

Integrative Medicine System Based On Music

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ABSTRACT

The lifestyle of today's world demands a reliable, comprehensive integrative medicine system with minimal side effects. One of the most prominent candidates is music, an enjoyable healthcare approach. The present article formulates a music based integrative medicine system. Specifically, the physician-patient interaction is explored. Based on this model, Ayurveda and modern science such as Quantum Consciousness, Chaos Theory, Statistical Theory of Communication, Information Theory and Neurodynamics, six dimensions are formulated. These are physiological (*TriDoshas*), emotional (*TriGunas*), Sociological (Temperament), Psychological (Brain Waves), Spiritual (*Chakras*) and Informational (Landscape). The connection between music and each of these dimensions are explored. The formulation created in this article thus opens the doors for reliable, enjoyable, holistic healthcare with minimal side effects using music.

INTRODUCTION

The current era of globalization and the ever-changing lifestyle has brought into limelight several deadly epidemics [1]. In such a scenario, the need for a comprehensive non-reductionist system of medicine with minimal side-effects cannot be over-emphasized [2]. As a consequence, traditional medicine systems from the Orient, such as those of the Indian and Chinese, which have been time-tested for thousands of years, gain significant attention and recognition [3]. It is from these systems that one of the most plausible candidates for non-reductionist healing, namely integrative medicine has emerged [4].

Integrative medicine can be loosely defined as a 'holistic' system of healthcare where the focus is not on a particular disease or its symptoms, but on the patient as a whole, including physio-psycho-socio-spiritual factors. Also, the physician-patient interaction gets prime significance [4]. Although there is no consensus as to which systems of medicine particularly constitute integrative medicine, a lot of options exist, some of which are Ayurveda, Chi, Acupuncture, Acupressure, Color Therapy, Music Therapy and Yoga [4]. Of these, of particular mention is Music Therapy, since it offers a couple of advantages over other systems. Firstly, since it is energy (sound energy) based healing, the side effects are minimal. Secondly, music, being one of the most powerful art forms, provides comfort and enjoyment along with the healing benefits. The study of music therapy is not new. Starting from the musical articulations and intonations of the *Sama Veda*, to various *UpaVedas* such as *Gandharva Veda* and other texts such as *Natya Shastra*, *Sangita Ratnakara*, to relatively recent treatises such as *Sangita Kalpadrumam*, music and music based healing find extensive treatment in Indian literature [5]. Nevertheless, a completely systematic approach to music therapy is yet to be formulated.

Integrative medicine approaches such as music therapy have gained credence in recent years, thanks to advances in modern physics, biology and mathematics. Specifically, the study of Chaos Theory captures

beautifully the complexity of the human self, such as for instance, the experimentally observed nonlinear dynamics in the electroencephalograms depicting brain activity, spatiotemporal patterns in electrocardiogram data [6]. An insightful understanding of soul and spirituality has been obtained using the studies of quantum consciousness [7]. The mathematical discipline of probability and statistics has given scientists the confidence to approach a problem with limited information at hand [7]. Finally, the study of neurodynamics and the inherent nonlinearities therein have enlightened mankind on the underlying processes and complexities of the world's most powerful supercomputer, the human brain [8].

Thus, it is seen that while none of the above mentioned disciplines of modern science directly mention music or Ayurveda, they do indeed give a reasonably thorough understanding of the various physiological and psychological mechanisms of the human body, using which, it becomes easier to formulate an integrative medicine system based on music.

The present article purports to such a formulation of an integrative medicine system based on Music, using principles from Ayurveda as well as modern physics and biology. Specifically, a six dimensional perspective of music comprising of Physiological (*TriDosha*), Emotional (*TriGuna*), Sociological (Temperament), Psychological (Brain Waves), Spiritual (*Chakras*) and Informational (Landscapes) aspects is devised, leading to systematic holistic healthcare using music.

THE PHYSICIAN-PATIENT INTERACTION

In order to devise a six dimensional music based integrative medicine, it is imperative to develop a model of the physician-patient interaction within the context of music therapy. Here, the performer is the physician and the listener is the patient. For the moment, live performance such as a concert/ chamber music is considered. The interaction model is illustrated in Figure 1.

The common paradigm on which the whole model is developed is that of information, explained as follows.

The first element in this model is the environment of the performer, specifically the factors such as temperature and sound level that affects the music produced. These factors directly affect the performer's mindset, comprising of intellectual, emotional and intuitive faculties. Here, the change in form of the information from environmental factors to the performer's thoughts is highlighted. These thoughts then directly generate the music through the human vocal system or a musical instrument. Speech processing studies have made detailed models of the human vocal system [10], and the change in the form of information from thoughts to sound signals is clearly witnessed.

The resulting outcome is the music produced by the performer, which is transmitted through the channel. This music generated is the outcome of a Composite Information System (CIS) of the Physician. Here, the primary states of the information are the frequencies (*Swaras*) constituting the melody generated (*Ragas*).

The music interacts with the patient in three significant ways. Firstly, the music interacts with the human auditory system. The ear drum converts the sound waves into mechanical vibrations, and the cochlea of the inner ear does a rough spectral analysis of music [11]. The nerve endings of the cochlea are sensitive to particular frequencies, and lead to various parts of the brain [12]. These nerves and their interactions with the brain are responsible for various psychological, sociological and emotional impacts of music on the self.

Secondly, music as sound waves, interact with the whole of the human body through vibrations. The interaction points are the skin and various other orifices, which in turn transmit the vibrations to inner layers and organs. This physical interaction of music is responsible for the physiological impact of music.

The third interaction is at the consciousness level. Quantum consciousness studies have shown that the human self consists of an informational self which is a localized entity in the information field [13]. Music enables the interaction of the performer and patient information fields through the medium of consciousness. This interaction accounts for the spiritual impact of music.

Finally, it is also noted that the effect of music therapy can be adjudged by the closeness of fit between the physician CIS and the patient CIS, where the above mentioned three interactions account for the patient CIS. This match provides the Informational impact of music.

THE COMPOSITION MATRIX

Since the basic states for the informational paradigm discussed earlier are frequencies, a crucial step in formulating the music based integrative medicine is to obtain the composition matrix X. This matrix details the relative dominance of various frequencies in a given musical piece. In Indian music, relative frequencies are mapped to musical notes, or *Swaras*. Within an octave, there are seven *Swaras*, namely, *Shadjam* (Sa), *Rishabham* (Ri), *Gandharam* (Ga), *Madhyamam* (Ma), *Panchamam* (Pa), *Dhaivatham* (Dha) and *Nishadham* (Ni). Some of these *Swaras* admit of two variations and some three. These correspond to minor notes (*Komal*) and major notes (*Teevra*). In Carnatic Music, in addition to these notes, *Vivaadhi*, or dissonant notes are also present. A table of the various notes (16, in total), and the relative frequencies are given in the appendix.

The six dimensions of the music based integrative medicine are highlighted in the following sections.

PHYSIOLOGICAL DIMENSION (*TRI-DOSHA*)

The physiological dimension deals with the ‘body’ aspect of the human self. Conventional medicine systems such as allopathy have taken a structural perspective on the human self, comprising of various organs, systems etc. Integrative medicine, on the other hand, takes a functional outlook on the human body. In this context, Ayurveda has detailed extensively the *TriDosha* concept, using which treatises such as the *Charaka Samhita* have successfully detailed the mechanism of the human body, as well as treating a wide variety of ailments [14].

The three *Doshas* or body humors are as follows. *Vata Dosha*, comprised of the basic elements of Air and Space, is responsible for the vital life force, *Prana*, as well as aiding in respiratory and gastric functions. *Pitta Dosha* comprised of Fire and Water is fiery and aids in digestion and metabolism. *Kapha* comprised of Water and Earth, is heavy, cool, slimy and aids in stability and support. It is easy to diagnose a patient using *Nadi Pariksha* to obtain details of the *TriDoshas* [15] An illustrative figure describing the health effects of the three *Doshas* is shown in Figure 2.

Music treatises such as the *Sangita Kalpadrumam* and the *Sangita Damodara* have illustrated in detail, the relation between the Seven *Swaras* and the Five Basic Elements, and thus the *TriDoshas*. The mapping is as follows:

Sa (C) and Ri (D) are mapped to Fire and thus each account for 33% of *Pitta Dosha*. Ga (E) is mapped to Earth and accounts for 50% of *Kapha Dosha*. Ma (F) is mapped to Space and accounts for 33% of *Vata Dosha*. Pa (G) is mapped to Air and accounts for 33% of *Vata Dosha*. Dha (A) is mapped to Water and accounts for 33% of *Pitta Dosha* and 50% of *Kapha Dosha*. Ni (B) is mapped to Space and accounts for 33% of *Vata Dosha* [16].

By obtaining the composition matrix X of any musical piece as detailed earlier, the relative dominance of the various *Swaras* and thus *Doshas* can be ascertained. For example *Mohanam Raga* contains all *Swaras* except Ma and Ni, thus resulting in a *Pitta-Kapha Dosha*. *Amrithavarshini Raga* contains all *Swaras*

except Ri and Dha, and thus exhibits *Vata Dosha*. A *Raga* such as *Shankarabharanam* has all *Swaras*, thus has *Vata-Pitta-Kapha Dosha*, also called *Sannipata Dosha*.

EMOTIONAL DIMENSION (*TRI-GUNA*)

Extensive studies on neuroscience have developed a consistent model of emotion states relating them to two aspects of brain activity – valence (positiveness of emotion) and arousal (activity of emotion). Specifically, Russell's Circumplex Model maps all major emotions onto a 2 dimensional valence-arousal plane [17]. The mapping between this plane and the three *Gunas* can then be easily inferred.

The three *Gunas*, namely *Sattva*, *Rajas* and *Tamas*, are 'activity modes' of the mind and are thus specifically mapped to purity of thoughts, motivation levels, positiveness of thoughts etc. The mapping between Russell's Valence-Arousal Circumplex model (RVAC) and the Three *Gunas* are as follows. The low arousal – positive valence region (270 degrees to 30 degrees) of the RVAC correspond to *Sattva Guna*, characterizing emotions such as serenity, contentment, Compassion, trust and peace. The high arousal region (30 degrees to 150 degrees) correspond to *Rajas Guna* comprising of emotions such as Love, Surprise, Courage, Fear, Anger, Disgust and Alarm. The low arousal – negative valence region (150 degrees to 270 degrees) correspond to *Tamas Guna*, including emotions such as Sorrow, Depression and Boredom. The salient features and traits of the three *Gunas* are illustrated in Figure 3.

The connection between music and the three *Gunas* can be inferred by modeling music as a communication system and then using Statistical Theory of Communication to map a music piece to a point in the valence-arousal plane. The model is shown in Figure 4.

The procedure for computing the *Gunas* are as follows. Two statistical events are described. Event 'x' is the singing of a *Swara* (note). The chance of a note being sung is restricted by the melody (*Raga*) as any *Raga* allows only certain notes to be used. Thus the Composition matrix X is viewed as a 16x1 probability matrix p(x) denoting the probabilities of each *swara* occurring in the *Raga*. Event 'y' is the arousing of emotion in the listener. There is uncertainty in y as no emotion is sure of occurring until the *Raga* is actually sung. However, y does depend on the composition of the *Raga*. This information is represented in the probability matrix p(y), which is a 8x1 matrix representing the eight basic emotions as identified by Plutchik [18]. Thus, before the *swara* is sung, probability matrix y denotes the emotion profile of the *Raga* and after the singing of the *swara*, 16x8 conditional probability matrix p(y/x) denotes the emotion of the *swara* sung. To obtain p(y), we use the relation $p(x,y)=p(y/x)p(x)$ where p(x,y) denotes joint probability. The matrix created using the sum of all elements in each column of p(x,y) gives p(y). The eight emotion values in p(y) are then mapped onto a single point in the 2D Valence Arousal Plane using Russell's Circumplex Model shown in Figure 5. From this mapping, the *Guna* of the music piece can be identified.

An example of a *Sattvic Raga* is *Bhauri* at 285 degrees on the RVAC plane. *Shankarabharanam* with 55 degrees is *Rajasic*, and *Varaali* with 225 degrees is *Tamasic*.

SOCIOLOGICAL DIMENSION (TEMPERAMENT)

The sociological dimension pertains to the focus and importance a person assumes when interacting socially. A comprehensive indicator of the sociological preferences is the Myers Briggs Type Indicator (MBTI) [19] which answers four important questions about an individual:

1. Where a person focuses his/her attention – Introvert(I)/Extrovert(E).
2. The way a person gathers information – Sensing(S)/Intuition(N).
3. The way a person makes decisions – Thinking(T)/Feeling(F).

4. How a person deals with outer world – Judging(J)/Perceiving(P).

From the MBTI, four crucial mutually exclusive combinations can be obtained, which comprehensively describes a person's sociological outlook. These are Orderly (SJ), Adaptive (SP), Curious (NT) and Harmonious (NF). Thus the six qualities of S, N, T, F, J and P can be mapped to music in the following fashion.

1. Intuitive(N)/Sensing(S): The lesser the note density in a melody, the more it gives in to silence, which in turn induces patterns, thoughts, imaginations etc, suggesting intuitive mood.
2. Thinking(T)/Feeling(F): Absolute values of valence above 50% indicate Dominance of Feeling.
3. Judging(J)/Perceiving(P): Simpler melody structures give rise to lot of spontaneous patterns and thoughts leading to improvisation, suggesting perceiving mood. Scales with a lot of complexities tend to be patterned, leading to Judging qualities.

Examples for the four temperaments are *Amruthavarshini* (NT), *Mohanam* (NF), *Kalyani* (SP) and *Behag* (SJ).

PSYCHOLOGICAL DIMENSION (BRAIN WAVES)

This dimension pertains to brain activity. Extensive EEG based neurodynamical studies have developed a brain wave based neural oscillation theory to link brain waves with cognitive functions such as information transfer, perception, motor control and memory as well as consciousness, awareness and wakefulness [20,21]. The most important brainwave states, characterized by the frequency of electrical activity are the Gamma state (31-120Hz) used in intensive mental involvement, Beta state (13-30Hz) used in normal wakefulness and alertness, Alpha state (8-12Hz) used in daydreaming and deductive and meditative thoughts, Theta state (4-7Hz) used in sleep and dreams and Delta state(0.5-3Hz) used in deep dreamless sleep.

Aural entrainment is a technique which uses the varying relative frequencies in music to trigger corresponding brainwaves. Thus, by mapping the relative frequency differences of all possible *Swara* pairs within a *Raga* or music piece, it is possible to identify how many such pairs lead into the various brainwave states. It is observed by simple calculation that all *Ragas* have atleast one *Swara*-pair combination leading into the alpha state. In addition, few *Ragas* also admit of pairs leading to Theta states. Thus all *Ragas* can be classified as Theta (containing both Theta and Alpha pairs) or Alpha (containing only Alpha pairs).

For example, *Kalyani* is an Alpha *Raga* whereas *Bhauri* is a Theta *Raga*.

SPIRITUAL DIMENSION (CHAKRAS)

This dimension pertains to the spirituality aspect of the human self, called by various names such as the astral body, the soul and so on. Compared to the earlier dimensions, this one has very less literature in science. However, modern studies of Quantum Information and Consciousness have thrown light on the understanding of spirituality. The full treatment of spirituality with the philosophical outlooks and metaphysical dimensions is out of the scope of the present article. Fortunately, most of the information on spirituality, some of which has also been validated by modern science, is present in the age old formulation of the seven *Chakras* [22].

Chakras are vortices of energy through which channels called *Naadis* pass. There are seven *Chakras*: *Muladhara* (Base of the Spine), *Svadishtana* (Pelvic), *Manipura* (Navel), *Anahata* (Heart), *Visuddhi* (Throat), *Ajna* (Third Eye) and the *Sahasrara* (Crown). These *Chakras* are responsible also for various functions in the human body and mind. The excess or deficiency of any *Chakra* creates health issues. The

associated colour and location of the seven chakras along with their association with different kinds of Yogas and Mantras are as shown in Figure 6.

The connection between *Chakras* and Music has clearly been illustrated in ancient texts [16]. The Seven Swaras Sa, Ri Ga, Ma, Pa, Dha and Ni correspond respectively to *Muladhara*(1), *Svadishtana*(2), *Manipura*(3), *Anahata*(4), *Visuddhi*(5), *Ajna*(6) and *Sahasrara*(7). Thus, in a *Raga* such as *Mohanam*, which contains all *Swaras* except Ma and Ni, all *Chakras* except *Anahata* and *Sahasrara* are dominant. Thus the *Chakra* Signature of *Mohanam* is 12356.

INFORMATIONAL DIMENSION (LANDSCAPES)

This dimension pertains to the level of matching between the physician CIS and the patient CIS. Specifically, the patient CIS pertains to the interaction of the various dimensions of the body, mind and soul, and the states of information therein. Physician CIS represents the interaction of the environment, mindset etc. and witnessed as the emanated music. This complex interaction provides increased sensitivity and results in a chaotic signal [23].

The states of information in this chaotic signal are the frequencies of the *Swaras*. Analysis of the chaotic signal is possible using a standard parameter such as the Lyapunov Exponent (LLE) [24]. The Lyapunov exponent is a measure of the sensitive dependence on initial conditions, and can be computed from a time series using the Rosenstein's algorithm [25]. The computed LLE represents the level of complexity in the physician CIS. This CIS, when interacting with the patient CIS provides the unique experience commonly associated with music. Thus, the LLE represents the match between the two CIS and thus denotes the influential capacity of music.

In order to better comprehend the significance of LLE and CIS interaction, a landscape model is devised using the values of LLE. Specifically, four windows are defined:

1. LLE between 4.5 and 6.5: The landscape is cropland. This landscape, depicted in ancient *Sangam* literature as *Marutham*, is most conducive to human life. This mapping denotes that *Ragas* in this LLE window represent Physician CIS best matched with the patient CIS. As a result, these *Ragas* exert maximum influence to such a level that, even an uninitiated person appreciates and enjoys these *Ragas*. Typical examples of Cropland *Ragas* are *Shivaranjani* and *Sindhubhairavi*.
2. LLE between 6.5 and 8.5: The landscape is forest. Depicted in *Sangam* as *Mullai*, this is not as conducive as *Marutham* but habitable nonetheless. Moreover it has a hint of ubiquity and nostalgia and is best viewed as rustic. *Ragas* in this window may not mesmerize an uninitiate, but will surely offer an exhilarating experience for the involved. *Mohanam*, *Suddha Saveri* and *Bhauri* are typical Forest *Ragas*.
3. LLE above 8.5: Landscape is Seashore. This landscape, denoted by the *Sangam Neithal* is characterized by patterns – tides, waves and so on. Similarly *Ragas* in this LLE window have a higher LLE than *Marutham* and *Mullai*, and hence, more chaotic. These *Ragas* are best characterized by patterns of *Swaras*. Examples are *Surati* and *Sahana*.
4. LLE below 4.5: Landscape is Mountainous. Denoted by *Sangam Kurinji*, this is the landscape least conducive for living. Nevertheless, it does offer an unmatched exotic experience. *Ragas* in this LLE window can best be described as exotic and strange. Examples include *Naata* and *Rasikapriya*.

CONCLUSION

An integrative medicine system based on music has been formulated based on ancient Ayurvedic and modern Physics and Biology principles. A physician-patient interaction model has been developed. Using

this model a six dimensional model consisting of Physiological, Emotional, Sociological, Psychological, Spiritual and Informational dimensions has been developed and elaborated.

Based on the principles and methodologies elaborated in the present article, the six dimensions for an assortment covering fifty popular as well as rare Ragas are tabulated in Table 2, as an illustration of the practical relevance and the applicability of the above mentioned techniques.

The proposed formulation is a cohesive weave of established results and observations from various disciplines, both ancient and modern, in the context of music, targeting the holistic body-mind-soul healing. Though most of the results presented, especially the second table lists the properties of musical entities such as Ragas in the six dimensions, in order to use the results in practice, it is necessary to formulate a diagnosis methodology covering all the six dimensions. While diagnosis methodologies in some of the dimensions, such as for instance, the *Nadi Pariksha* for the *TriDoshas* and the MBTI Typology tests are well established, diagnosis methodologies for other dimensions such as spiritual and emotional are far from being standard and universal. This is thus the highest priority for future work, and once done, the principles and results mentioned in this article can be completely used for a pragmatic and comprehensive medicine system. The highlights of the present article include the formulation of a six dimensional music integrative medicine system, which may be a promising and effective healthcare approach with minimal side effects.

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APPENDIX

In this section, the methodology used to formulate two of the six dimensions, namely Emotional and Informational, are elaborated. The formulations of these two dimensions arise respectively from statistical physics and chaos theory, which are used to quantitatively describe abstract concepts, such as emotion.

A. STATISTICAL PHYSICS AND THE TRIGUNAS

As a starting step, two statistical events are described. Event 'x' is the singing of a note (swara). The chance of a note being sung is restricted by the melody (raga) as any raga allows only certain notes to be used. Probability matrix $p(x)$ denotes probabilities of each swara occurring in the raga. In other words, this denotes the raga composition. Event 'y' is the arousing of an emotion in the listener. There is uncertainty in y as no emotion is sure of occurring until the swara is sung. However, 'Y' depends on the composition of the raga. Hence, before the swara is sung the probability matrix $p(y)$ denotes the emotion profile of the raga, and after the singing of the swara, the conditional probability $p(y/x)$ denotes the emotion of the swara sung. To obtain $p(y)$ we can use the probability relation $p(x,y) = p(y/x)p(x)$, where $p(x,y)$ denotes joint probability. Then the matrix created using the sum of all elements in each column of $p(x,y)$ gives $p(y)$. Hence, to obtain $p(y)$, the first step is to get $p(y/x)$. This is done in 3 steps as follows:

STEP 1: Major notes (white keys in piano) give more pleasant feeling than minor notes (black keys). Moreover pairs of notes in cycles of fifths and fourths (c-g, d-a, c-f, etc.) yield a pleasant feeling. Notes being major/minor contribute more to emotions than them being in the cycle of 5th and 4th. These facts were taken into consideration, all possible combinations of note pairs (major-5th, major-4th, minor-5th, minor-4th, major-not in cycle, etc.) were listed, and arbitrary numbers were assigned to them such that

they represented the “pleasantness” in the combination. These numbers were called PJ (points of joy). All swara pairs are listed and PJ’s are allotted to them based on the combination under which they fall. Using this, PJ of all *Melakartha* ragas (a comprehensive set of Ragas each consisting of 7 notes) were calculated by adding the PJs of all swara pairs that featured in the raga. This gives the pleasantness or “positiveness of emotion” in a raga.

For example, *Sankarabharanam*, a happy raga has a PJ of 159. *Kalyani*, a soothing raga, has a PJ of 147. Sad raga *Shubhapanthuvrali* has a PJ of 70 and *Charukesi*, a raga depicting love has a PJ of 100. Then, PJ of a Swara was isolated by taking the average of PJ’s of all ragas having that swara in common. For example, PJ of Ma (F) is 129.5, PJ of Dha (G#) is 93.67 and that of Ni (Bb) is 95.83.

STEP 2: Since any parameter measured for a *Melakartha* raga can then be isolated to that of a single swara (just like PJ), we need some means of tabulating emotions of *Melakartha* ragas. Here 3 means are used:

1. Referring to ancient books and treatises on ragalakshana
2. Browsing through various reviews, reports, opinions and blogs for comments on emotions in a particular rendering.
3. Allowing people to hear certain pieces and conducting a survey of the emotions experienced, (this was done with a sample size of 85). All 3 means were adopted and the results were tabulated. For example, *Sankarabharanam* - joy, love, little surprise, *Mechakalyani* - joy, love, little surprise, little sympathy and *Charukesi* - little joy, sympathy, little love, submission. Then the emotions of individual swaras were isolated, and are illustrated in Fig. 7.

STEP 3: The 8 basic emotions suggested by Plutchik were taken. For each emotion the swaras are classified into 3 groups (yes, no and partial) and in each group swaras are arranged in increasing/decreasing PJ depending on whether the emotion is positive/negative. Then numbers were arbitrarily allotted such that they represent the magnitude of an emotion in a swara. These were normalized to give probabilities. Using these values a 16x8 matrix was formed, where the 16 rows denote the 16 swaras, and 8 columns denote 8 basic emotions namely joy, fear, surprise, trust, sorrow, anger, anticipation and disgust. This is the matrix $p(y/x)$ and is as shown in Figure 8. The next step is to obtain “Emotion Metrics” of a Raga. Emotion Metrics are parameters that describe the emotional capability of a Raga. In information theory, entropy is a measure of the uncertainty associated with a random variable. Mutual Information of two random variables is a quantity that measures the mutual dependence of the two variables. It measures how much knowing one of these variables reduces our uncertainty about the other. In other words, Mutual information gives the measure of how emotions are changed on singing a Swara. In other words, it denotes the “Influence of a Raga”.

For example, the mutual information of *Mohanam* is 0.076 as compared with 0.081 of *Sankarabharanam* and 0.086 of *Kalyani*.

There is another emotion metric called “Richness” and is obtained by taking the standard deviation of the matrix $P(Y)$ and denotes the variety in emotions the Raga offers. For example, *Mohanam* has a richness of 0.166 compared with 0.102 of *Sankarabharanam* and 0.152 of *Kalyani*.

Following this procedure, the matrix $p(y)$ of a given Raga is mapped to a single point in the 2D valence-arousal plane according to Russel’s Circumplex model, as shown in Fig. 5. By reading the chart in angular coordinates, starting anticlockwise with 0 degrees as the positive X-Axis, the segregation of this plane into three regions as follows gives the *TriGunas*.

1. 30 degrees to 150 degrees – High Arousal with positive/negative valence – *Rajas Guna*.
2. 150 degrees to 270 degrees – Low Arousal with Negative Valence – *Tamas Guna*.
3. 270 degrees to 30 degrees – Low Arousal with Positive Valence – *Sattva Guna*.

B. CHAOS THEORY AND INFORMATIONAL LANDSCAPES

It is a well-known fact that the fundamental properties of sound are dynamics (loudness), pitch (frequency) and timbre (tone). While the frequencies indeed correspond to the Swaras, the choice of musical instrument (including vocal) affect the timbre [26]. From a signal processing perspective, Swaras merely determine the central frequencies of each of the 7 bands, whereas the timbre determines the

amount of harmonic content around the central frequencies, and differs from instrument to instrument. Various attempts have been made at studying the spectral and timbre characteristics of various musical instruments and formulating mathematical expressions to synthesize such sounds, of which the most interesting result yields empirically the following expression as the output of a flute, the instrument with least number of harmonics, for a Swara S with centre frequency f_s [27-33]:

$$S(t) = \frac{1}{2.7490} \sum_{i=1}^4 A_i \cos(2\pi i f_s t) \quad (1)$$

where $A_1=2.54$, $A_2=0.245$, $A_3=0.009$ and $A_4=0.00001$.

The above equation describes the time domain waveform obtained for the flute output of a single Swara. However, a typical Raga has 12 possible Swaras, with Sa and Pa having one variety each, and Ri, Ga, Ma, Da and Ni having two varieties each. Of these 12, any Raga only allows a certain subset, and certain Ragas also have a proportion distribution among Swaras. For instance, *Shankarabharanam*, the 29th *Melakartha* Raga often associated with the Major Scale of Western Music has Sa, R2, G2, M1, Pa, D2 and N2, all in equal proportions, while *Mohanam*, a “child” Raga has Sa, R2, G2, Pa and D2. A Raga such as *Kedhaaram*, a “child” of *Shankarabharanam*, has this structure – Sa M1 G2 M1 Pa N2 – Sa N2 Pa M1 G2 R2.

A convenient method to express these details is the Composition Matrix M . This matrix is formed by the computing the number of non-zero Swara types the Raga has, and expressing each Swara as a relative proportion of that sum. The composition matrix is a 1x12 1 Dimensional Row Vector with the following structure:

$$M = [Sa \ R1 \ R2 \ G1 \ G2 \ M1 \ M2 \ Pa \ D1 \ D2 \ N1 \ N2] \quad (2)$$

The Composition Matrices of Shankarabharanam, Mohanam and Kedhaaram are respectively as follows:

$$M_{Shankarabharanam} = [1 \ 0 \ 1 \ 0 \ 1 \ 1 \ 0 \ 1 \ 0 \ 1 \ 0 \ 1] \quad (2a)$$

$$M_{Mohanam} = [1 \ 0 \ 1 \ 0 \ 1 \ 0 \ 0 \ 1 \ 0 \ 1 \ 0 \ 0] \quad (2b)$$

$$M_{Kedhaaram} = [0.17 \ 0.0 \ 0.08 \ 0.0 \ 0.17 \ 0.25 \ 0.0 \ 0.17 \ 0.0 \ 0.0 \ 0.0 \ 0.17] \quad (2c)$$

The Swara value for each Swara in the Composition Matrix is taken as a coefficient (weight) for equation 1 of that corresponding Swara. By forming 12 such equations for all the Swaras, and adding them up, the “experience equation” of a “Raga”, yielding the Raga Waveform $R(t)$ is obtained as follows:

$$R(t) = \sum_{j=1}^{12} \frac{M(j)}{2.4790} \sum_{i=1}^4 A_i \cos(2\pi i f_s(j)t) \quad (3)$$

In this equation, the term $f_s(j)$ refers to the central frequencies of the 12 Swaras, represented as a 1D vector, similar to M , as follows:

$$f_s = f_0 [1.00 \ 1.06 \ 1.13 \ 1.18 \ 1.25 \ 1.33 \ 1.42 \ 1.50 \ 1.59 \ 1.67 \ 1.78 \ 1.89] \quad (4)$$

The term f_0 is the fundamental frequency of Sa, left to the choice of the performer. All calculations in the present article use a value of 100Hz for f_0 , a mathematically convenient value corresponding to the voice frequency of a typical adult male. However, as mentioned earlier, it is the ratio and not absolute frequency that contributes to the experience of Indian Music.

From the time domain equation of the Raga given in Equation 3, one obtains the time derivative $dR(t)/dt$ as follows:

$$\frac{d R(t)}{d t} = - \sum_{j=1}^{12} \frac{M(j) f_s(j)}{2.4790} \sum_{i=1}^4 2 \pi i A_i \sin(2 \pi i f_s(j) t) \quad (5)$$

Using this, we rewrite the derivative $dR(t)/dt$ as a difference term $R_n - R_{n-1}$, and discretize the entire equation to obtain the following iterative function, termed the “Music Iterative Map”.

$$R_n = R_{n-1} - \sum_{j=1}^{12} \frac{M(j) f_s(j)}{2.4790} \sum_{i=1}^4 2 \pi i A_i \sin(2 \pi i f_s(j) n) \quad (6)$$

Equation 6 is the final equation depicting the evolution and behavior of the Raga equation.

It is seen from equation 6 that the behavior of the Raga waveform and subsequently the experience of music heavily depends on the product term $P=M(j)f_s(j)$, which gives the relative proportion of each frequency in the overall waveform.

Different Ragas with different values for P show widely diverse behavior due to this property. A slight change in the value of $M(j)$ or alternatively P will cause a drastic change in the evolution of R . This property is well-known in physics; it is sensitive dependence on Initial Conditions, the starting point in “Chaos Theory”, with P playing the role of initial condition or “control parameter”. The “Sensitive Dependence on Initial Conditions” is explained more popularly as the “Butterfly Effect”, which states that a Butterfly flapping its wings in Texas will in due course, cause a Tornado in Brazil [34-38]. Furthermore, the property that the initial events are carried over to subsequent events amplified implies that chaos contains “memory”.

Chaos is essentially deterministic. This means that if one knows the initial conditions, one can easily find the output of a chaotic system at any point in time [34-38]. But since the behavior is so fluctuating and it is almost always impossible to know all initial conditions, it appears like as if the chaos looks random, which is a clearly misleading appearance.

The starting step in most cases of chaotic characterization is the definition of iterative map, which in this article is defined by Equation 6. Following this, various plots are used for the visualization of chaotic map, like for instance the Bifurcation Plot, which describes how values of R vary with P [34-38]. However, since P is a matrix in itself, this leads to multiple control parameters manipulating the output, corresponding to the case of a multidimensional chaotic system [34-38].

One useful plot to understand and confirm the presence of chaotic behavior is the phase portrait, which plots the derivative of R , given in Equation 5, as a function of R , given in Equation 3. This plot describes the stability aspects of the system behavior and points of stability around which the system revolves, while also assessing various related parameters such as sensitivity and ergodicity [34-38]. As an example, the time domain waveform $R(t)$ and corresponding phase portrait of *Shankarabharanam* are shown in Fig. 9 and Fig. 10.

A quantitative characterization technique ideally used to characterize the sensitive dependence of a system on initial conditions is the largest Lyapunov Exponent, denoted as the LLE where a positive value of LLE asserts the presence of chaos [25,39,40]. Methods such as the Rosenstein’s Algorithm exist to determine the Lyapunov Exponent from the time series $R(t)$ [25,40]. Specifically, an evolution time Δt is defined and the i th sample of the divergence d for the j th trajectory is expressed as a function of λ in the

Integrative Medicine System Based On Music

following manner, where the λ_i 's denote the Lyapunov Exponents and C_j denote normalization constants [40,41]: $d_j(i) = C_j e^{\lambda_i(i\Delta t)}$.

The LLE then is the largest of the obtained λ_i 's, and is an indicator of the presence of chaos. For *Shankarabharanam*, an LLE value of 5.01 is obtained, confirming its chaotic nature.

This value of LLE is indicative of the “complexity” of a Raga, and hence is a quantification of the “Composite Information System” (CIS). The match between the physician CIS and patient CIS for a chosen Raga determines the extent of influence of the said Raga on the patient, and to comprehend this, four regions, or “informational landscapes” are defined as follows:

1. Cropland (LLE between 4.5 and 6.5) – Maximum influence, even on the musically uninitiated.
2. Forest (LLE between 6.5 and 8.5) – Exhilarating experience for the initiated, with a rustic feel.
3. Seashore (LLE above 8.5) – Very patterned, usually most influential on the musically inclined.
4. Mountainous (LLE below 4.5) – Exotic and Strange “out-of-the-world” experiences.

FIGURES

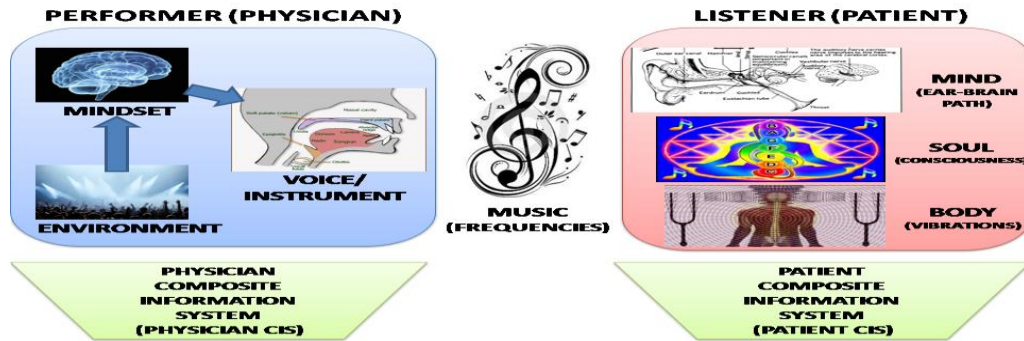


Figure 1 The Physician-Patient Interaction Model

	Balance	Imbalance
Vata	Inspiration, Emotional balance, Clear mind, Enthusiasm, Good complexion, Good digestion, Fertility	Worry, insomnia, Poor memory, cough, Fatigue, cancer, Diarrhea, gas, Constipation, Low back pain, Sexual disorders, Arthritis, Poor circulation
Pitta	Good digestion, Strong heart, Motivation, Good eyesight, Sweating	Indigestion, addictions, Anger, liver problems, Anemia, heart attack, Visual problems, Acne, rashes, Skin cancer, indecision
Kapha	Strength, immune Response, Lymphatic movement, Protecting brain, Fluid joints Movement	Obesity, Food sensitivity, Asthma, lethargy, Slow digestion, Swelling, headaches, Irritability

Figure 2 Health Effects of the three Doshas

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Sattva	Raja	Tamas
Truth	Activity	Inertia
Light / illumination	Passion / desire	Darkness
Essence	Energy	Mass / matter
Intelligence	Movement	Sloth / dullness
Binds by means of attachment to knowledge and joy.	Binds by passion born of craving and attachment.	Binds by means of ignorance and obstruction.
Is the ruling trait when the light of knowledge shines forth.	Is the ruling trait when greed, excessive projects, cravings and restlessness arise.	Is the ruling trait when darkness, dullness, stagnation, indolence, confusion, torpor, and inertia appear.

Figure 3 Features and traits of the three Gunas

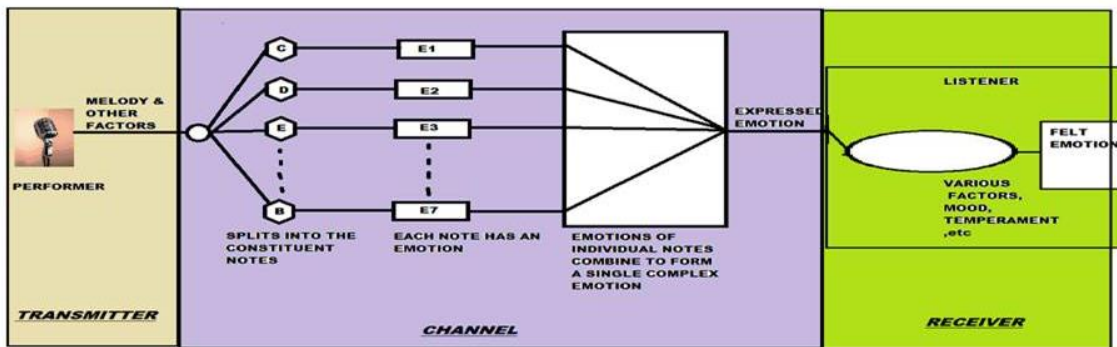


Figure 4 Information Theory Model of Music

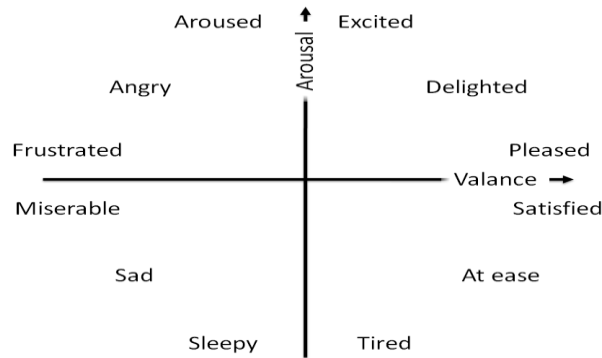


Figure 5 Major emotions in the Russel's Valence Arousal Circumplex Model.

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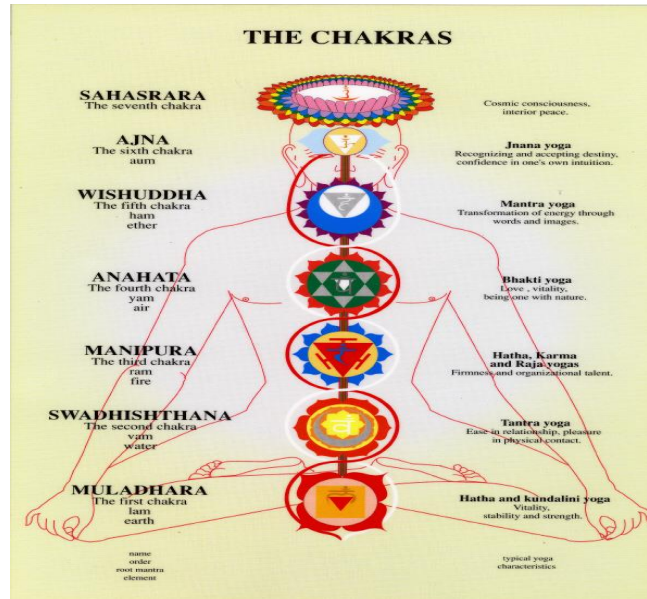


Figure 6 The 7 Kundalini Chakras

SWARA	EMOTION
SA	ATHARA SWARA(FIRMNESS TO THE RAGA)
RA	FEAR, SYMPATHY, SORROW
RI	JOY, SYMPATHY, LITTLE SURPRISE, LOVE
RU	SURPRISE, LITTLE JOY
GA	FEAR
GI	SYMPATHY, LITTLE JOY
GU	HAPPY, SURPRISE
MA	JOY, LITTLE FEAR
MI	SUBTLE JOY, SOOTHINGNESS
PA	NO EMOTION(FIRMNESSTO THE RAGA)
DHA	FEAR, SYMPATHY
DHI	JOY, SYMPATHY, LITTLE SURPRISE LOVE
DHU	SURPRISE, LITTLE JOY, LITTLE LOVE
NA	FEAR
NI	SYMPATHY, SUBTLE JOY, SORROW, LOVE, LITTLE SUBMISSION
NU	JOY, LOVE, SURPRISE

Figure 7 Emotion Descriptions of the Swaras

SWARA	JOY	FEAR	SURPRISE	TRUST	SORROW	ANGER	ANTICI	DISGUST
SA	0.25	0	0.25	0.25	0	0.25	0	0
RA	0.053575	0.196425	0.10715	0.25	0.196425	0.053575	0.14285	0
RI	0.214275	0.089275	0.1607	0.193361	0.035725	0.160725	0.0893	0.05664
RU	0.125	0.1607	0.214275	0	0.125	0.0893	0.035725	0.25
GA	0.071425	0.214275	0.125	0.046657	0.178575	0.035725	0.125	0.203425
GI	0.14285	0.14285	0.071425	0.186682	0.10715	0.10715	0.178575	0.06325
GU	0.23215	0.10715	0.25	0.03975	0.01785	0.14285	0	0.210336
MA	0.25	0.178575	0.178575	0.09125	0	0.071425	0.071425	0.158755
MI	0.1607	0.125	0.089275	0.0635	0.0893	0.125	0.160725	0.186513
PA	0.25	0	0.25	0.25	0	0.25	0	0
DHA	0.01785	0.23215	0.01785	0.223337	0.23215	0.01785	0.23215	0.026675
DHI	0.196425	0.01785	0.14285	0.183364	0.053575	0.23215	0.10715	0.06675
DHU	0.089275	0.071425	0.196425	0	0.160725	0.178575	0.053575	0.25
NA	0.035725	0.25	0.035725	0.075375	0.214275	0	0.214275	0.17464
NI	0.10715	0.053575	0.053575	0.186682	0.14285	0.196425	0.196425	0.063325
NU	0.178575	0.035725	0.23215	0.0516	0.071425	0.214275	0.01785	0.198419

Figure 8 The P(Y/X) matrix

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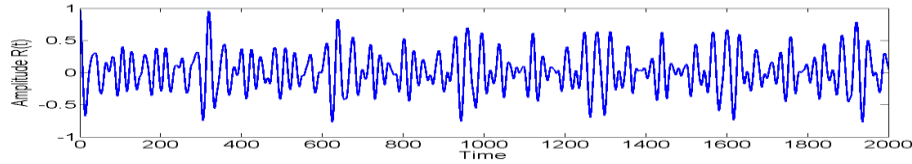


Figure 9 Time Domain waveform R(t) of Shankarabharanam

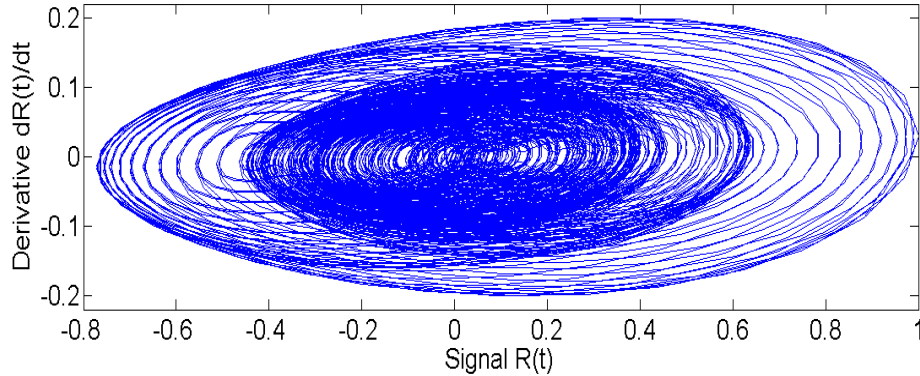


Figure 10 Phase Portrait of Shankarabharanam. The ornamental pattern seen is a typical signature of chaotic systems

TABLES

Table 1 Relative Frequencies of 16 Swaras, with the base Swara Sa normalized to 100Hz

<i>Swara Name</i>	<i>Swara Type</i>	<i>Frequency (Hz)</i>
<i>Shadjam</i>	Sa	100
	Ra	106.66
<i>Rishabham</i>	Ri	112.5
	Ru	116
	Ga	112.7
<i>Gandharam</i>	Gi	118
	Gu	125
	Ma	133
<i>Madhyamam</i>	Mi	142
	Pa	150
<i>Panchamam</i>	Dha	159
	Dhi	167
	Dhu	175
<i>Dhaivatham</i>	Na	167
	Ni	178
	Nu	189

Table 2 The Six Dimensional Qualities for an assortment covering fifty popular as well as rare Ragas

<i>Raga Name</i>	<i>Physiological</i>	<i>Emotional</i>	<i>Sociological</i>	<i>Psychological</i>	<i>Spiritual</i>	<i>Informational</i>
<i>Ahiri</i>	<i>Sannipata</i>	<i>Sattva</i>	Orderly	Theta	1234567	Forest
<i>Anandabhairavi</i>	<i>Kapha</i>	<i>Sattva</i>	Orderly	Alpha	123456	Seashore

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<i>Arabhi</i>	<i>Pitta</i>	<i>Rajas</i>	Harmonious	Alpha	12456	Forest
<i>Ataana</i>	<i>Vata</i>	<i>Rajas</i>	Orderly	Alpha	1245	Mountainous
<i>Bhairavam</i>	<i>Pitta-Kapha</i>	<i>Rajas</i>	Adaptive	Theta	123456	Seashore
<i>Bhauri</i>	<i>Pitta-Kapha</i>	<i>Sattva</i>	Curious	Theta	12356	Forest
<i>Bhoopalam</i>	<i>Pitta-Kapha</i>	<i>Sattva</i>	Harmonious	Theta	12356	Forest
<i>Chintamani</i>	<i>Kapha</i>	<i>Sattva</i>	Orderly	Alpha	2345	Seashore
<i>Deepakam</i>	<i>Pitta</i>	<i>Rajas</i>	Curious	Theta	1234	Seashore
<i>Desakshi</i>	<i>Pitta-Kapha</i>	<i>Rajas</i>	Adaptive	Alpha	12356	Forest
<i>Dhanyasi</i>	<i>Vata</i>	<i>Sattva</i>	Curious	Theta	13457	Forest
<i>Gamanashrama</i>	<i>Sannipata</i>	<i>Rajas</i>	Adaptive	Theta	1234567	Cropland
<i>Gaula</i>	<i>Vata</i>	<i>Rajas</i>	Orderly	Theta	24	Seashore
<i>Gauri</i>	<i>Vata</i>	<i>Rajas</i>	Curious	Theta	12457	Cropland
<i>Ghanta</i>	<i>Vata-Kapha</i>	<i>Sattva</i>	Orderly	Theta	13457	Cropland
<i>Guntakriya</i>	<i>Vata</i>	<i>Rajas</i>	Orderly	Theta	12457	Forest
<i>Gurjari</i>	<i>Kapha</i>	<i>Tamas</i>	Adaptive	Theta	1234567	Cropland
<i>Hindhola</i>	<i>Kapha</i>	<i>Tamas</i>	Harmonious	Alpha	13467	Cropland
<i>Kaanada</i>	<i>Vata</i>	<i>Sattva</i>	Orderly	Alpha	12347	Seashore
<i>Kalyani</i>	<i>Sannipata</i>	<i>Rajas</i>	Adaptive	Alpha	1234567	Forest
<i>Kambhoji</i>	<i>Pitta-Kapha</i>	<i>Rajas</i>	Adaptive	Alpha	123456	Seashore
<i>Kedaram</i>	<i>Vata</i>	<i>Rajas</i>	Harmonious	Alpha	13457	Cropland
<i>Kharaharapriya</i>	<i>Sannipata</i>	<i>Sattva</i>	Adaptive	Alpha	1234567	Cropland
<i>Kurinji</i>	<i>Pitta</i>	<i>Rajas</i>	Orderly	Alpha	1	Forest
<i>Lalitha</i>	<i>Pitta-Kapha</i>	<i>Tamas</i>	Harmonious	Theta	123467	Mountainous
<i>Maadhyamavathi</i>	<i>Vata</i>	<i>Sattva</i>	Harmonious	Alpha	12457	Forest
<i>Malahari</i>	<i>Pitta</i>	<i>Sattva</i>	Curious	Theta	12456	Forest
<i>Malavi</i>	<i>Vata</i>	<i>Rajas</i>	Orderly	Alpha	4	Seashore
<i>Mayamalavagaula</i>	<i>Sannipata</i>	<i>Tamas</i>	Adaptive	Theta	1234567	Cropland
<i>Mohanam</i>	<i>Pitta-Kapha</i>	<i>Rajas</i>	Harmonious	Alpha	12356	Forest
<i>Mukhari</i>	<i>Vata-Pitta</i>	<i>Sattva</i>	Orderly	Alpha	124567	Cropland
<i>Naata</i>	<i>Vata</i>	<i>Rajas</i>	Curious	Alpha	12457	Mountainous
<i>Neelambari</i>	<i>Vata-Kapha</i>	<i>Rajas</i>	Orderly	Alpha	35	Cropland
<i>Paadi</i>	<i>Vata</i>	<i>Sattva</i>	Curious	Theta	12457	Cropland
<i>Panthuvarali</i>	<i>Sannipata</i>	<i>Tamas</i>	Adaptive	Theta	1234567	Cropland
<i>Poorvikalyani</i>	<i>Sannipata</i>	<i>Rajas</i>	Orderly	Theta	123456	Seashore
<i>Punnagavarali</i>	<i>Vata-Pitta</i>	<i>Tamas</i>	Orderly	Theta	127	Cropland
<i>Sahana</i>	<i>Vata-Kapha</i>	<i>Rajas</i>	Orderly	Alpha	234	Seashore
<i>Sama</i>	<i>Pitta</i>	<i>Rajas</i>	Harmonious	Alpha	12456	Forest

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<i>Sankarabaranam</i>	<i>Sannipata</i>	<i>Rajas</i>	Adaptive	Alpha	1234567	Cropland
<i>Saranga</i>	<i>Vata-Pitta</i>	<i>Rajas</i>	Orderly	Alpha	125	Forest
<i>Saurashtra</i>	<i>Vata-Kapha</i>	<i>Rajas</i>	Orderly	Theta	46	Forest
<i>Saveri</i>	<i>Pitta</i>	<i>Sattva</i>	Curious	Theta	12456	Seashore
<i>Shree</i>	<i>Vata</i>	<i>Sattva</i>	Orderly	Alpha	257	Cropland
<i>Shubapantuvarali</i>	<i>Sannipata</i>	<i>Tamas</i>	Adaptive	Theta	1234567	Cropland
<i>Suddha Deshi</i>	<i>Pitta</i>	<i>Sattva</i>	Orderly	Alpha	2	Forest
<i>Suddha Dhanyasi</i>	<i>Vata</i>	<i>Sattva</i>	Harmonious	Alpha	13457	Cropland
<i>Suddha Saveri</i>	<i>Pitta</i>	<i>Sattva</i>	Harmonious	Alpha	12456	Forest
<i>Surati</i>	<i>Vata</i>	<i>Rajas</i>	Orderly	Alpha	12457	Seashore
<i>Thodi</i>	<i>Sannipata</i>	<i>Tamas</i>	Adaptive	Theta	1234567	Forest
<i>Varaali</i>	<i>Kapha</i>	<i>Tamas</i>	Orderly	Theta	3	Cropland
<i>Vasantha</i>	<i>Kapha</i>	<i>Rajas</i>	Curious	Theta	13467	Cropland
<i>Yadukulakamboji</i>	<i>Pitta</i>	<i>Rajas</i>	Harmonious	Alpha	12456	Forest

SUPPLEMENTARY MATERIAL – FINGERPRINTS OF RAGAS

In light of the six dimensional approach formulated above, based on Ayurveda, Yoga, Chaos Theory, Quantum Consciousness, Neurodynamics, Psychology, Statistical Physics and Information Theory, to say that the musical experience is a rich one is truly an understatement. Perhaps the most ideal method of characterizing and studying the richness in a multidimensional system such as music is the Distance Plot.

The main premise in the concept of distance plot is that most natural processes including music possess recurrent behavior in the form of periodicities and irregular cyclicities. Here, a recurrence is defined as a condition where states in the system are arbitrarily close after some time of divergence.

On this concept, the distance plot (DP) is defined as follows: For a discrete signal with N samples denoted by $R(n)$, $n \leq N$, the distance between the i th and j th point $D(i,j)$ is given by $D(i,j) = \|R(i) - R(j)\|$.

The collection of all the distance points $D(i,j)$ for all $i,j < N$ form the Distance Matrix D , a plot of which is termed the Distance Plot (DP), usually plotted in black and white by setting a threshold level T . It has been shown that certain dynamical invariants such as the Correlation Dimension, Kolmogorov Entropy and Mutual Information can be derived from DPs. The key advantage of distance plots is that these plots provide useful information about the chaotic nature even for short term and non-stationary data.

Thus, the DP clearly shows interesting patterns of grouping, branching, isolations and periodicities, which when studied in detail would reveal vital details about the nature of chaos in a given Raga. For this reason, the DP of a Raga may be rightly viewed as the “Fingerprint of a Raga”, a pattern unique for each Raga, and for each music entity.

The following three figures, S1 to S3 are a compilation of the DPs of the assortment of Ragas mentioned in Table 2. Each of the DPs is a testimony to the artwork of nature, and is a treasure trove of information regarding the corresponding Raga and its associated musical experience.

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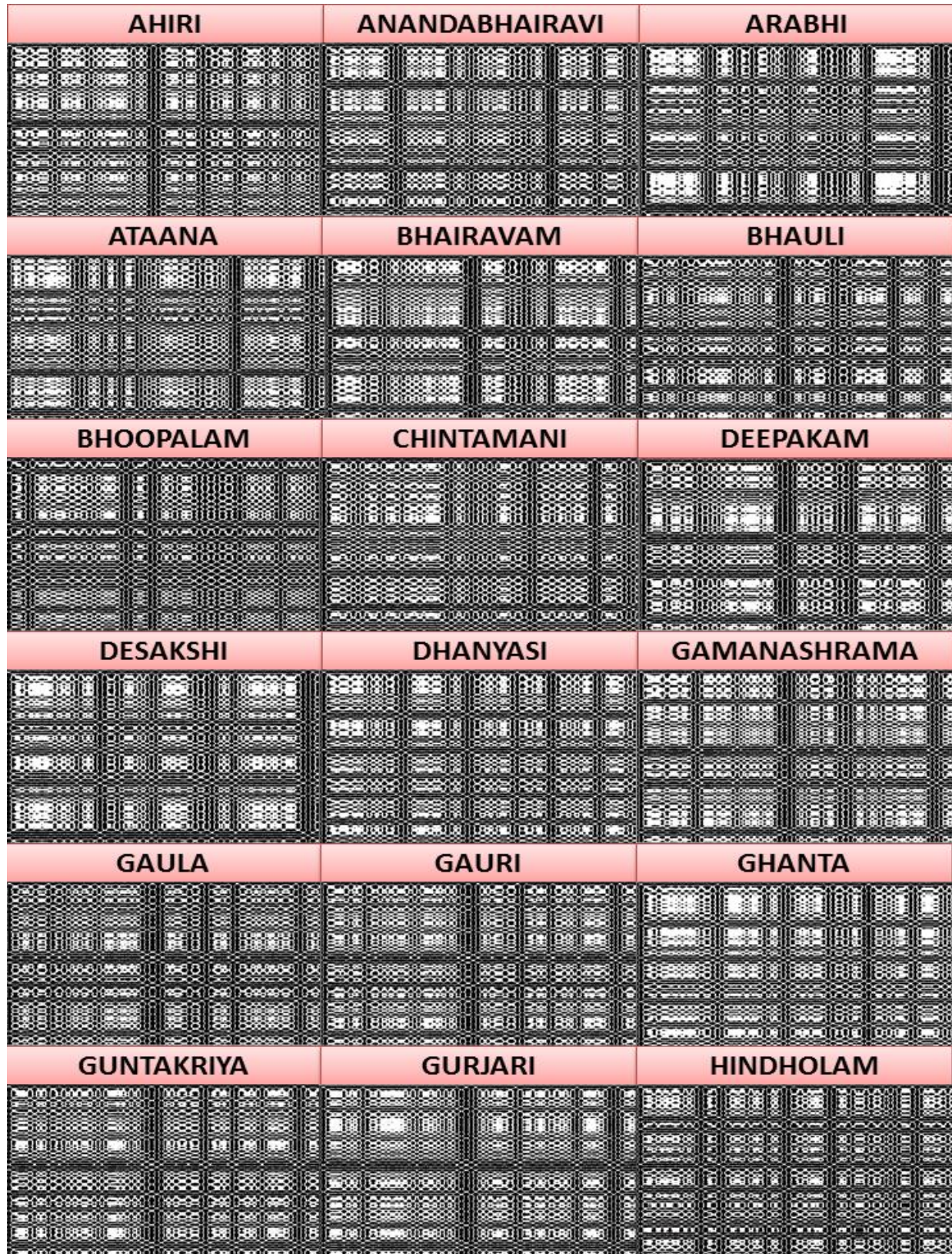


Figure S1 Distance Plots of Ragas - Part 1

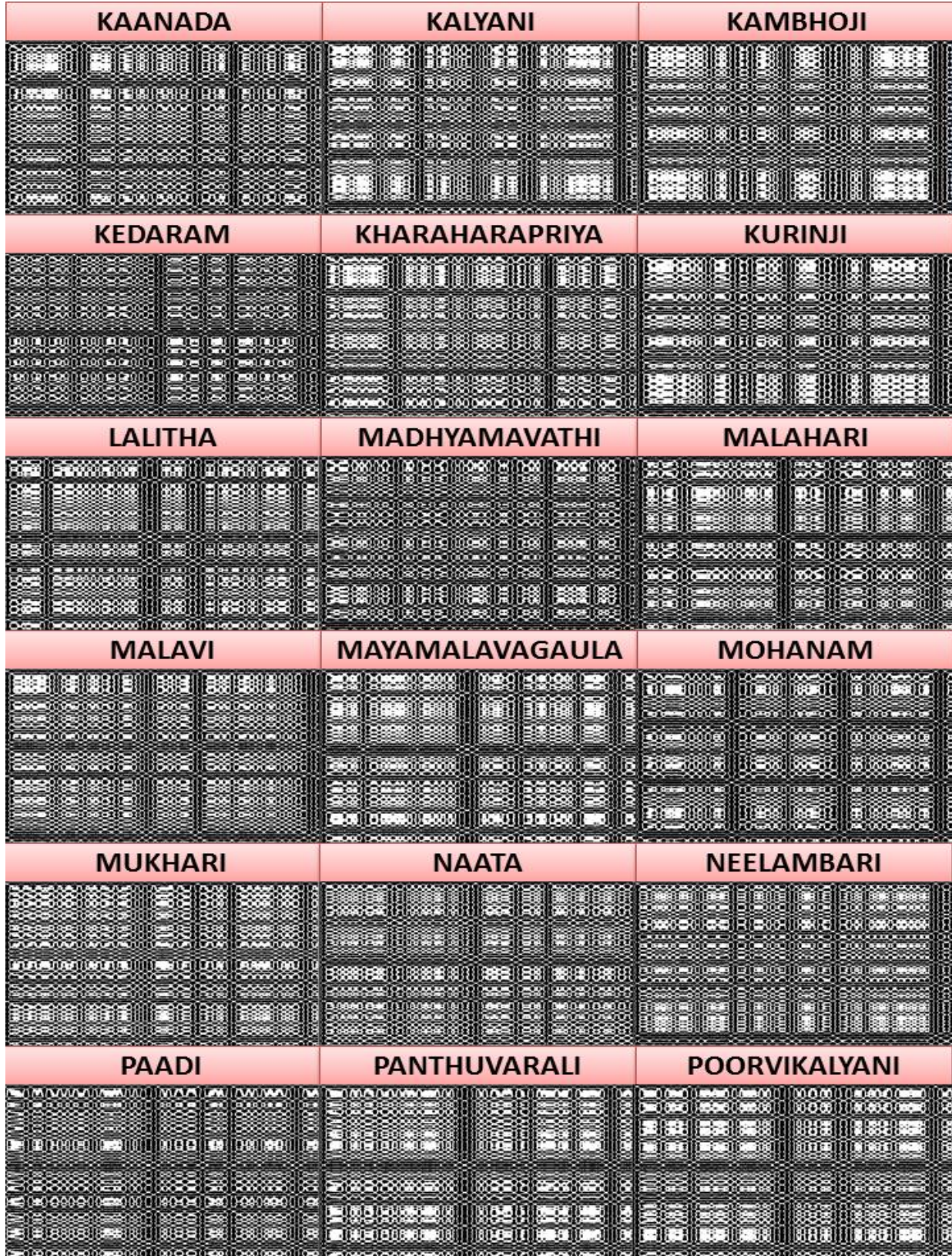


Figure S2 Distance Plots of Ragas - Part 2

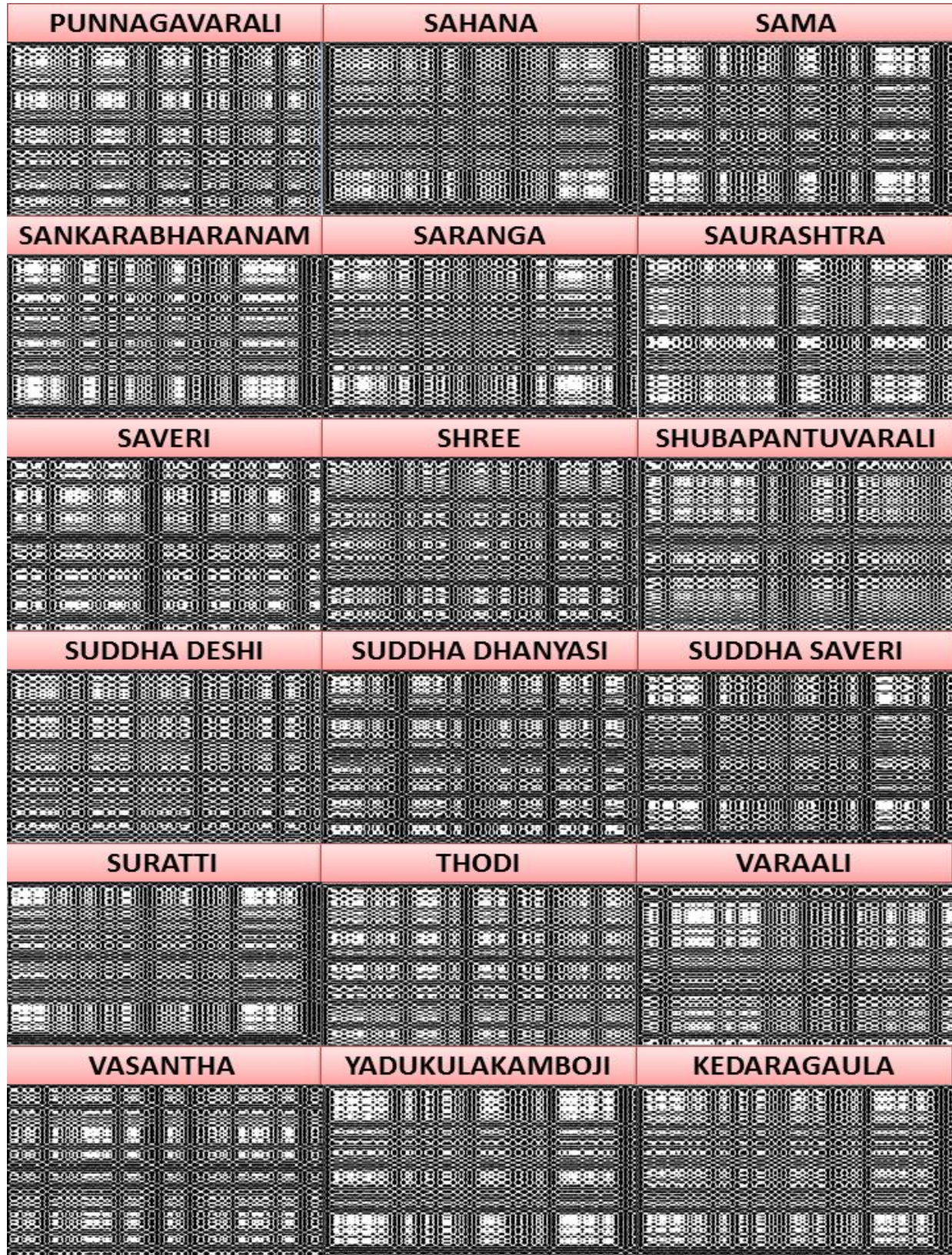


Figure S3 Distance Plots of Ragas - Part 3