, 1990). Thus, during a performance, a singer steadily loosens the strangle hold of the rules of music in a subtle way. He does not flout them, he merely interprets them in a new way, which is the beauty of Hindustani classical music and there comes the wisdom that *Raga* and its grammar are only means and not ends in themselves.

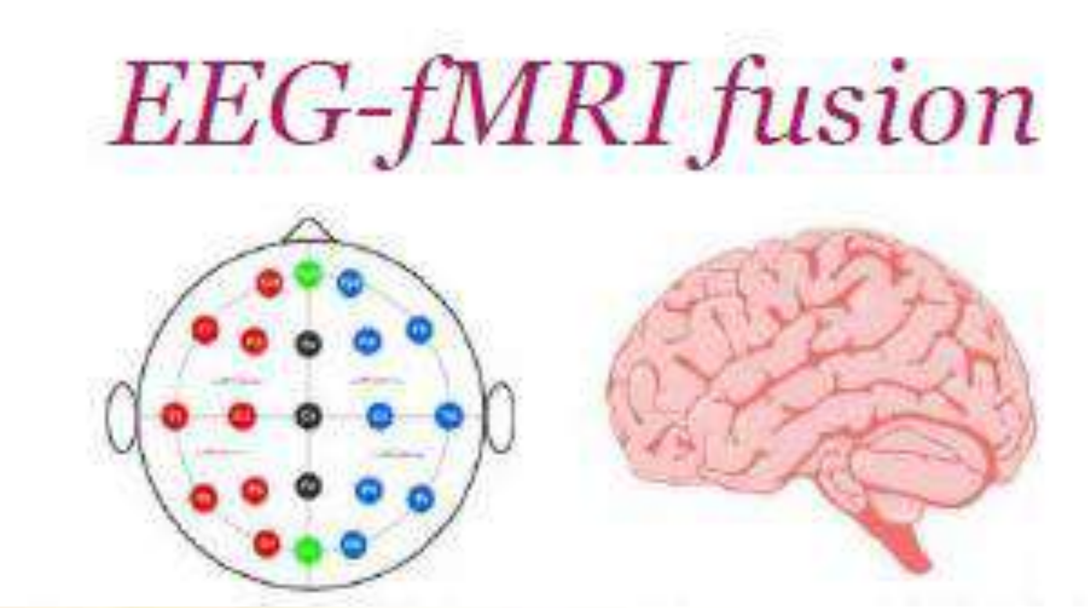
Emotion Recognition --Use of EEG as Biosensor

•Mostly techniques to understand the emotions are mostly based on a single modality such as Positron Emission Tomography (PET), functional Magnetic Resonance Imaging (fMRI), Electroencephalography (EEG) or static face image or videos.

•Since emotion expresses natural instinctive state of mind, the outward expression may be voluntarily controlled as per the environment or the circumstances.

•A person when feeling angry may shout at his child, but may suppress this in front of his boss.

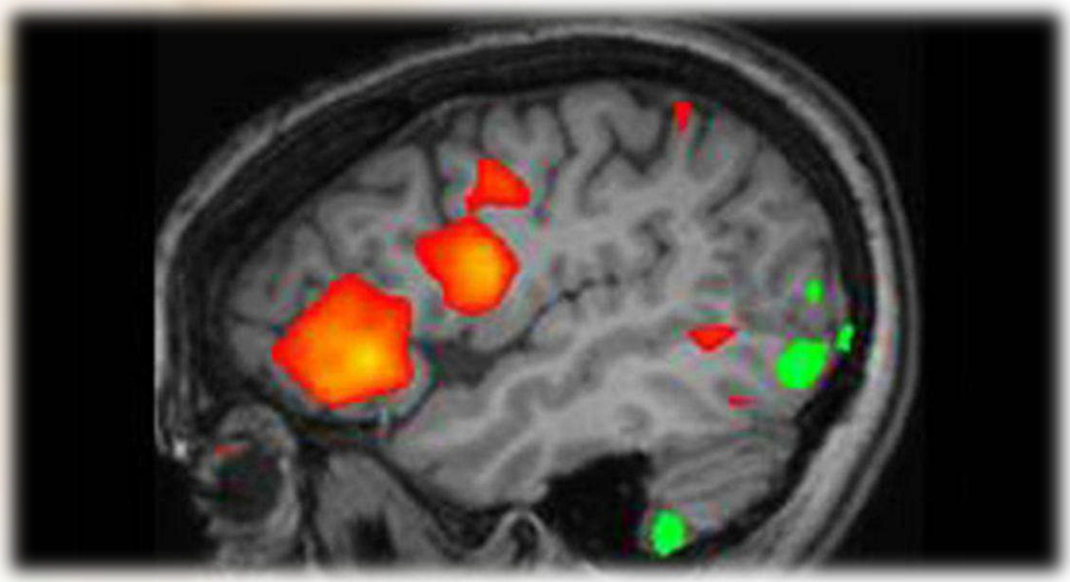
•Straightforward connection of facial actions with neural signals or with emotions may not be correct.



•EEG signal changes according to the emotion state.

•On the other hand changes that occur in EEG signal cannot be voluntarily controlled and hence become a better indicator of emotions.

•EEG can detect changes in brain activity over milliseconds, which is excellent considering an action potential takes ~0.5–130 ms to propagate across a single neuron, depending on the type of neuron. Nevertheless, EEG measures the brain's electrical activity directly, while fMRI and PET record changes in blood flow or metabolic activity, which are indirect markers of brain electrical activity.

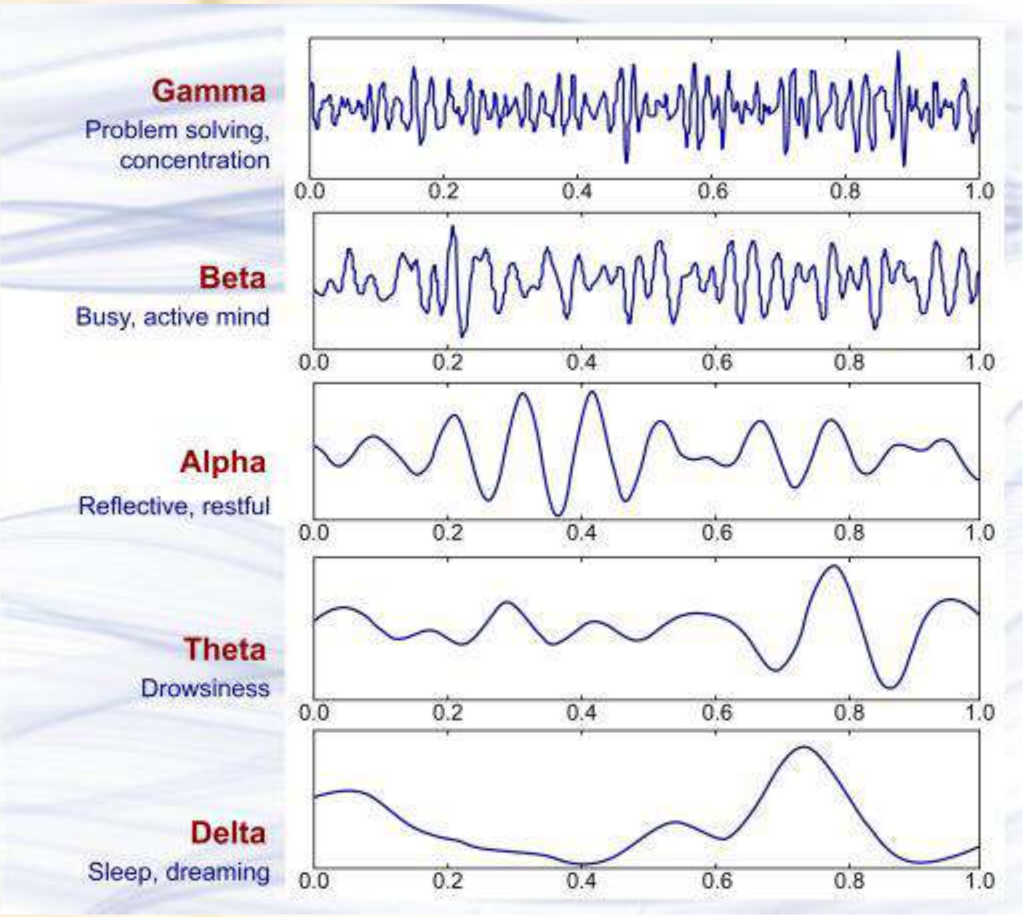


• EEG can be considered as the most studied potentially non-invasive brain activity detector system in computational emotional systems, mainly due to its fine temporal resolution, ease of use or portability, been not as invasive as the other alternatives and relatively low cost.

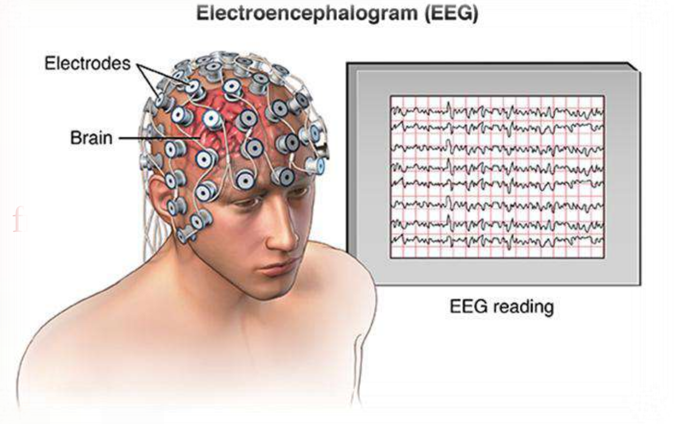
• However, EEG alone does not record indirect brain electrical activity markers, such as changes in blood flow or metabolic activity.

• Therefore, combining EEG with other non-invasive biometric information detection systems is a promising way to improve emotion detection.

•In the past few years, different methods have been proposed for automatic human emotion recognition which relies mainly on brain signals generated from central nervous system and observed using electroencephalograph (EEG), electrocorticographies (ECoG) and functional magnetic resonance imaging (fMRI).



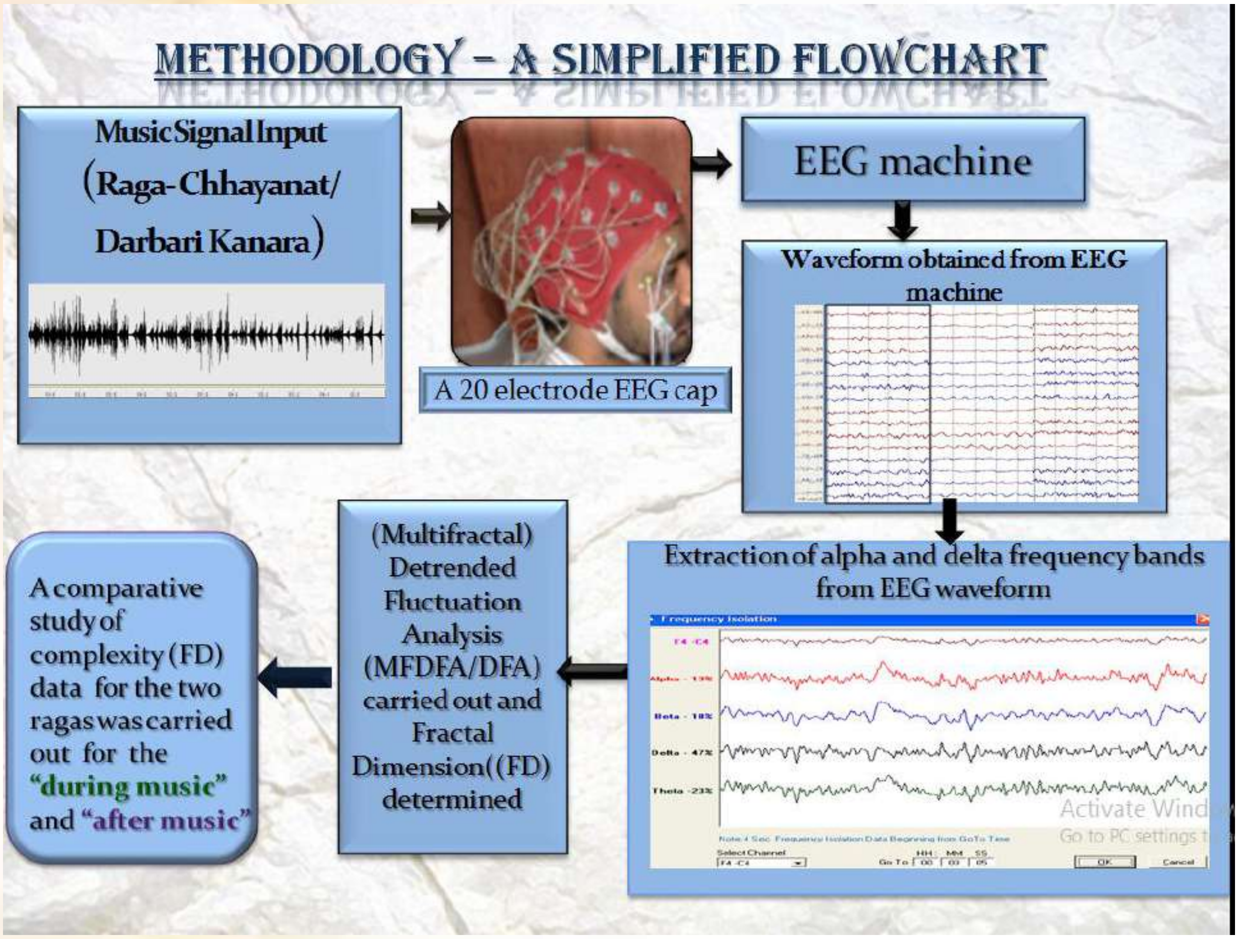
- Among different modalities of brain signals, EEG is considered as the best choice to record information due to its unique characteristics in response to the human emotional states.
- Emotion estimation from human brain activity recorded using EEG is quite effective, since these signals are generated from the limbic system that is strongly responsible for cognition activities.
- EEG signals are recorded from scalp using electrodes, and there are mainly two types of EEG recordings: (i) mono-polar (ii) bipolar. Mono-polar recording measures the voltage difference between active electrodes on the scalp and a reference electrode. On the other hand, bipolar electrodes provide the voltage difference between two active electrodes.
- The EEG signals comprise of numerous frequency bands with ranges f 0Hz to 80 Hz. EEG signal can also be categorized into five major frequency rhythms: Delta, Theta, Alpha, Beta and Gamma. All these show different mental conditions of the subject.



- EEG signals have been used by brain researchers and human computer experts to recognize human emotions.
- We proposed a noninvasive assessment tool for the automatic detection of musical emotions using a biosensor EEG and nonlinear computational technique for analysis of EEG data.

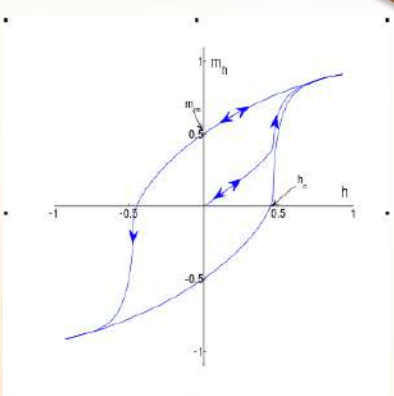
Overview of Our Work:

The objective of this study is to analyze the effect of Hindustani music on brain activity during the normal relaxing condition, using electroencephalography (EEG). Four (4) different Hindustani music raga clips of contrasting emotion (romantic/sorrow) were used in the study. EEG was performed on ten (10) subjects while they listened to the two pair of clips conventionally known to portray contrast emotions. The subjects were made to64 listen to the 3 min 40 second clip of happy emotion (*Chayanat/ Bahar*) first followed by the 3 min 40 second clips which convey sad emotion (*Darbari Kanada/ Mian ki Malhar*).

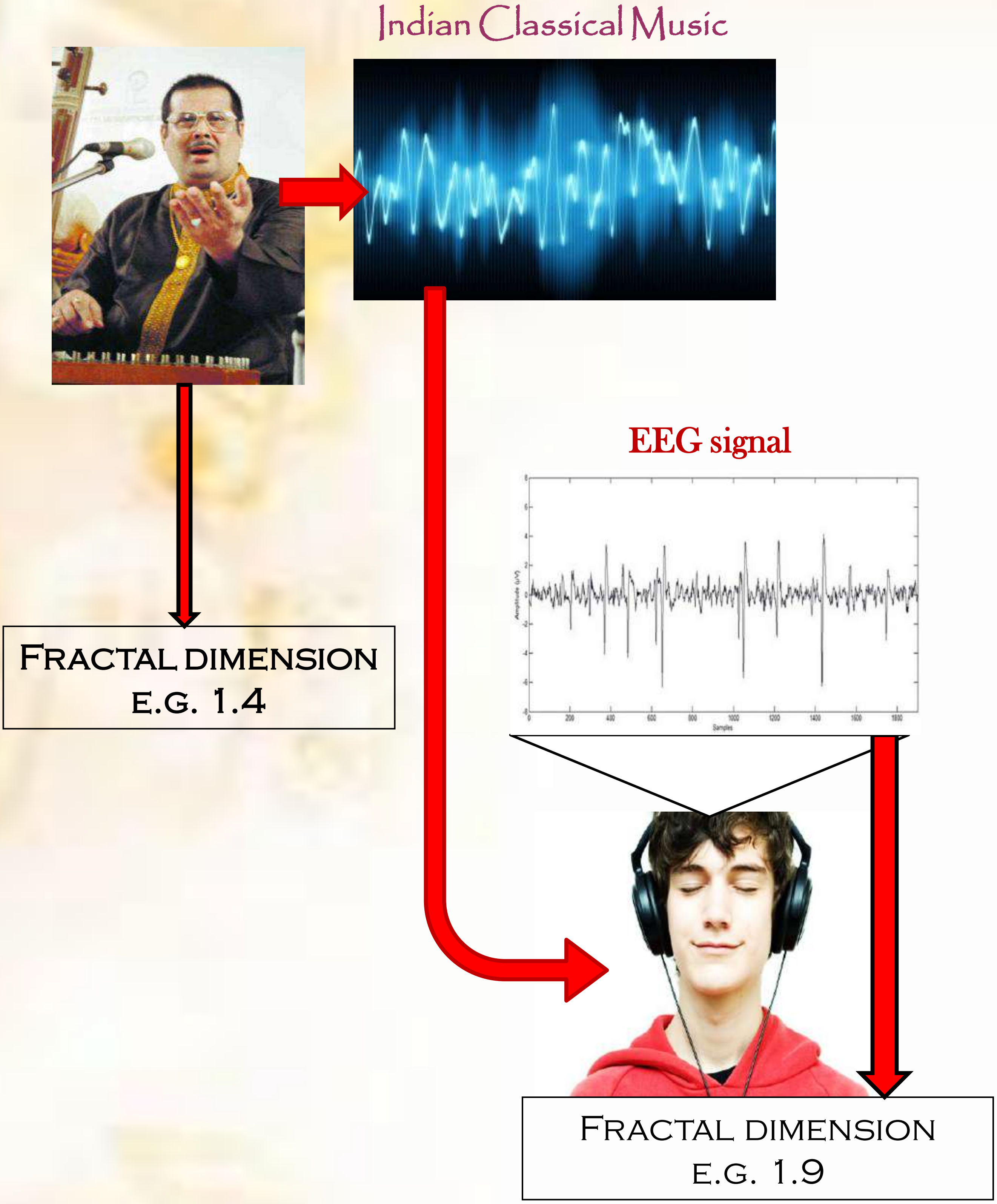


Each period of listening was separated from the other by a resting period of 3 min 40 seconds which was maintained to see how long the arousal based activities persisted in human brain after the removal of stimulus. Two different experiments were conducted to assess the emotional response from *Chayanat/ Darbari Kanada* and *Bahar/Mian ki Malhar.* While the objective of the first experiment is to study the hysteresis like phenomenon in human brain while the second study mainly focuses on the categorization and quantification of emotional cues from Hindustani classical music. The brain response corresponding to the frontal electrodes were only taken in consideration throughout this chapter as the frontal lobe proves to be the most important when it comes to higher order cognitive processing. Also, In this context, we studied the valence lateralization theory in human brain which proposes that a particular emotion is processed in a particular direction of the brain.

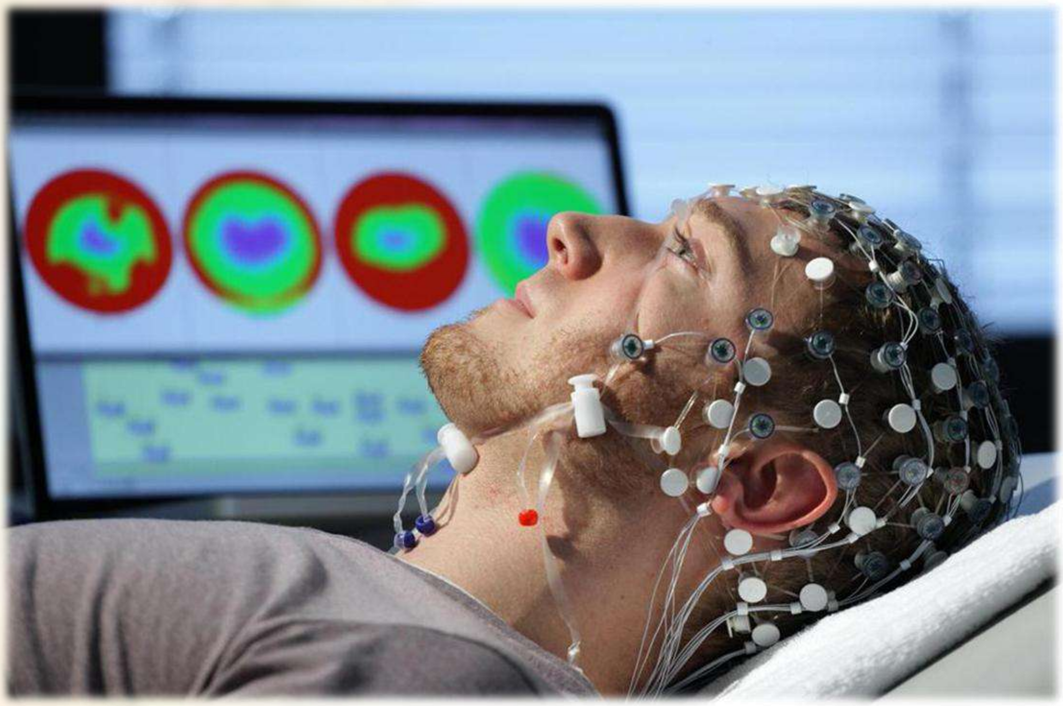
In neuroscience it is said that the property by which some neurons do not return to their basal conditions from a stimulated condition immediately after removal of the stimulus, **is an example of hysteresis.**



EEG with input of musical stimuli



DFA technique was used to quantify how the scaling pattern of EEG frequency rhythms changed as the emotional appraisal from a certain music clip changed. The findings show that alpha and theta frequency ranges showed consistent arousal based activities as is evident from their respective rise of DFA scaling exponents while the subjects were listening to the music clips. The arousal based activities persisted for quite some time even after the stimulus were removed. The gamma frequency ranges were also studied in this context, but failed to provide any conclusive results in this direction which may possibly due to the limitations of EEG system. It was also observed that when the music stimuli were removed, significant alpha brain rhythms persisted, showing residual arousal activities. This is analogous to the conventional 'Hysteresis' loop where the system retains some 'memory' of the former state, but in case of emotions induced by musical stimuli.



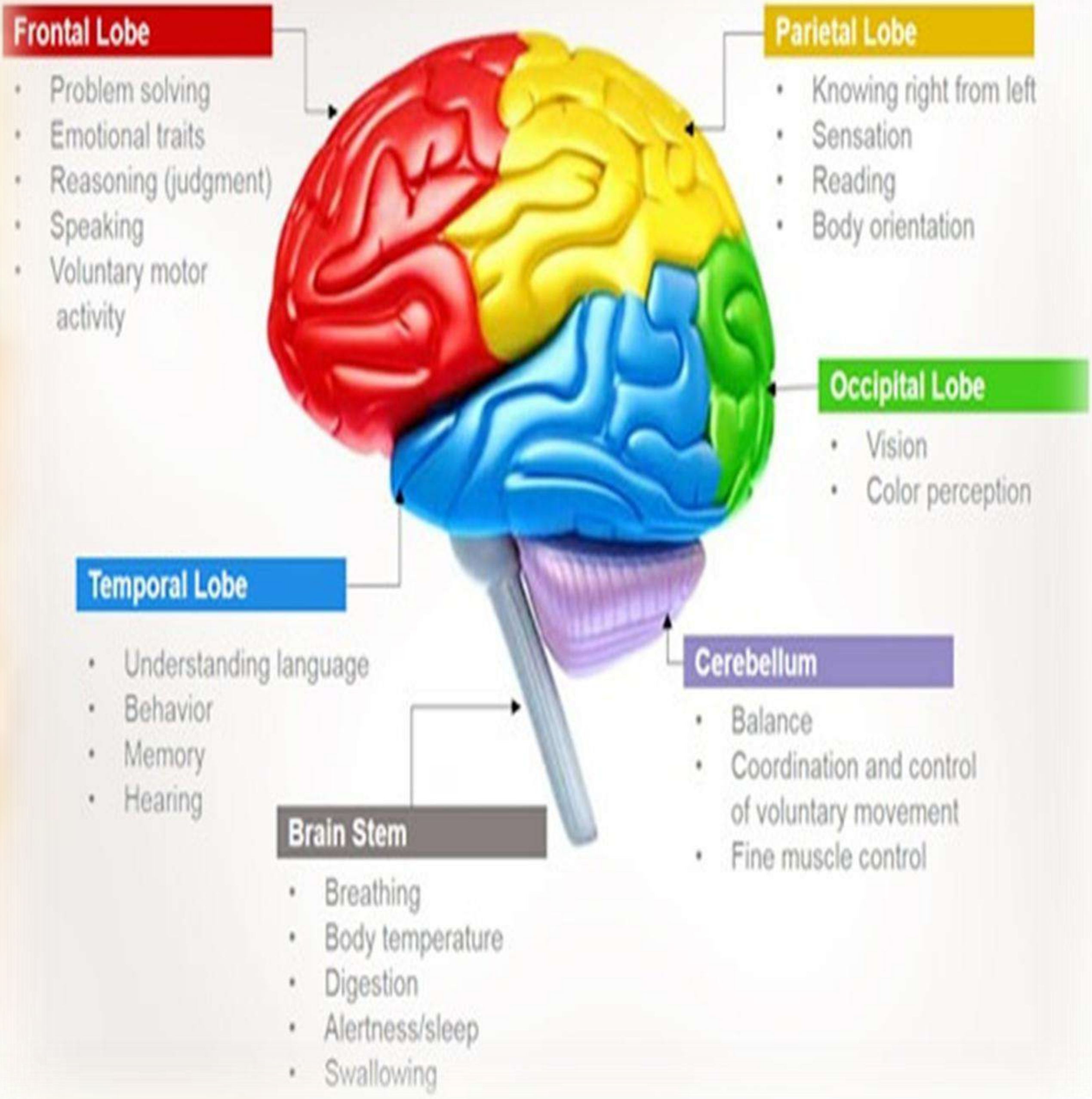


Fig. Function of different lobes of human brain

Choice of *Ragas: Chayanat and Darbari Kanada/Bahar and Mian ki Malhar*

The two pair ragas chosen for our analysis were “Chayanat”/”Bahar” (romantic/joy) and “Darbari Kannada”/ “Mian ki Malhar” (pathos/ sorrow). Variations in the timbre were avoided by making the same artist play the two ragas with the same sitar. Both the signals were normalized to within 0dB and hence intensity or loudness and attack cue are not being considered. Each of these sound signals was digitized at the sample rate of 44.1 KHZ, 16 bit resolution and in a mono channel. From the complete playing of the ragas, segments of about 3 minutes and 40 seconds were cut out for analysis of each Raga. Help was taken of some experienced musicians for identifying the emotional phrases in the music signal along with their time intervals, based on their feelings. A sound system (Logitech R_Z-4 speakers) with high S/N ratio was used in the measurement room for giving music input to the subjects. The EEG experiment was conducted in the afternoon (around 2 PM) in a room with the subjects sitting in a comfortable chair. There were two round of experiments with the two sets of music clip of contrast emotion.

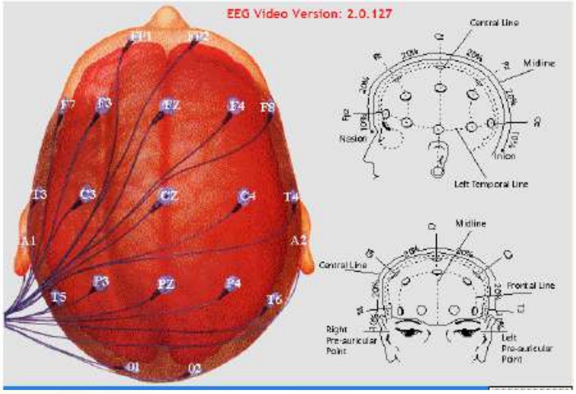


Fig. : The position of electrodes on the head are depicted

Experimental Protocol

Since the objective of this study was to analyze the effect of Hindustani music on brain activity during the normal relaxing condition, the frontal lobes were selected for the study. EEG was done to record the brain-electrical response of ten male subjects. Each subject was prepared with an EEG recording cap with 19 electrodes (Ag/AgCl sintered ring electrodes) placed in the international 10/20 system. Another experiment was also conducted with *Bahar/ Mian ki Malhar* as the two set of clips which conveyed contrast emotion with 10 more participants using the same methodology as in this experiment.

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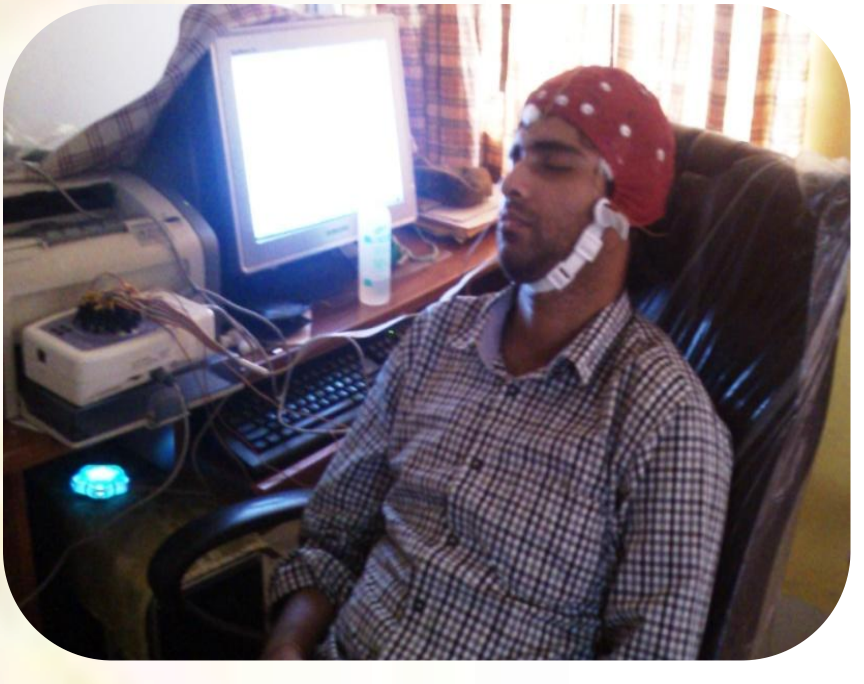
Fig. depicts the positions of the electrodes. Impedances were checked below 5 kOhms. The ear electrodes A1 and A2 linked together have been used as the reference electrodes. The same reference electrode is used for all the channels. The forehead electrode, FPz has been used as the ground electrode. The EEG recording system (Recorders and Medicare Systems) was operated at 256 samples/s recording on customized software of RMS. The data was band-pass-filtered between 0 and 50 Hz to remove DC drifts. Each subject was seated comfortably in a relaxed condition in a chair in a shielded measurement cabin. They were also asked to close their eyes. Since the subjects were not instructed to gaze at a fixation cross presented on a screen and to simultaneously rate the music during the recording, closing eyes helped them to attentively yet comfortably listen to music in the long experiment. The subjects were not instructed to identify any specific musical structures.

A sound system (Logitech R_Z-4 speakers) with high S/N ratio was set up in the measurement room that received input from outside the cabin. After initialization, a 17 min 40secs recording period was started, and the following protocol was followed:

•Three Minutes No Music
•3 mins. 40 secs With Music (Chayanat)
•3 mins. 40 secs No Music
•Sequence 2-3 was repeated With Music (Darbari Kannada)

Each signal length was 3mins. 40 secs. Markers were set at start, signal onset/offset, and at the end of the recording. On the second day, the same protocol was followed, only Music 1 and Music 2 have been replaced by “Bahar” and “Mian Ki Malhar” respectively.



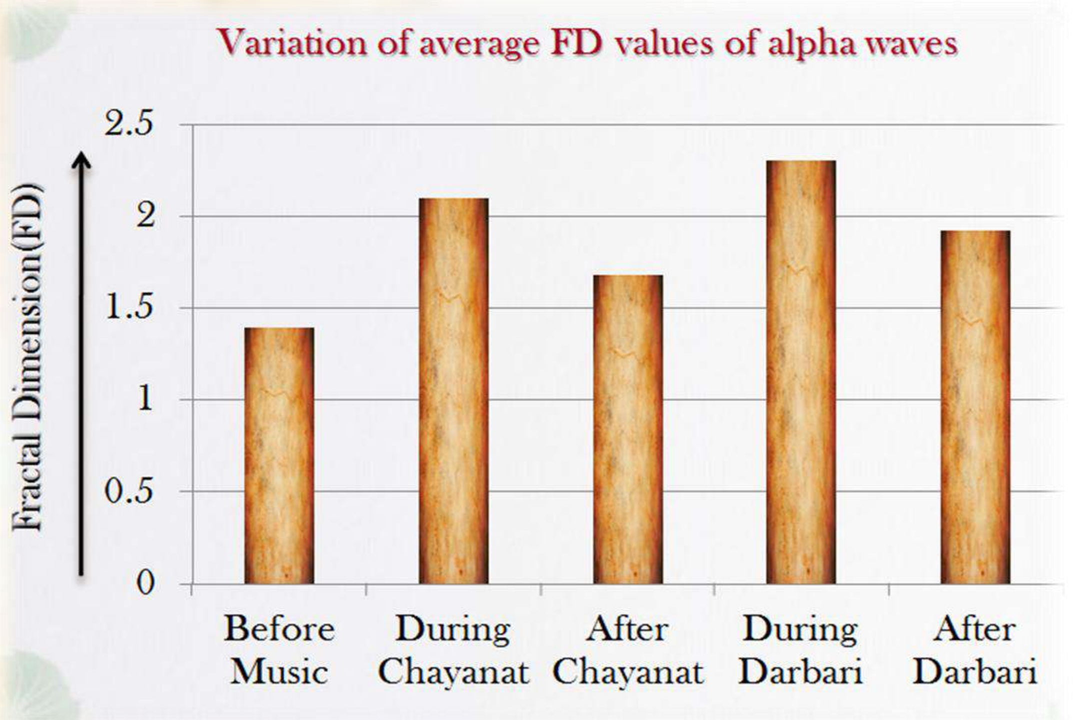
Results and Discussion

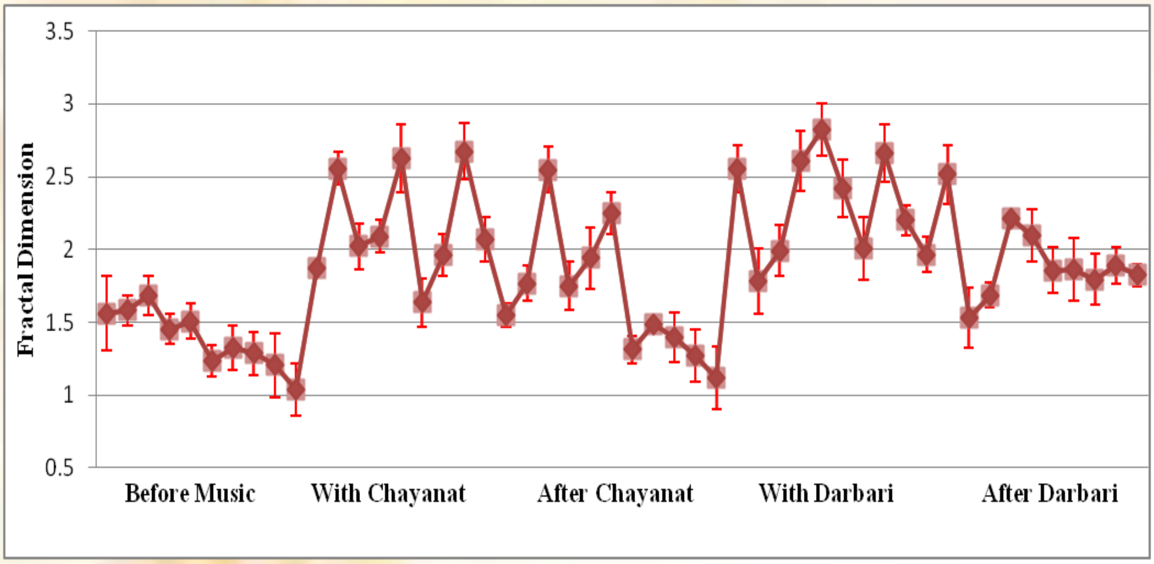
Fractal dimension was computed against the EEG channels for frontal, occipital and temporal lobes corresponding to alpha frequency rhythm using eqn. (4). The FD values of the 'after the withdrawal of music' tend to be lower than the 'with music' condition. Due to multivariable data, the three lobes were selected to simplify further investigation.

The plot for the variation of the FD in the latter case was done for 220 seconds in the 'without music' condition. For comparison they are drawn in the same time scale. The figures depict the FD values of the frontal, temporal and occipital lobes in time intervals of 22 seconds. Since both the music specimens are of 220 seconds duration, EEG was continued for another 220 seconds after the withdrawal of music. The error bars in all the plots represent the SD values computed for different time windows in each experimental condition.

The sole objective was to see how long the memory of the former state (i.e. that particular music) remains after its withdrawal. It is observed that in Chayanat, FD of the alpha at frontal lobe shows high complexity in the neural processing in different time regions, depicting high arousal for happy music. After its withdrawal, in the next 220 seconds, the FD of alpha remains high up to 120 seconds and then falls, thereby showing retention of the emotion of Chayanat for 120 seconds.

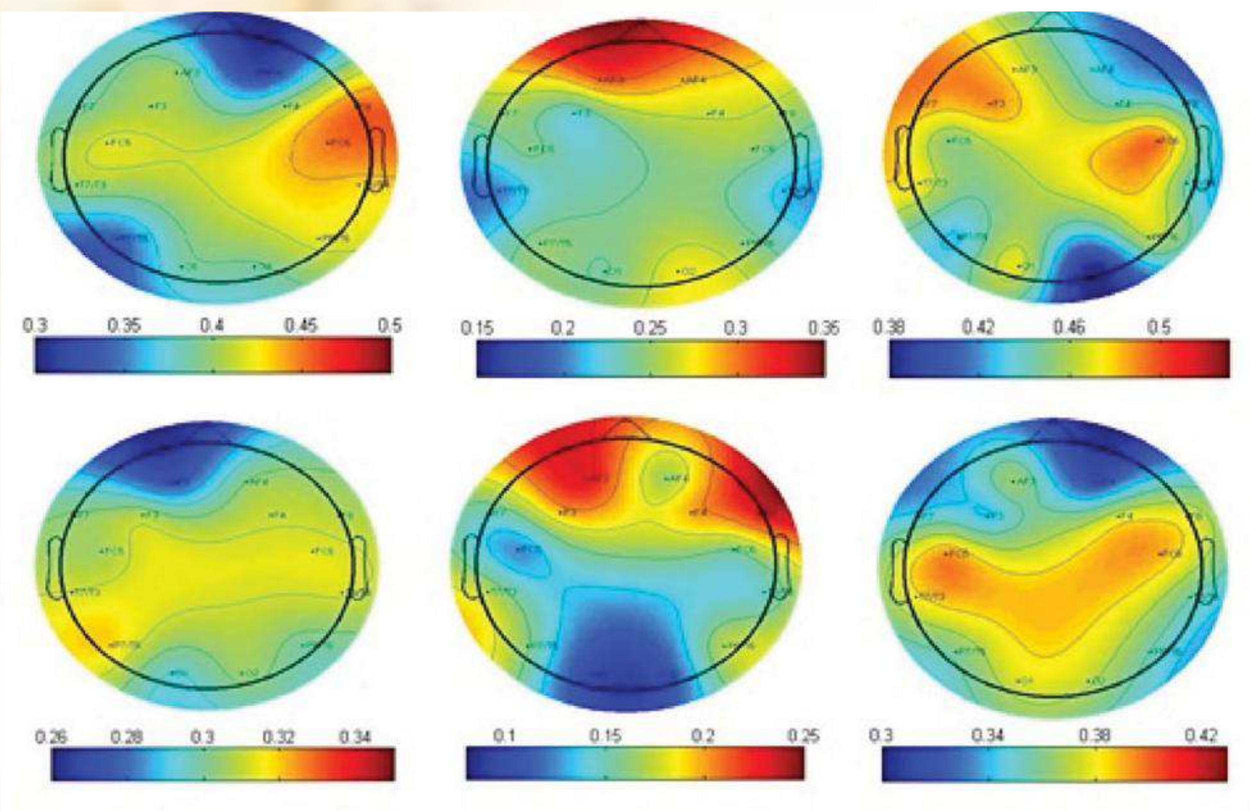
In the case of Darbari also, FD of the alpha at frontal lobe shows high complexity in the neural processing in different time regions depicting high arousal for sad music. After its withdrawal, in the next 220 seconds, the FD of alpha remains high up to 77 seconds and then falls, thereby depicting retention of the emotion of Darbari for 77 seconds. In case of temporal lobe, it shows high complexity till 77 seconds for Chayanat and then decays. But in occipital lobe, neural complexity of theta decreases roughly 33s after the removal of Darbari. In case of parietal lobe though, we failed to find any such residual arousal effects as is evident from **Fig.** . The variation of FD values after the removal of Chayanat and Darbari corresponding to parietal lobe is absolutely random and is unable to decipher any conclusive result.





Variation of averaged FD values in frontal lobe

Before Music **With Chayanat** **After Music**



Before Music **With Darbari** **After Music**

4

Neurocognitive studies of visual stimuli of dance performance (Indian Classical) with biosensor (EEG)

NEUROCOGNITIVE CHARACTERIZATION OF EMOTION ELICITED BY INDIAN CLASSICAL DANCE

Dance is a pleasurable and captivating activity that involves motor, cognitive, visuospatial, social, and emotional engagement.

• Although practiced for thousands of years in rituals and as a leisure activity, the long-term effects of systematic dance training on cognition, and brain structure and function are not well understood.

•Dance is a rich source of material for researchers interested in the integration of movement and cognition.

•The multiple aspects of embodied cognition involved in performing and perceiving dance have inspired scientists to use dance as a means for studying motor control, expertise, and action-perception links.

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Dance emotion recognition and Fractals

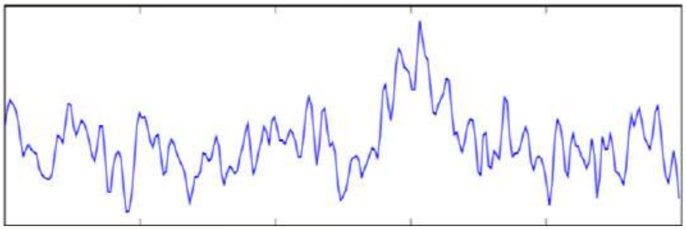
•A fractal is a rough or fragmented geometrical object that can be subdivided in parts, each of which is (at least approximately) a reduced-size copy of the whole. Fractals are generally self-similar and independent of scale (fractal dimension) – the degree of roughness or brokenness or irregularity in an object.

•They are created by repeating a simple process over and over in an ongoing feedback loop.

•A fundamental characteristic of fractal objects is that their measured metric properties, such as length or area, are a function of the scale of measurement.

•Chaos has been already studied and discovered in a wide range of natural phenomena such as the weather, population cycles of animals, the structure of coastlines and trees and leaves, bubble-fields and the dripping of water, biological systems such as rates of heartbeat, and also acoustical systems such as that of woodwind multiphonics.

Stimuli



Fractal Dimension of EEG = 1.9

•The study of chaos is approached and modeled through the use of nonlinear dynamic systems, which are the mathematical equations whose evolution is unpredictable and whose behavior can show both orderly and/or chaotic conditions depending on the values of initial parameters.

•What has attracted the non-science community to these dynamic systems is that they display fractal properties and, thus, patterns of self-similarity on many levels. Already, the art community has employed such chaotic patterns, and many examples exist of nonlinear/fractal visual art created with the assistance of the computer.

Thus, non-linear dynamical modeling for source clearly indicates the relevance of non-deterministic/chaotic approaches in understanding the speech/music signals. In this context fractal analysis of the signal which reveals the geometry embedded in signal assumes significance.

Bharata's Natyashastra and Rasa

•The concept of *"Rasa"* is said to be the most important and significant contribution of the Indian mind to aesthetics.

•The study of aesthetics deals with the realization of beauty in art, its relish or enjoyment, and the awareness of joy that accompanies an experience of beauty; but till date science had nothing to do with the aesthetic experiences corresponding to a particular performance and was kept as a separate entity.

•From the time of Bharata's Natyashastra, there have been a number of treatises which speak in favor of the various *rasas* (emotional experiences) that are conveyed by the different forms of musical performances.

•The consolidation and evocation of *rasa* represent the function of all the fine arts.

•This is the central conception in India since Bharata's Natyashastra first expounded the doctrine of rasa with its eight categories, viz., Love or Romance (*Śṛngāra*), Gaiety or Humor (*Hāsya*), Compassion (*Kāruṇya*), Fury (*Raudra*), Valor (*Veera*), Terrible (*bhayankara*), Loathesomeness (*bibhatsa*), and Wonder (*adbhuta*).

•From the third or fourth century onwards Silence or Tranquillity (*shanta*) was not only added as the ninth category but considered as the supreme.

•The aim of any dramatic performance is to emote in the minds of audience a particular kind of aesthetic experience, which is described as *"Rasa"*.

Protocol Followed

EEG was done to record the brain-electrical response of 2 subjects. Each subject was prepared with an EEG recording cap with 19 electrodes (Ag/AgCl sintered ring electrodes) placed in the international 10/20 system. Figure 1 depicts the positions of the electrodes. Impedances were checked below 50 kΩ. The EEG recording system (Recorders and Medicare Systems) was operated at 256 samples/s recording on customized software of RMS. Each subject was seated comfortably in a relaxed condition in a chair in a shielded measurement cabin. They were also asked to close their eyes. After initialization, a 10 minutes recording period was started, and the following protocol was followed:

•60 seconds No Stimulus (Resting Condition)
10 seconds Clip 1 (Adbhuta)
•10 seconds No Stimulus
•10 seconds Clip 2 (*bhaya*)
•10 seconds No Stimulus
•10 seconds Clip 3 (*bibhatsa*)
•10 seconds No Stimulus
•10 seconds Clip 4 (*hasya*)
•10 seconds No Stimulus
• 10 seconds Clip 5 (*karuna*)
• 10 seconds No Stimulus
• 10 seconds Clip 6 (*roudra*)
• 10 seconds No Stimulus
• 10 seconds Clip 7 (*shanta*)
• 10 seconds No Stimulus
• 10 seconds Clip 8 (shringara)
•10 seconds No Stimulus
•10 seconds Clip 8 (veera)
• 60 seconds After Stimulus

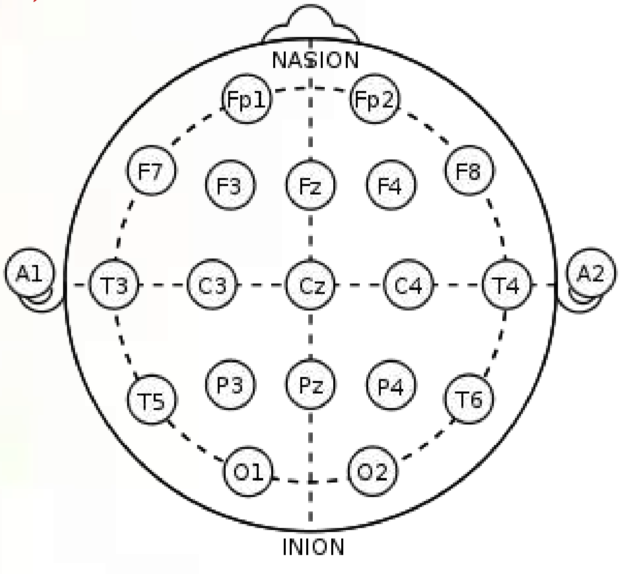
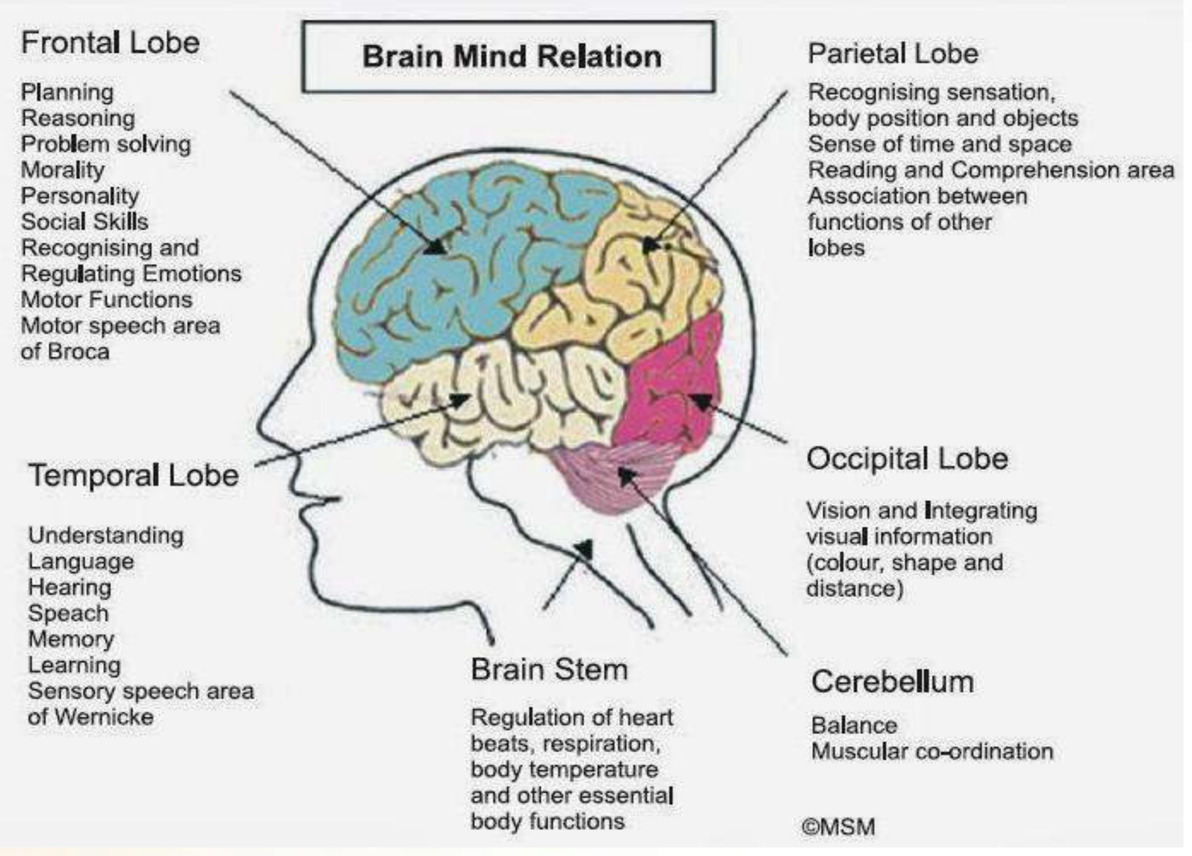


Fig. The position of electrodes according to the 10-20 international system

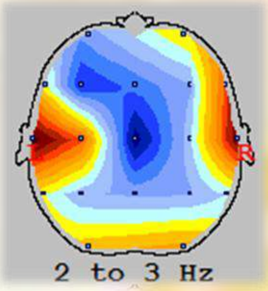
Markers were set at start, signal onset/offset, and at the end of the recording.

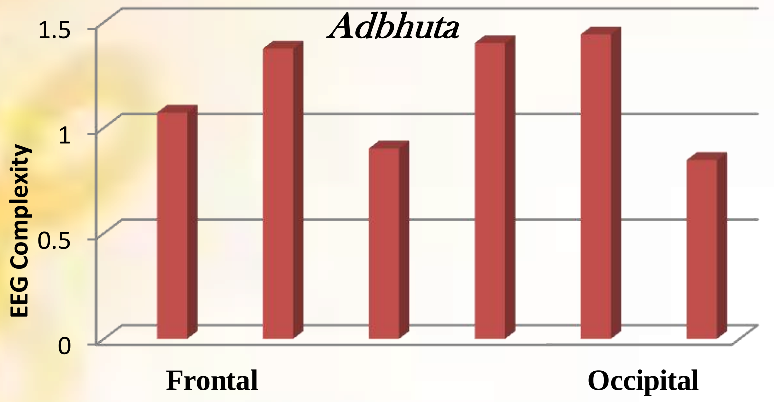
FUNCTION OF DIFFERENT LOBES OF BRAIN



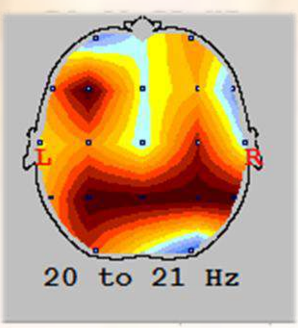
- We intend to categorize and quantify the emotional arousals related to the nine *rasas* as conveyed in dance performance in different lobes of human brain using Electroencephalography (EEG) data and novel nonlinear chaos based techniques.
- The EEG signals were obtained from four frontal electrodes (Fp1, Fp2, F3, F4) and two occipital electrodes (O1/O2).
- The signals from each electrode were preprocessed with the well known EMD technique to make it free from blink/ muscular artifacts.
- EEG brain rhythms were subject to the MFDF analysis which gives the multifractal spectral width corresponding to each *rasa*.
- These neuronic arousals might be a manifestation of change of complexity as obtained from the variation of the multifractal width.
- The multifractal spectral width is known to be a measure of complexity of the EEG signal.
- The spectral width significantly from one *rasa* to another and has unique manifestation in frontal, temporal and occipital lobe.
- This could be helpful as a parameter for emotion identification from dance performances.
- Also, the arousal based effects from a particular *rasa* can be localized with the help of this technique along with the identification of a parameter from which we can nullify or support the valence lateralization theory.
- Summing up, in this study, we provide a novel technique where, with the help of a single parameter (i.e. multifractal width) we can categorize, quantify dance induced emotion processing accomplished by different regions of human brain.

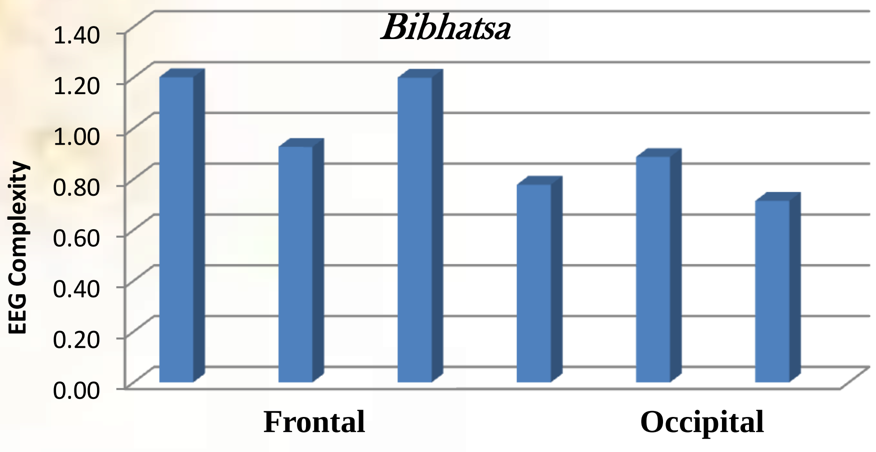
The following plots have been obtained from the Table which denotes the variation of brain signal complexity corresponding to different lobes.



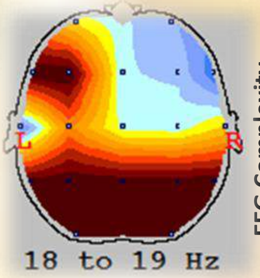


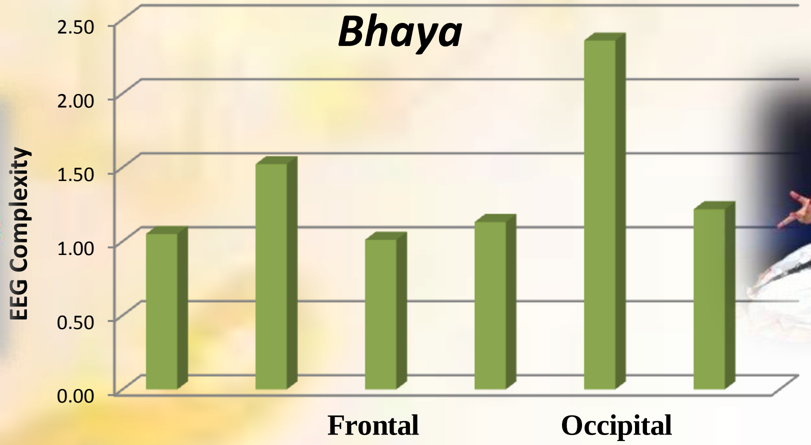
•In case of rase adbhuta, we find the right pre-frontal, frontal and left occipital lobe are the most activated while in case of rasa bibhatsa, the left pre-frontal and frontal are the ones that are most activated depicted by the higher values of EEG signal complexity.



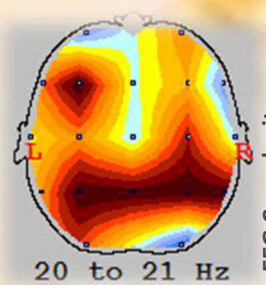


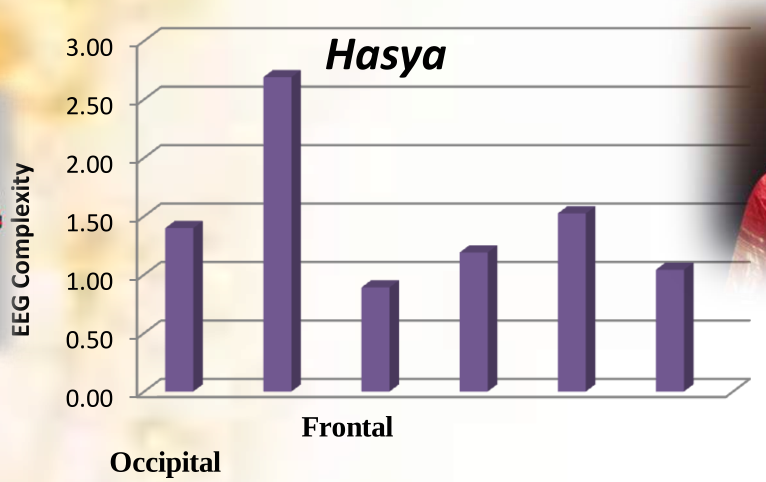
•\The right pre-frontal, frontal and left occipital lobe are the most activated while in case of *rasa bibhatsa*, the left pre-frontal and frontal are the ones that are most activated depicted by the higher values of EEG signal complexity.



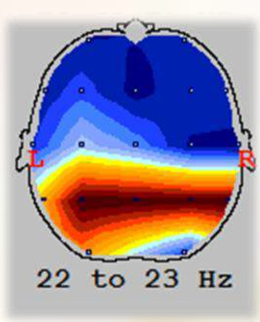


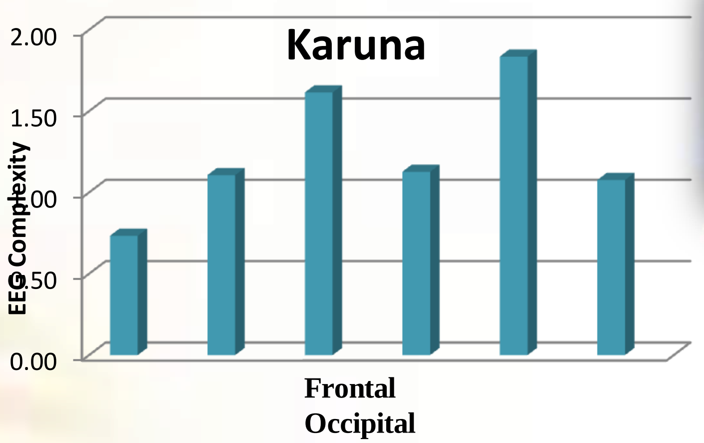
In case of *rasa bhaya,* we find that the left occipital lobe is the one which is most activated.



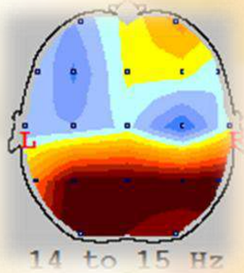


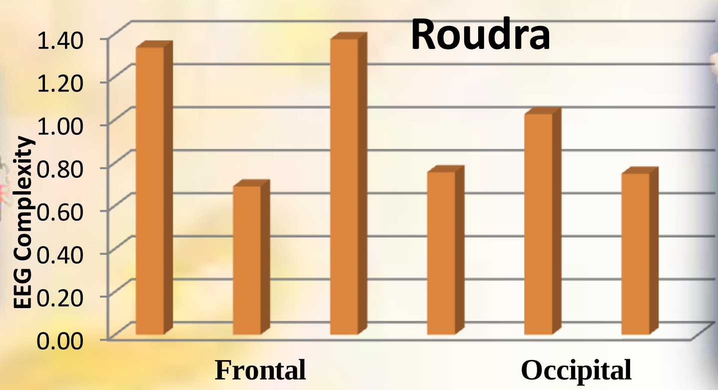
In case of *rasa hasya*, the right pre-frontal electrode is the one where the signal complexity is maximum.



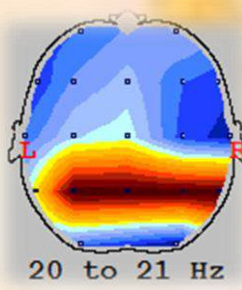


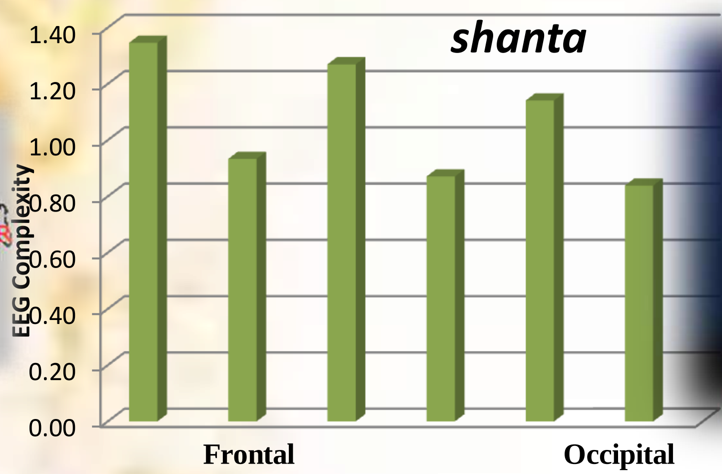
In case of *rasa Karuna*, we see that again F3 and O1 are the ones where we find maximum arousal.



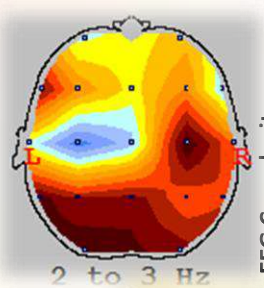


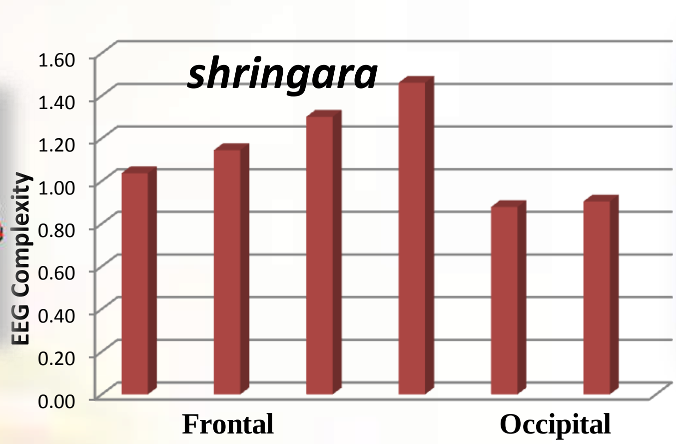
In case of *roudra* left pre frontal and frontal lobe are the most dominant.





In case of *rasa shanta*, the left hemisphere dominates with Fp1, F3 and O1 showing the maximum arousal.





In case of *shringara*, mostly the right frontal electrodes show higher values of complexity.

Humans have engaged in artistic and aesthetic activities since the appearance of our species. Our ancestors have decorated their bodies, tools, and utensils for over 100,000 years. The expression of meaning using color, line, sound, rhythm, or movement, among other means, constitutes a fundamental aspect of our species' biological and cultural heritage. Art and aesthetics, therefore, contribute to our species identity and distinguish it from its living and extinct relatives. Science is faced with the challenge of explaining the natural foundations of such a unique trait, and the way cultural processes nurture it into magnificent expressions, historically and ethnically unique. How does the human brain bring about these sorts of behaviors? What neural processes underlie the appreciation of speech, music, drama and dance? How does training modulate these processes? How are they impaired by brain lesions and neurodegenerative diseases? How did such neural underpinnings evolve? Are humans the only species capable of aesthetic appreciation, or are other species endowed with the rudiments of this capacity?

In *Natyashastra,* a classical treatise by Bharata, a famous saying by Bharata needs mentioning here "that which can be relished – like the taste of food – is rasa (emotions)": *"Rasyate anena iti rasaha (asvadayatva*). The concept of rasa is unique to Indian poetics and dramatics and is essentially a creation of the Indian genius—Bharata. With his organized presentation, Bharata carved a niche rasa-sutra in the annals of poetics and dramaturgy. He presented rasa formula in context to natya in his Natyasastra. Later on the rasasutra became the touchstone for all the poetics. The aim of a dramatic performance is to evoke sentiment or rasa in the mind of the learned audience. The ultimate goal, purpose of writing, presenting and viewing a play is to experience rasa realization. It has been found that no one word or phrase is adequate to convey the total meaning of rasa. Rasa is actually the impression created on the mind of the sympathetic audience by the expression of emotions and is an experience the individual is subjected to on account of this expression.

Emotion identification has recently been considered as a key element in advanced human-computer interaction. In seventeenth century,.

Descartes considered emotion to mediate between stimulus and response. Though self report measures form the cornerstone of emotion recognition research, recently, other physiological measures have gained importance in identifying high arousal levels.Human beings embody express, process, inhibit, function, act, and feel. All the verbs I just listed, along with many more, have as their sources the essential parts of what constitutes a human: body, mind, emotion, and behavior. Kemp states that cognitive science acknowledges the central role of the body and enables a better understanding of understand the relationship between thought and expression (p. 20). Acting, on the other hand, does not explain the body-mind-soul relationship, but rather provides the richest material for exploration of and experimentation with human emotions. A recent discovery in the brains of primates, mirror neurons is special neurons that show activity both when a subject performs an action and when it observes the same action performed by another. Some scientists consider mirror neurons one of the most important findings in neuroscience in the last decade, in part because they are thought to be responsible for the empathic response in humans. In particular, these neurons allow a person to empathize with someone who is having a traumatic experience. How does this adaptation come into play for an actor? Actors must draw on various sources—memory, imagination, observation—to elicit their own deep emotional responses. This emotional activity must have a level of authenticity, on a physiological and even a neurological level, in order to provoke empathy in the observer, whether it's another actor or a member of the audience. Drawing on the perspectives of neuroscience, drama therapy, kinesiology and acting technique, the mirror neuron theory is expected to explain the mechanisms that allow the actor to move an audience emotionally.

In the context of aesthetics in both arts and science it is very important to appreciate the following: Symmetry and asymmetry are at the heart of our aesthetic experience in music, dance, drama and art. Also, symmetry and search for broken symmetry guide us in understanding of all Laws in Physics. Time has come to study contemporary view of space-time and cosmology from the view point of symmetry and we may use learning strategy from the art to develop a deeper understanding of the reality which is beyond our sensory perception and which is described by mathematics. More precisely, chaos based scientific techniques are attempted to decipher symmetry in terms of fractals. Fractals are known for their aesthetic appeal. The term "fractal" coined by Mendelbrot describes a shape or pattern with a greater pattern of which it is a scaling piece identical to the greater pattern and in which are reproduced an infinite number of patterns or fragments which are also identical to it, thus, identical to whole in all scale.

In the ongoing project, "Emotion cognition based categorization and learning of Indian Classical Music (*guru-shishya parampara*) using novel nonlinear techniques" as Tagore National Scholar, a new and novel method was proposed and developed based on rigorous chaos based scientific approach and in a way readily accessible to musicians in general. In the pilot study, pedagogy is presented as a scientific supplement with the existing *guru-shishya parampara* technique. The preliminary study is encouraging. Since emotion characterization is a difficult task remembering extensive shades of emotions rendered in different *ragas* as well as even in one *raga*, extensive research is needed. This approach is new in the global scenario so far as music teaching and learning is concerned. The Indian guru-shishya parampara can be sustained using modern techniques of science and technology.

Based on the initial study in music, we propose to extend this methodology in case of emotion elicitation in dance and drama. In case of drama, both audio and video data will be analyzed with the same chaos based non linear computation techniques. So far as human response is concerned, we would use both self-reporting of audience as well as biosensors like Electroencephalogram (EEG). EEG signal will also be analyzed with nonlinear chaos based techniques yielding a quantitative parameter.
Dance is one of the most expressive types of affective body language. Yet, few of us can imagine dance without the accompaniment of one of the other grand art forms: music. Music often potentiates the experience of affect expressed in movement; and in theatre and cinema alike, directors use music to great effect in order to regulate the audience's emotions. Psychological research has provided ample evidence to confirm that our affective perception of an emotional stimulus presented to one sensory modality (e.g., visual) is altered by the emotional information presented to another modality (e.g., auditory), even when participants are asked to ignore the latter. This effect is called the cross-modal bias, and was first described in the purely perceptual domain, showing that visual perception (e.g., intensity) is enhanced by simultaneous auditory stimuli.

In case of drama, a recent neuro-cognitive study indicates that special type of neurons known as “mirror neurons” are fired during witnessing drama. That mirror neurons can be studied with EEG using a special EEG frequency range called mu-wave. It is highly interesting to mention that the oldest treatise of drama “Abhinay Darpan” by Nandikeshwar contained the name “Mirror of Gesture”. This association of ancient wisdom with modern science is our motivation of this study and a pioneer work is proposed in global scenario which will deal with Indian age old heritage of music, dance and drama.

Proposed Methodology:

While studying dance or drama, in general the video has to be taken instead of audio signal used in music study. The video can be analyzed frame wise and pixel wise in terms of fractal methodology and the emotion can be characterized quantitatively using state of art computation techniques following the same procedure adopted in case of music. Further using biosensors, the effect of the stimuli (audio and/or video) in cross-modal bias, the response of the brain can be assessed quantitatively. As mentioned earlier, we will focus on mu band of EEG to obtain the information of “mirror neuron” dynamics.

This is a pioneering venture of studying Indian rich heritage of art and culture (ancient mind) with rigorous scientific approach of today and this kind of research is rare in global perspective. One may phrase this as revisiting *Abhinaya Darpana* by Nandikeshwar in neuro-cognitive and neuro-aesthetics perspective

Chapter FOUR

"Emotion, empathy and mirror neuron"

Frontiers of Neuro-cognitive research of Assessment of Emotions elicited by music, dance and drama in a different perspective using concept of mirror neurons.

A BRIEF OVERVIEW

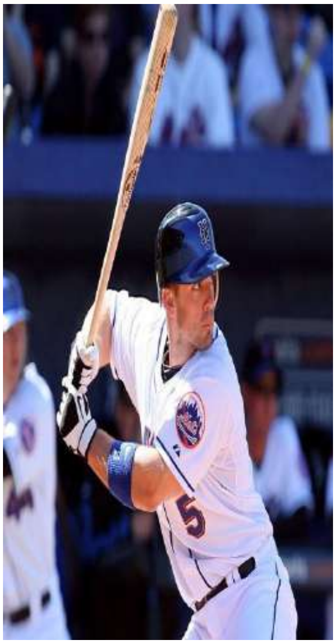
- The ability to create and enjoy music is a universal human trait and plays an important role in the daily life of most cultures. Music has a unique ability to trigger memories, awaken emotions and to intensify our social experiences.

- Recent neuroimaging evidence suggest that music, like language, involves an intimate coupling between the perception and production of hierarchically organized sequential information, the structure of which has the ability to communicate meaning and emotion.

- **These aspects of musical experience may be mediated by the human mirror neuron system.**

This theory has a great potential to explain the functionality of performance in general.

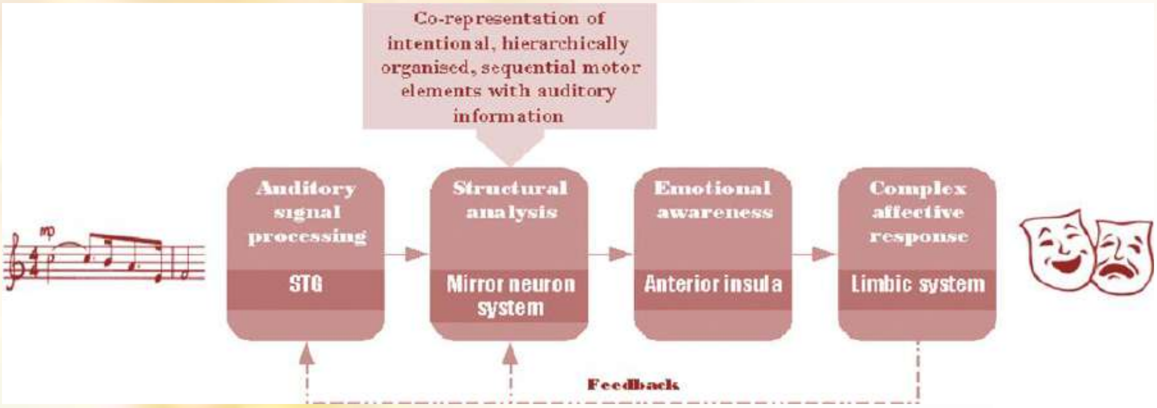
Mirror neurons, are elements in the brain that fire unconsciously in the presence of another person's activity.



Consider a baseball fan watching a player hit a ball;

Fmri imaging research shows that mirror neurons light up in the same area of the fan's brain as those in the brain of the hitter.

The viewers of the game and the player have the same neuronal pattern; their brains are synchronized by the firing of these mirror neurons



- Model of the possible involvement of the human mirror neuron system in representing meaning and affective responses to music.

- One aspect of the experience of music involves the perception of intentional, hierarchically organized sequences of motor acts with temporally synchronous auditory information.

- Auditory features of the musical signal are processed primarily in the superior temporal gyrus (STG) and combined with synchronous structural features of the 'motion' information conveyed by the musical signal in the posterior inferior frontal gyrus (BA 44) and adjacent premotor cortex.

- Possible feedback mechanisms may influence the subsequent processing of the musical signal at the immediate and more long-term timescales.

- The shared recruitment of this neural mechanism in both the sender and the perceiver of the musical message allows for co-representation and sharing of the musical experience. Music notes from 'The Lady Sings the Blues' by Billie Holiday and Herbie Nichols.

■ One of the defining features of music is its ability to induce an emotional response in listeners and one of the main reasons people give for listening to music is to experience or modulate their emotional state.

■ Recent neuroimaging evidence that the anterior insula, the right amygdala and mirror neuron areas in the posterior inferior frontal gyrus, show enhanced activity during imitation of emotional facial expressions *vs* simple observation, providing additional support for the role of sensorimotor-affective coupling in understanding the emotions of others.

■ The mirror neuron system is involved not only in the intersubjective representations of actions but also in emotion—representations that allow us to feel connected with other agents.

■ The perception of emotion in music may arise in part from its relation to physical posture and gesture.

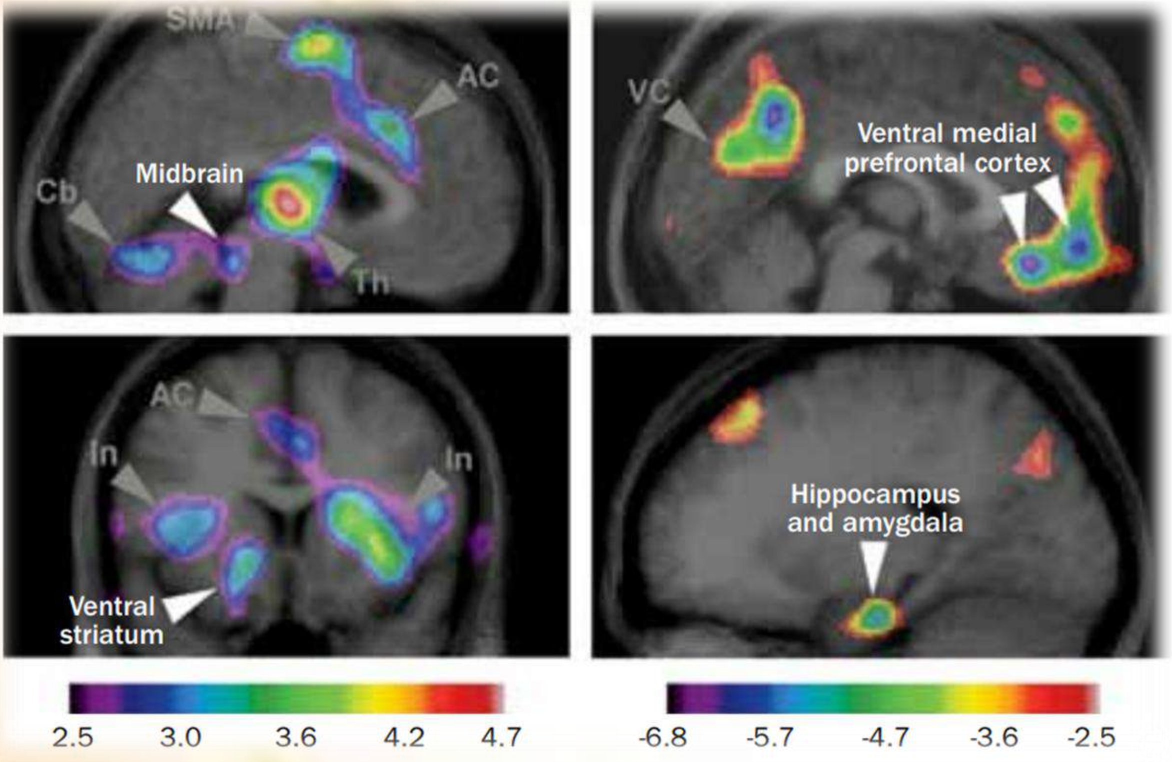
■ Expressive music can induce subliminal facial expressions in listeners, and these in turn may induce subjective and physiological emotional expressions .

■ As posture, gesture and facial expressions are important implicit cues in social communication, one can easily imagine that 'musical gesture' can have similar effects in communicating emotions.

■ The posterior inferior frontal gyrus (BA 44) is the frontal component of the human fronto-parietal mirror neuron system. With its ability to link perceptual and behavioral representations of a stimulus during the perception of emotionally arousing music, the mirror neuron system may simulate an emotional state in the listener.

■ The mirror neuron system may provide a domain-general neural mechanism for processing combinatorial rules common to language, action and music, which in turn can communicate meaning and human affect.

■Although it is yet to be determined which specific aspects of processing linguistic, musical or motor syntax may recruit frontal mirror neuron regions, the emerging picture from the literature suggests that the mirror neuron system provides a neural substrate for representing infinite combinations of hierarchical structures, a computation that may underlie more general cognitive abilities.



■There is also evidence that perhaps **posterior inferior frontal gyrus (BA 44)** may be the source of **predictive models of upcoming events in sequential processing**, a feature also common to language, music and action

■ **While the evolutionary advantage of musical ability is still under debate, there is growing evidence that music plays an role in cognitive development, emotion regulation and social interaction.**

A pioneering new fMRI-based study conceived and directed by musicologist Zachary Wallmark which found that high-empathy people use their social cognitive circuitry to process music.

Mirror Neurons and Emotions in Drama

- How does theatrical performance/activity conceptually relate to the cognitive science and affective neuroscience?

- The main things that both disciplines share is the idea of duality of the human nature. Are the emotions manifested through the body, or is the body producing emotions as integral parts of its purpose?

- Can the physical work stimulate imagination to the point that the actor lives through the emotions of the character, or does the psychological approach to acting guarantee deep understanding and therefore meaningful expression?

"Haven't you ever been aware, in life or on stage, when in communication with other people, of a current emanating from your will flowing through your eyes, your fingertips, your skin?

What shall we call this method of communication?

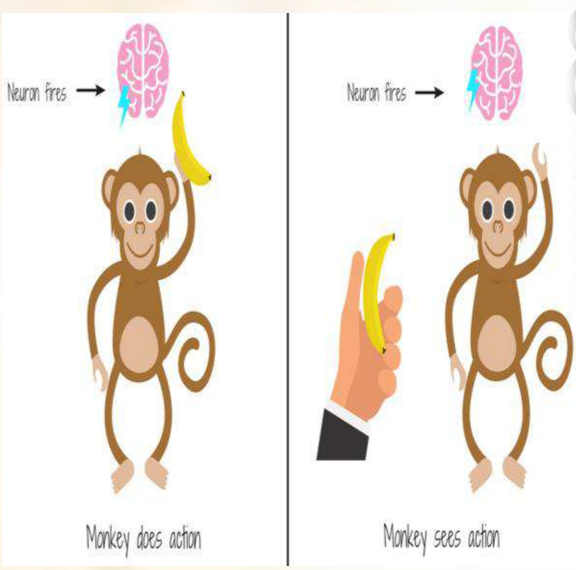
Emitting and receiving rays, signals? Radiating out and radiating in?

In the near future, when this invisible current has been studied by science, a more appropriate terminology will be established."

………Konstantin Stanislavski

These rays/signals, radiating out and radiating in were encountered in a laboratory in Parma, Italy in 1996 by a team of neurophysiologists led by Giacomo Rizolatti.

This team was studying the brain responses of Macaque monkeys when grasping objects with their hands.



- If the action/intention is conceived of physically, its effectiveness for the actor and for his/her partner is stronger.

- **Such physical imagery on the part of the actor activates the actor's mirror neurons,**
simply through the kinesthetic visualization necessary to conceive it.

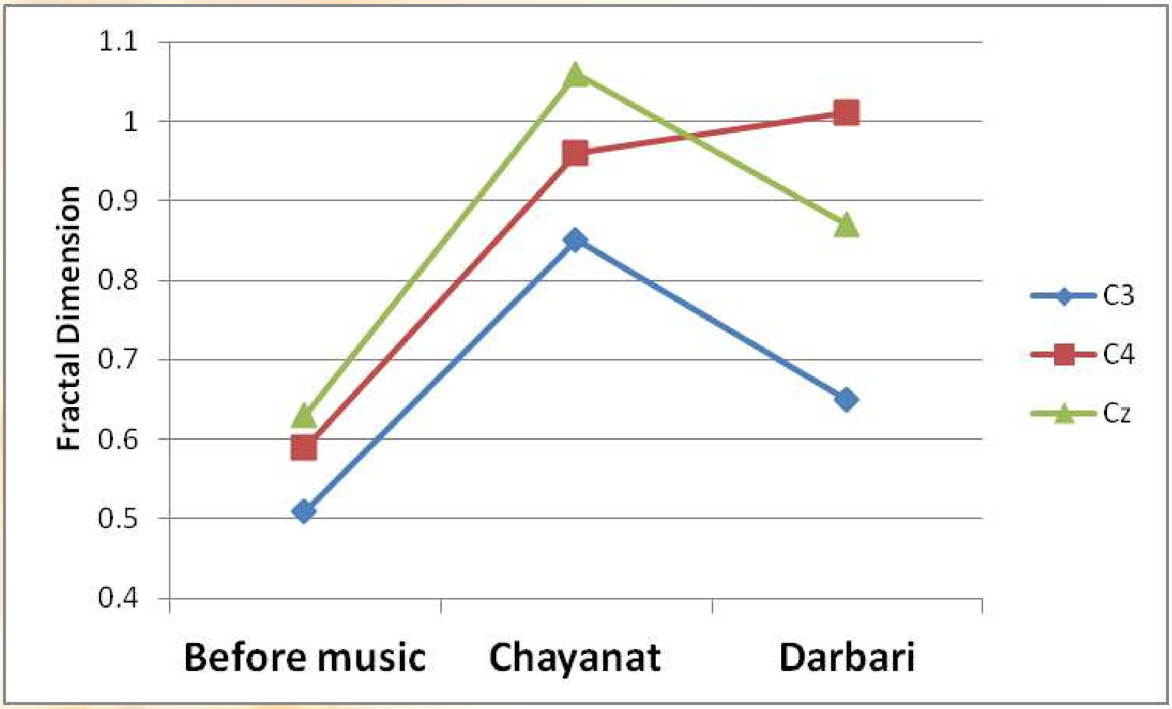
- Another aspect of mirror neuron research strongly suggests that these neurons pick up not only the physical aspects of action but also the intention behind it for the viewer.

OUR WORK ON MIRROR NEURONS

Electroencephalography (EEG) methods have mainly focused on mu rhythms. Mu rhythms refer to sensorimotor activity in alpha bands (8–13 Hz in adults, 6–9 Hz in children) recorded over central scalp locations C3, Cz, and C4; it is also referred to as "rolandic alpha."

Mu power decreases during both execution and observation of movements, and even when imagining movements. It is therefore called mu suppression or mu power desynchronization.

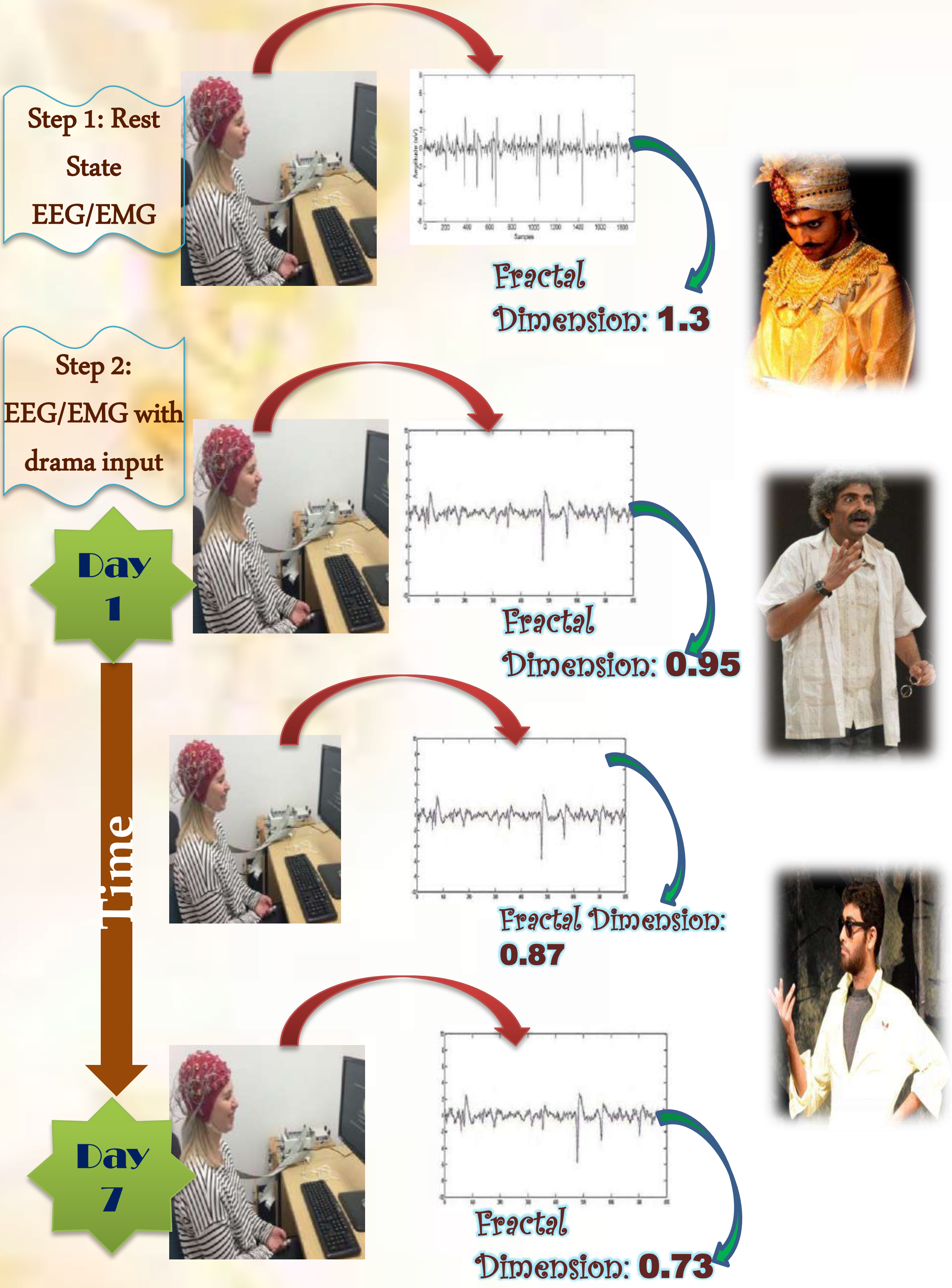
Some studies have reported infant's mu rhythm in central regions of the brain. A recent EEG study indicated greater mu suppression (putatively reflecting mirror neuron activation) in infants and adults when observing transitive movements compared to intransitive movements.



Activation of Mirror Neuron System with music input quantified with Fractal dimension of EEG signals

Functioning of Mirror Neurons In Drama- An Example

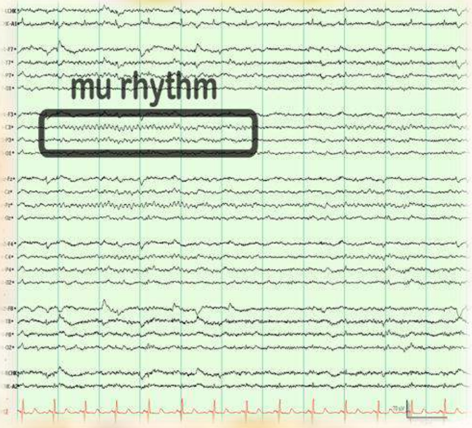
Protocol For studying neuro-cognition of Drama



Neurocognition of Drama with EEG signals

Assessing Human Mirror Activity with mu rhythm

For inferring mirror system activity in humans changes in a particular frequency band in the electroencephalogram (EEG) called the mu rhythm is reported.



- Mu rhythm is the central rhythm of alpha EEG band (8-10 Hz)
- Usually asymmetric, asynchronous and independent in two hemispheres

A recent study reviewed 85 studies (1,707 participants) of mu that infer human mirror system activity.

The researchers conclude that changes in EEG **mu activity provide a valid means for the study of human neural mirroring**

Chapter FIVE

"Details of Scientific Methods adopted"

Chaos

- Chaos is defined as the irregular, unpredictable behaviour of deterministic, non-linear dynamical system. e.g. Lorentz Attractor.

- Chaos embodies 2 important properties:

  - Sensitive – Chaotic systems are extremely sensitive to initial conditions, since any perturbation, no matter how minute, will forever alter the future of the chaotic system.

  - Deterministic – Chaotic systems are completely deterministic and not random.

Relation between Chaos & Fractals

- Fractals are considered the geometry of chaos.
- An object which is chaotic in space is called a fractal.
- Thus fractals can help, detect chaos.

Lorentz Attractor

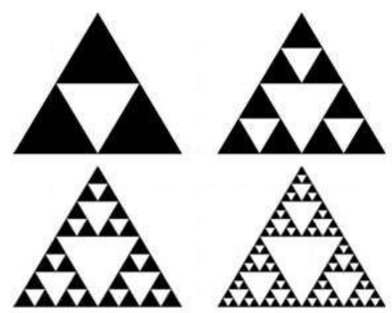
Fractals: A Brief Overview

- Fractal is a geometrical pattern that is iterated at even smaller or larger scales to produce self similar irregular shapes or surfaces that cannot be represented by Euclidean geometry.

- objects that occur in nature

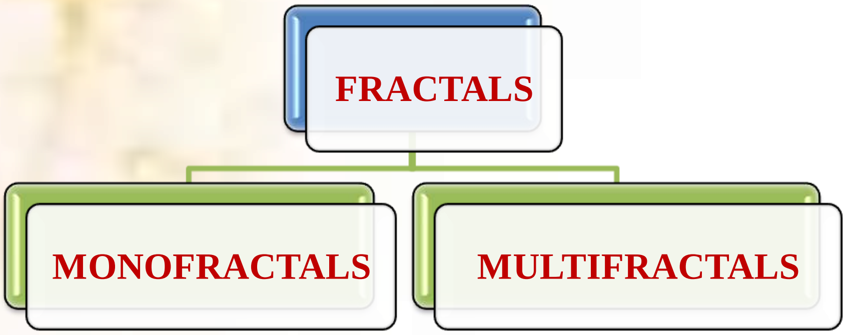
Broccoli

- mathematical constructions



Sierpinski Triangle

Classification



- Monofractals are those whose scaling properties are the same in different regions of the system.

- Multifractals are a type of fractal that scale with multiple scaling rules. Multifractals are more complicated self-similar objects that consist of differently weighted fractals with different non-integer dimensions. Thus the fundamental characteristics of multifractility is, the scaling properties may be different in different regions of the system.

Different Methods

- Fractal and multifractal properties of several time series (geophysical, biophysical, neurophysical, financial etc) have been extensively investigated.

- Several methods have been proposed for this purpose namely:

  - Spectral Analysis
  - Rescaled Range Analysis
  - Fluctuation Analysis (FA)
  - Detrended Fluctuation Analysis (DFA)
  - Wavelet Transform Modulus Maxima (WTMM)
  - Multifractal Detrended Fluctuation Analysis (MF-DFA)
  - Multifractal Detrended Cross-Correlation Analysis (MF-DXA).
  - Detrended Moving Average (DMA) etc.

- It is now the common consensus that MF-DFA and WTMM have the highest precision in the scaling analysis.

Detrended Fluctuation Analysis

- Detrended Fluctuation Analysis (DFA) was introduced by Peng et al., as a method for the determination of monofractal scaling properties and the detection of long range correlations in non-stationary signals.
- Time series of total length N is first integrated and then divided into segments of length s.
- Each segment is then detrended by subtracting the best linear fit.
- Finally, fluctuation function F(s) is calculated as root mean square of the detrended time series as a function of the segment size s.
- If long-term correlations are present in original series, F(s) increases with s according to a power law

$$F(s) \propto s^{\alpha}, \text{ where } \alpha \text{ is the scaling exponent}$$

- α can be estimated by a linear fit on the log-log plot of F(s) versus s.
- α represents the correlation properties of the signal.

Multifractal Detrended Fluctuation Analysis

- Multifractal Detrended Fluctuation Analysis (MF-DFA) proposed by Kantelhardt et al., is a generalization of the DFA and allows one to define the nature of the fractal behaviour.

- It is based on identification of scaling of the qth order moments of the data segments of varying length.

- It can reliably determine the multifractal scaling behaviour of non-stationary signals.

- In contrast to other conventional methods MF-DFA requires less effort in programming and provides reliable results in detection of monofractal and multifractal character of the non–stationary time series that are affected by trends or that cannot be normalized.

- It has applications in diverse fields such as physiological, ecological, geophysical, climatic and financial data.

Algorithm

- The MF-DFA algorithm consists of five steps –

  Let x (i) be a non-stationary time series of length N.

(i) In the DFA procedure the signal profile Y(i) is derived from the time series x(i), i = 1, . . . ,N by the following expression

(ii) Y (i) is then divided into Ns = int (N/s) segments of length s (s < N) starting from both the beginning and the end of the time series thus, 2Ns segments are obtained altogether.

(iii) Now for each segment least-square fit of the series is performed and the variance is determined.

$$Y(i) \equiv \sum_{k=1}^{i} [x_k - \langle x \rangle]$$

<x> is average value of x

(iv) Next the qth order fluctuation function Fq(s) is obtained after averaging over 2Ns segments .

(v) Finally the scaling behaviour of the fluctuation function is determined by analyzing log-log plots of Fq(s) vs s for each value of q. If the series are long-range power-law correlated, Fq(s) increases, for large values of s, as a power-law

$$F_q(s) \propto s^{h(q)}$$

where h(q) is Generalized Hurst exponent

Parameters

- The aim of the MF-DFA procedure is principally to determine the behaviour of the q dependent fluctuation functions Fq(s) with regard to the time scale s, for various values of q.

- Each time series is transformed according to the MF-DFA algorithm and the following parameters are determined :

- The qth order fluctuation function Fq(s) for q= -10 to +10.

- The generalized Hurst exponent h(q) is obtained from the linear fit of ln Fq(s) vs ln s

- The classical scaling exponent $\tau(q)$

$$\tau(q) = qh(q)-1$$

- The singularity strength or Hölder exponent α and the singularity spectrum $f(\alpha)$ is calculated

$$\alpha = h(q) + qh'(q) \; ; \quad f(\alpha) = q[\alpha - h(q)] + 1$$

- Since width of the multifractal spectra ($f(\alpha)$ vs α) is a measure of degree of multifractility, the spectra is fitted to a quadratic function around the position of its maximum at α_0

$$f(\alpha) = A(\alpha - \alpha_0)2 + B(\alpha - \alpha_0) + C$$

- The exponents A, B, C and W(width of the spectra) are obtained by a least square procedure.

- Finally the auto-correlation exponent γ is estimated from the relation

$$\gamma = 2 – 2(h) \text{ for } q = 2$$

Chapter SIX

"Few interesting new concepts"

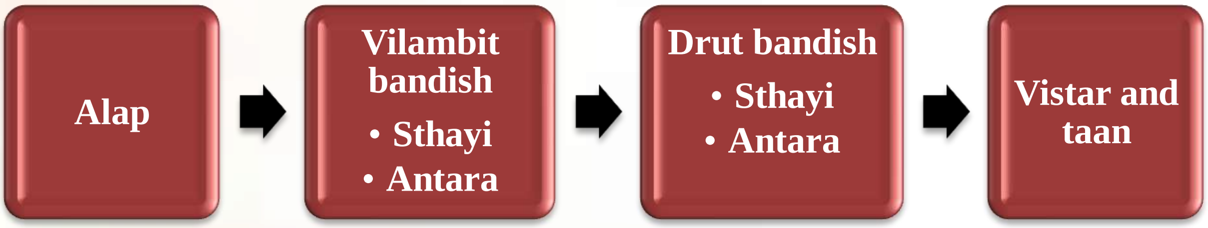
Gharana system in Hindustani Classical Music*:*

➢Differences in presentation across the country while rendering a particular *raga*....different "*Gharanas*". In Hindustani music, a ***"Gharana"*** or school refers to the **adherence of a group of musicians to a particular musical style**.

➢*Gharanas* have their own traditional mode of musical training and education. Every *Gharana* has its own distinct features which distinguishes one from another.

➢Though individual creativity of performers lead to significant changes in singing styles over generations of artists within a particular *Gharana*.

Overall structure of a complete Raga performance (observed in gharana):



❖ *Alap:*

- ❑ Opening section of a *Raga* performance.
- ❑ In the *alap* part the *raga* is introduced and the paths of its development are revealed.
- ❑ *Alap* is usually accompanied by the tanpura drone only.
- ❑ Sung mostly without tempo.

❖ *Vilambit bandish:*

- ❑ In this part the lyrics and *tala* i.e., tempo are introduced. Tempo is very low in vilambit – max. 10-40 beats per minute.
- ❑ ***Bandish*** is a fixed, melodic composition in Hindustani vocal or instrumental music, set in a specific *raga*.
- ❑ Usually performed with rhythmic accompaniment like tabla or pakhawaj, a steady drone, and melodic accompaniment by a sarangi, harmonium etc.

Present scenario:

Now-a-days, the "*Gharana*" system in Hindustani classical music is affine to a number of ambiguous ideas among artists.

According to a few performers, *gharana* system exists, while some others are against this thought.

Now the questions are –

➢Which features define the *gharana*?

➢Is it really true that the artists of the same *gharana* keep their singing style unchanged over generations or evolution of music takes place like everything else in nature?

…. These questions are still mostly unanswered; at least from a scientific point of view.

Now, as we attempt to get an answer to the questions by analyzing the sound signals using robust latest-state-of-the-art non-linear technique, the questions come…

1. Why do we choose a non-linear approach?

&

2. Which non-linear technique is most applicable to the analysis of sound signals?

❖ At every instant the components of music (pitch, timbre, accent, duration etc) are closely linked to each other both (in micro and macro scale.

❖These properties are peculiar of systems with chaotic, self organized, and generally, non linear behavior.

❖ Therefore, music analysis using linear and deterministic frameworks seems unrealistic and a non-deterministic/chaotic approach is needed for speech/music signals.

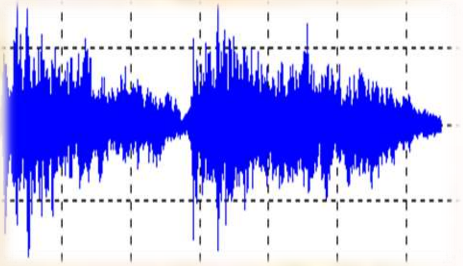
❖ Fractal analysis of the signal, which reveals the geometry embedded in a complex music signal assumes significance.

Then comes the question…

Which non-linear technique is most applicable to the analysis of sound signals?

❖Music signals are self-similar, structural repetition features in nearly all music signal waveforms.

❖The complexity variation of a musical piece with time features very irregular dynamics, i.e. different parts of the system scales differently. Such a system is better characterized as ‘multifractal’.



❖A multifractal can be loosely thought of as an interwoven set constructed from sub-sets with different local fractal dimensions.

To study such a signal

Multifractal Detrended Fluctuation Analysis (MFDFA)

which determines the multifractal scaling behavior of a time series would certainly be a very good tool.

Nonlinear quantization
of
style of music

EXPERIMENTAL DETAILS :

In this study,

❖ 4 vocalists of successive generations of a particular *gharana* (Patiyala) of Hindustani music can be chosen for analysis.

From older to younger –

Artist 1 → Artist 2 → Artist 3 → Artist 4

❖The renditions of two well known basic *ragas* – *Bageshri* & *Jaijawanti* containing *alap* & *vilambit bandish* (both *sthayi* and *antara*) part sung in same scale by those 4 vocalists were taken.

❖For each *raga* the chosen ***bandish* will be same** for all the 4 vocalists.

❖For detailed analysis, *alap* part, *sthayi* & *antara* of the *bandish* part will be cut separately from each rendition.

❖It is expected that in the *alap* part, chances of improvisations is much higher while establishing the *raga* and hence total length of the *alap* varied significantly for all 4 vocalists.

❖So, to minimize the variation due to improvisations, about 20 seconds of the *alap* part were cut out which led only to identification of the *raga*. The said 20 seconds clips were selected by an eminent musician of this genre.

❖On the contrary, the *bandish* being same for all 4 vocalists for each raga, it has lesser chances of variation in note combinations. Although for different vocalists significant variations in the scansion of the *bandish* i.e. the distribution of the lyrics over the whole cycle of the *tala* are expected.

❖All the signals are digitized at the rate of 44100 samples/sec in mono channel 16 bit format.

❖Then each of the chosen *alap, bandish sthayi and bandish antara* parts was divided into 4 equal parts and their Multifractal Spectral Widths (W) were calculated using the MFDFA technique and widths were compared for 2 *raga*s.

CAN
WE HEAR THE SOUND OF
OUR BRAIN
???

IS THERE ANY TECHNIQUE

WHICH CAN ENABLE US TO HEAR THE

NEURO-ELECTRICAL IMPULSES

ORIGINATING FROM THE DIFFERENT LOBES OF

BRAIN

????

The answer to all these questions is
YES

The technique is called

“SONIFICATION OF EEG DATA”

OBJECTIVE

We propose to develop a novel method with which we can sonify the **Electroencephalogram (EEG)**
data recorded in rest state as well as under the influence of a simplest
acoustical stimuli - a **tanpura drone**

and

to find a direct correlation between the audio and EEG signal

DEFINING "SONIFICATION"

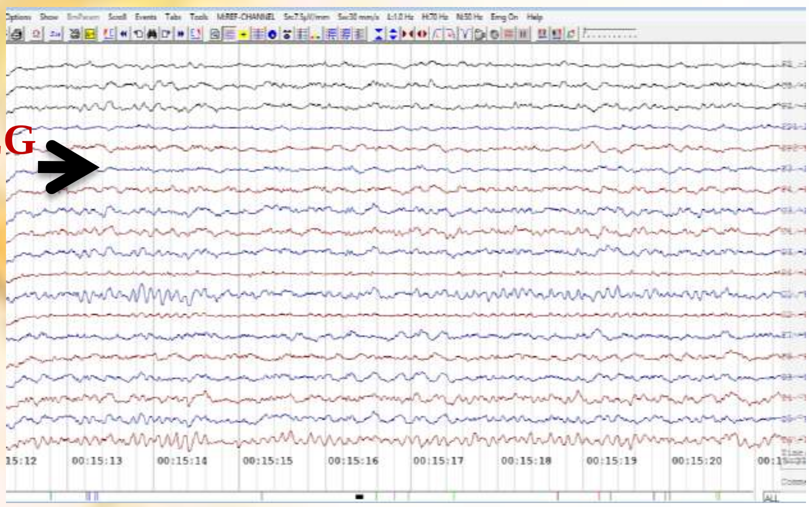
As per the definition of ICAD "the use of non-speech audio to convey information; specifically **sonification** is the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation" [1].

Hermann [2] gives a classic definition for sonification as "a technique that uses data as input, and generates sound signals (eventually in response to optional additional excitation)".

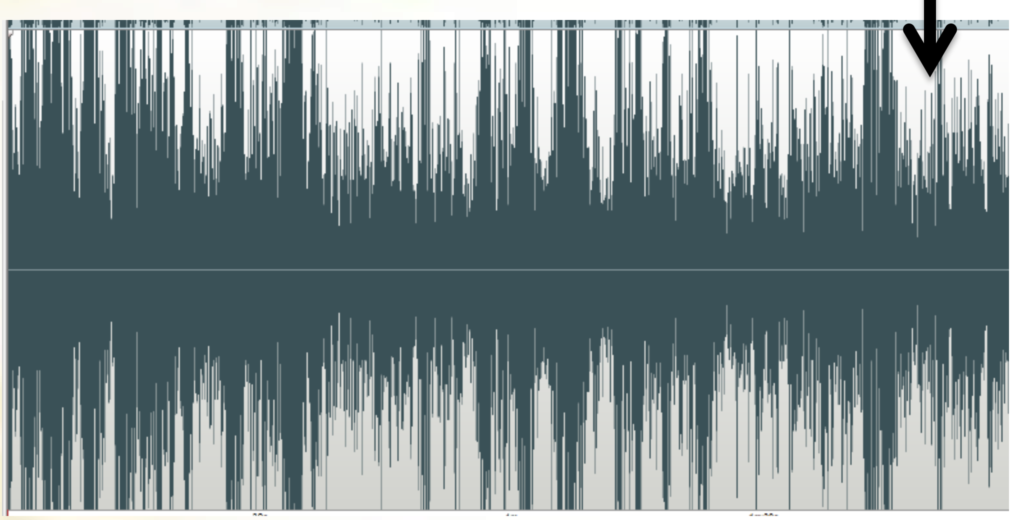
SONIFICATION OF EEG SIGNALS

Individual EEG brain waves can be sonified to obtain their musical analogy

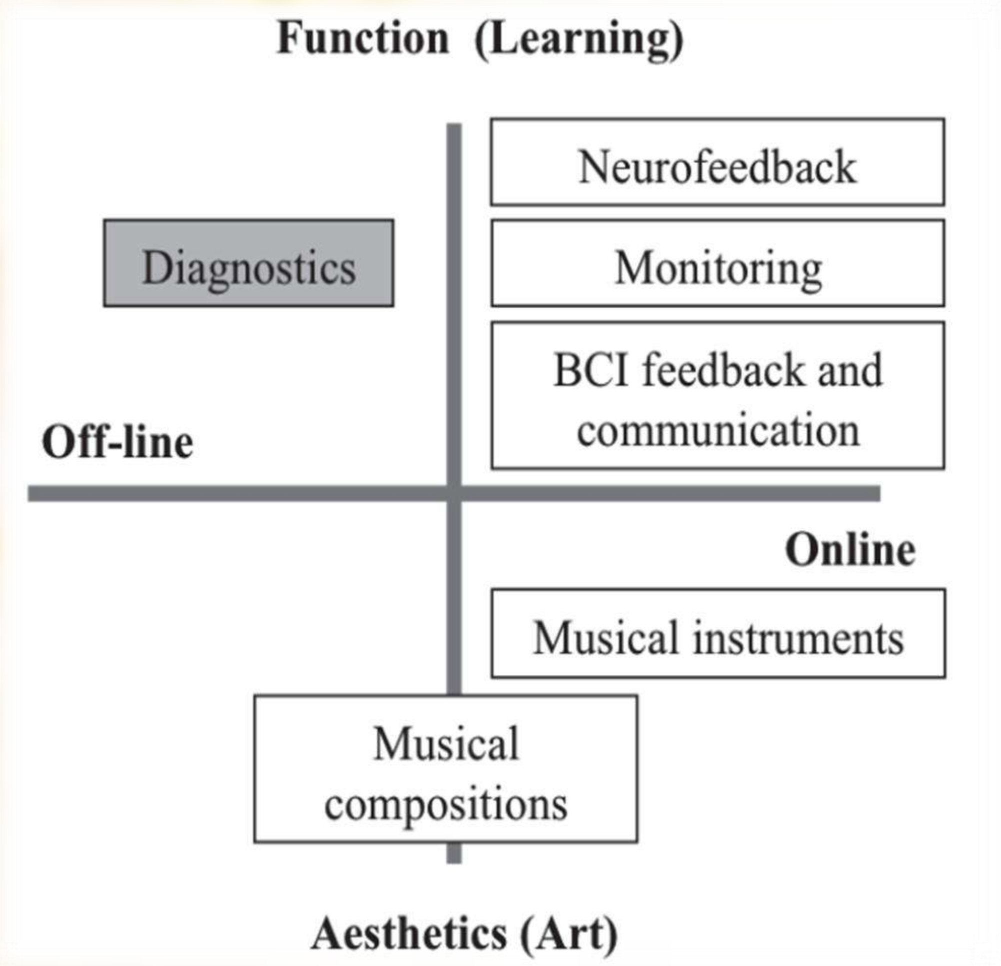
Raw EEG data



Sonified EEG data



WHY EEG SONIFICATION ???



&

A DIRECT CORRELATION BETWEEN EEG AND MUSIC SIGNALS

OVERVIEW OF OUR WORK

- The main attempt is to device a new methodology which looks to obtain a direct correlation between the external musical stimuli and corresponding internal brain response using latest state of art non-linear tools for characterization of bio-sensor data.
- For this, we chose to study the EEG response corresponding to the simplest (and yet very complex) musical stimuli - the *Tanpura* drone.

- The main constraint in establishing a direct correlation between EEG signals and the stimulus sound signal is the **disparity in sampling frequency of the two**; while an EEG signal is generally sampled at up to **512 samples/sec** (in our case it is 256 samples/sec), the sampling frequency of a normal recorded audio signal is **44100 samples/sec**.
- **Hence the need arises to up-sample the EEG signal to match the sampling frequency of an audio signal so that the correlation between the two can be established.**
- This phenomenon is called **"sonification"** and we propose a novel algorithm to **sonify EEG signals** and then to compare them with the **source sound signals**.

Overview (Contd..)

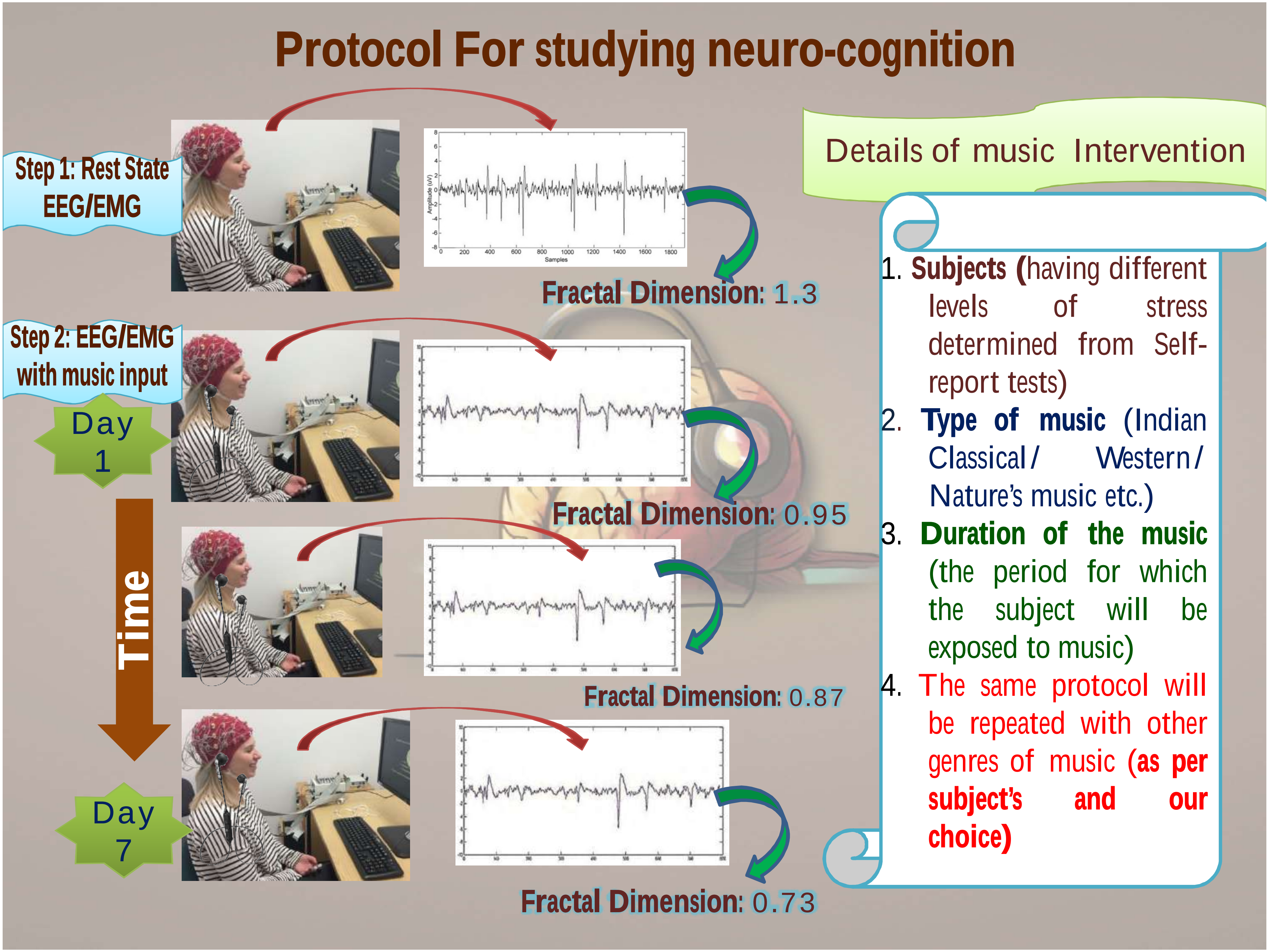
- A robust non-linear method called Multi Fractal Detrended Cross Correlation Analysis (MFDXA) will be used to measure the cross-correlation, taking ***tanpura*** **drone signal as first input** and a **music induced modulated EEG signal (electrode wise)** as the second input.

- The output is γ_x **(or the cross-correlation coefficient) which determines the degree of cross-correlation of the two signals.**

- For the "no music/rest" state, γ_x is evaluated using the **"rest" EEG data** as one input and a simulated **"white noise"** as the other input.

- **A comparative analysis of the variation of correlation between the "rest" state EEG and the "music induced" EEG signals will be done.**

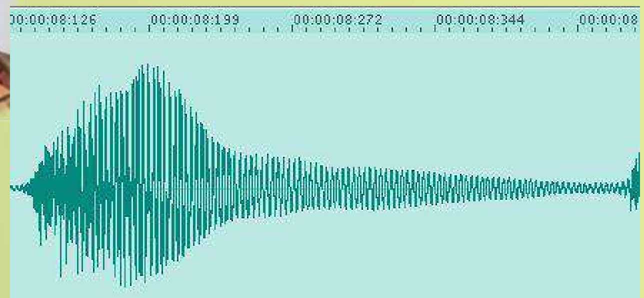
ANNEXURE


Protocol For studying neuro-cognition
Step 1: Rest State EEG/EMG
Fractal Dimension: 1.3
Step 2: EEG/EMG with music input
Day 1
Fractal Dimension: 0.95
Time
Fractal Dimension: 0.87
Day 7
Fractal Dimension: 0.73
Details of music Intervention
1. Subjects (having different levels of stress determined from Self-report tests)
2. Type of music (Indian Classical / Western / Nature's music etc.)
3. Duration of the music (the period for which the subject will be exposed to music)
4. The same protocol will be repeated with other genres of music (as per subject's and our choice)

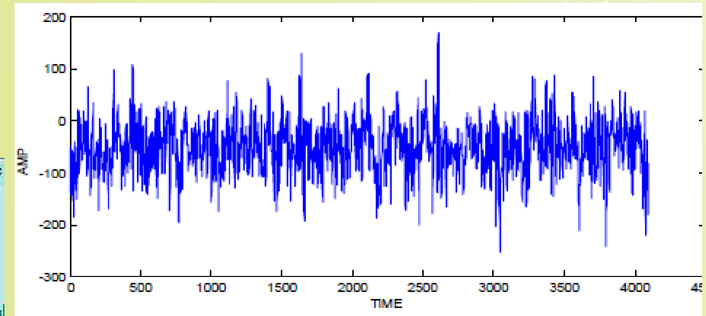
EEG with input of musical stimuli

Stimulus:

Indian Classical Music



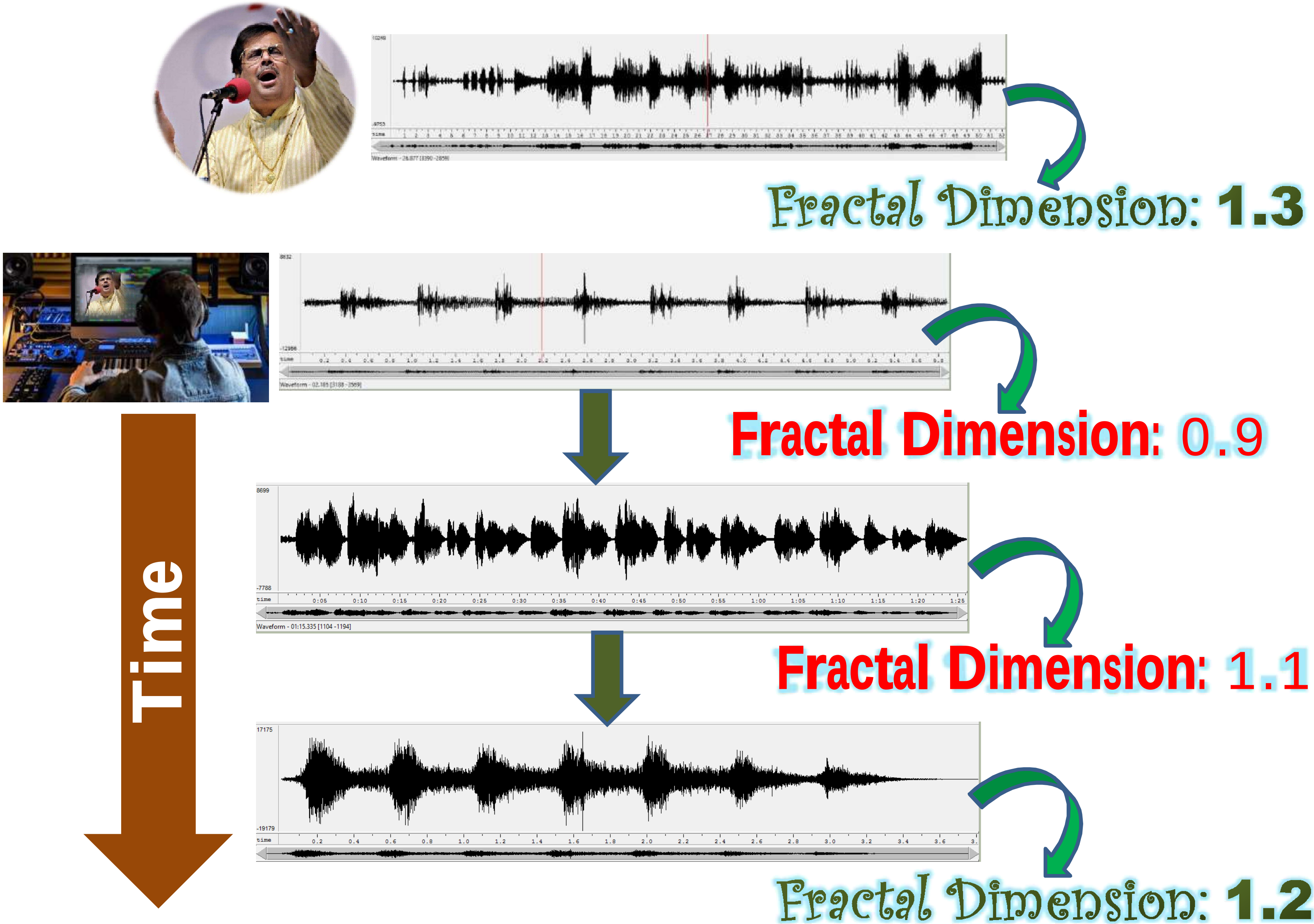
EEG Signal

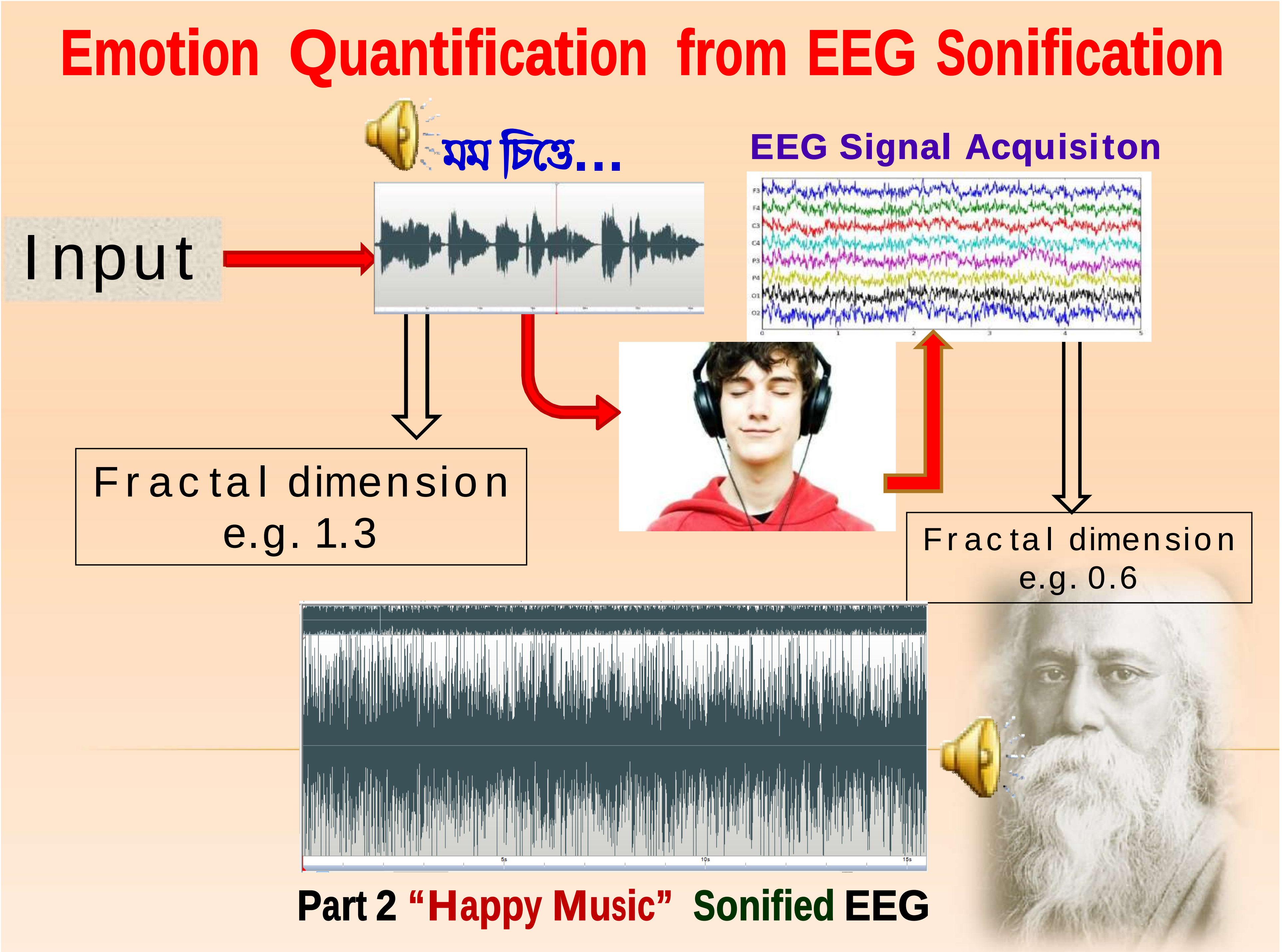


Fractal dimension
e.g. 1.4

Fractal dimension
e.g. 1.9


ONLINE TEACHING OF INDIAN CLASSICAL MUSIC
Fractal Dimension: 1.3
Fractal Dimension: 0.9


Fractal Dimension: 1.3
Fractal Dimension: 0.9
Time
Fractal Dimension: 1.1
Fractal Dimension: 1.2

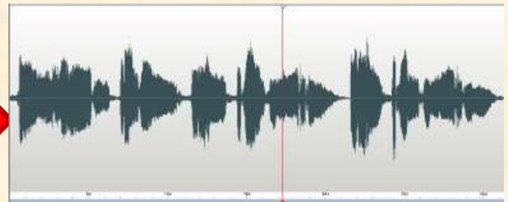

Emotion Quantification from EEG Sonification
মম চিত্তে...
EEG Signal Acquisiton
Input
Fractal dimension e.g. 1.3
Fractal dimension e.g. 0.6
Part 2 "Happy Music" Sonified EEG

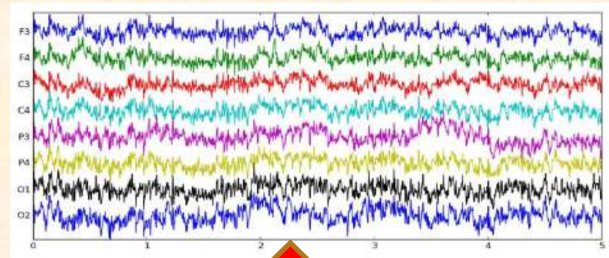
Emotion Quantification from EEG Sonification

কার মিলন চাও …

EEG Signal Acquisiton

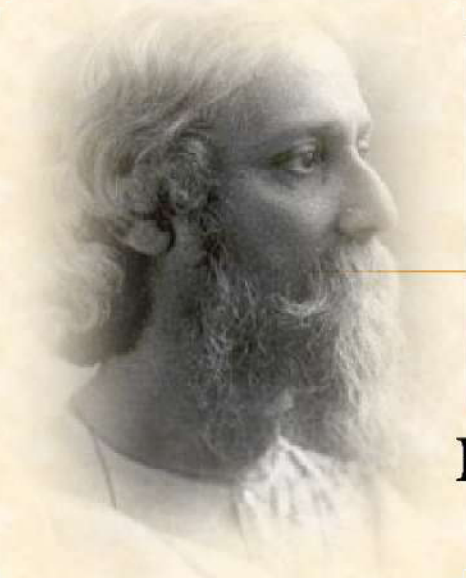
Input

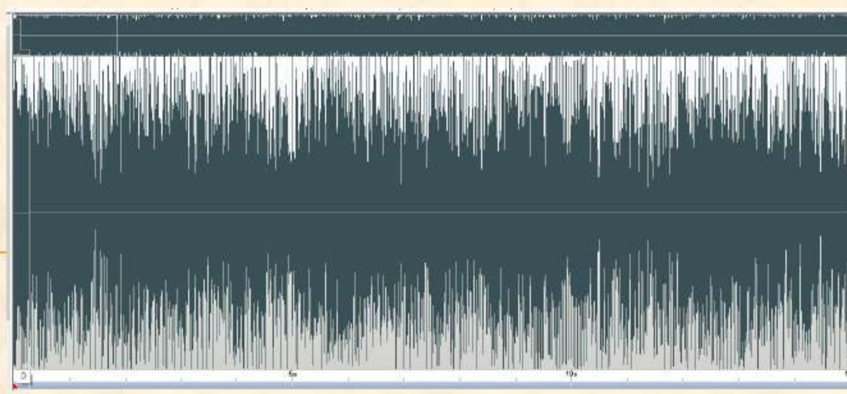




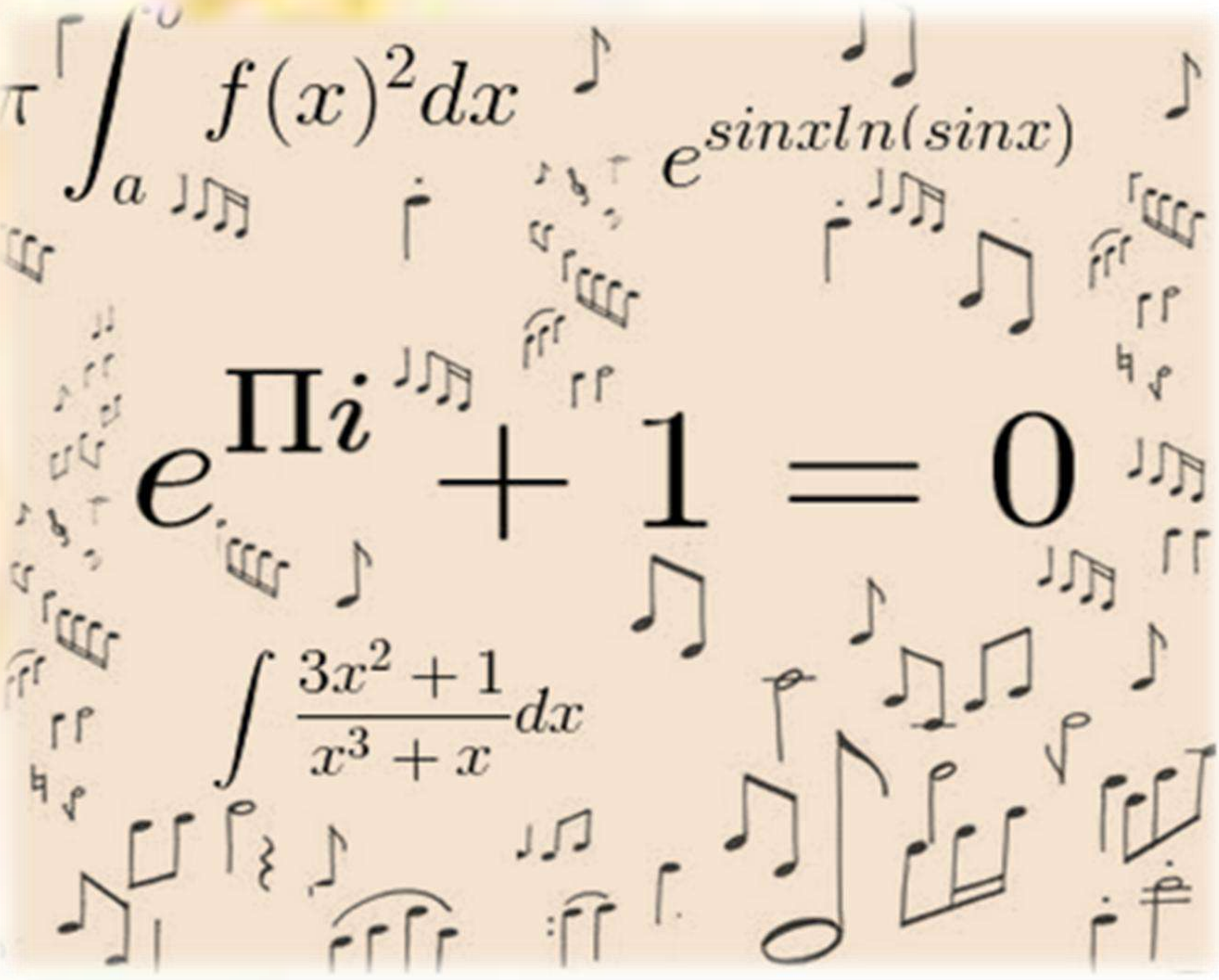
Fractal dimension
e.g. 0.9

Fractal dimension
e.g. 1.7





Part 2 "Sad Music" Sonified EEG



$\int_a f(x)^2 dx$
$e^{sinxln(sinx)}$
$e^{\Pi i} + 1 = 0$
$\int \frac{3x^2+1}{x^3+x} dx$