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# Nonlinear Signal Processing Method Detects Emotional Changes Induced by Indian Classical Music

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***Abstract:*** ***Music is one of the major activities that alters the emotional experience of a person. Musical processing in the brain is a complex process involving coordination between various areas of the brain. There are less number of studies that focus on analyzing brain responses due to music using modern signal processing techniques. This research aims to apply a nonlinear signal processing technique i.e. the Recurrence Quantification Analysis (RQA) technique to analyze the brain correlates of happy and sad music conditions while listening to happy and sad ragas of North Indian Classical Music (NICM). EEG signals from 20 different subjects are acquired while listening to excerpts of raga elaboration phases of NICM. Along with behavioural ratings, the signals were analyzed using the Recurrence Quantification Analysis technique. The results showed significant differences in the recurrence plot and recurrence parameters extracted from the frontal and fronto-temporal regions in the right and left hemispheres of the brain. Therefore, from the results, it can be concluded that RQA parameters can detect emotional changes due to happy and sad music conditions.***

***Keywords: Classical Music, EEG, Happy and sad emotions, Music and cognition, Nonlinear analysis, RQA***

## I. INTRODUCTION

Brain is a very unique organ in the body that has the ability to modify its environment and the environment modifies the functions of the brain. When the brain is exposed to certain stimuli, the structure and functioning of the brain is referred as 'brain plasticity' or 'neuronal plasticity'. Music is a product of complex brain functions. Indulging in the product has been known from ancient times to have the ability to restore and alter brain functions. Music and emotion share a unique association between each other. The relationship between music and emotion has led to debates and researches in wide arena of domains like philosophy, musicology, psychology, neurosciences etc. Music is known to elicit psychological changes in individuals through modulation of emotional experience. Processing of music by the brain involves a high level coordination between various brain areas.

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There have been increased attempts by cognitive neuroscientists to study the role of music in the modulation of emotional experience and its neurobiological basis.

Music is ubiquitous. Either actively or passively, every one of us gets involved in musical behavior. The emotional experience derived by an individual is mostly the reason for the ubiquitous nature of music in our lives [1]. For obvious reasons, music is considered as a language of emotions [2]. Internally, the brain indulges itself in an array of cognitive functions like attention, learning, memory, decision making during automatic processing of music. The brain also has to keep in mind the musical features like pitch, rhythm, memory, emotional content etc. while creating music. Music creation can be used for training higher cognitive functions like focused attention, working memory etc. Engaging the brain in musical behavior has been proven to be an excellent indication of mental and emotional fitness and flexibility [3]. In general, if an individual is capable of producing and expressing through music, then the individual is said to possess higher intellect and a creative mind.

Lot of research has been aimed at understanding the response of the brain to musical stimuli among musically trained and untrained individuals. Researchers have found it interesting to study the association between music and language and the brain networks that are common and unique for processing the two functions [4]. It is also proven that music can alter physiological conditions such as heart rate and respiratory changes. It was noted that happy musical excerpts induced large changes in respiration measures and sad musical excerpts produced perceivable changes in temperature, skin conductance, blood pressure and heart rate. It was also seen that fear excerpts of music induced changes in blood transit times [5]. Music is also a source of bodily sensations like chills, thrills and tingles down the spine [6],[7].

Music is known to induce emotions intentionally and humans tend to experience emotional changes with or without the knowledge of music. Emotions are defined as the adaptive responses of the brain that have positive effect on the survival value. They are a result of the integrated activity of the affect generating brain systems and the emotional effector systems. It has six subcomponents, a) Cognitive appraisal (Appraisal of a situation as dangerous) b) Subjective feelings (Feeling afraid) c) Physiological arousal (Pounding of heart) d) Expression (Scream) e) Action tendency (Running away from a situation) f) Regulation (Calm oneself) [8]. Studies in psychology have proven that individuals are consistently able to associate emotions like happiness, sadness, fear and anger to musical compositions [9]-[12].

A study also proposed an emotion model according to which emotions are based on tendencies of approach and avoidance and that they are differentiated in the frontal brain regions indicated by asymmetrical frontal brain activity. Positive emotions like happiness are perceived in the left frontal area and negative emotions like fear and sadness are perceived in the right frontal area of the brain which is evident by the relatively greater EEG activity in the respective regions [13].

To determine the musical behavior of the brain and the emotions perceived through music, neuroscientists have used direct methods like interviewing and behavioral rating by the listeners. Advanced tools like Magneto Encephalography (MEG), Electro Encephalography (EEG), Event Related Potentials (ERP), Positron Emission Tomography (PET) and functional Magnetic Resonance Imaging (fMRI) have been proven to be more advantageous for measuring the electrical activity and flow of blood in regions of the brain during musical stimuli. The primary indices of emotional processing, heart rate variability, sweating, respiration changes, are being measured with the help of polygraphs. The cognitive aspects of musical stimuli such as the rhythm, contour, pitch and expectancy have been focused upon, in studies involving the processing of music by the brain. It is evident from the literature that the frontal, parietal and temporal regions of the brain are active in music processing [14],[15]. Researchers have shown more interest during the last decade in studying the neural correlates of music evoked human emotions. Activities in brain areas like the amygdala, hippocampus, insula, cingulate cortex, nucleus accumbens and the hypothalamus have been shown to be modulated by music in the various studies that involve functional neuroimaging of the brain. Recent neuro-scientific researches have indicated that the superficial amygdala plays the central role in processing of musical stimuli. Also, studies have shown that the mesolimbic pathway is involved in processing of music evoked pleasure and the hippocampus is associated with emotions related to social attachments. All these studies also imply that music can be used to develop therapies for psychiatric and neurological disorders involving these brain structures.

In the next section, we provide a brief overview of the various studies carried out to determine the effect of music on various brain areas and networks and study the variations of emotions induced in the brain due to listening to music. The primary focus in most studies is on the asymmetrical activation of frontal hemispheres and overall frontal region activation seen in the EEG signal.

A study was conducted with an objective to relate the valence and intensity of the emotions induced by music to regional EEG activity and eventually validate the usage of EEG activity to differentiate emotions. The study was conducted by using excerpts of music that were pre-rated to induce fear (intense-unpleasant), joy (intense-pleasant), happy (calm-pleasant) and sad (calm-unpleasant) emotions. EEG was recorded specifically from frontal and parietal regions only. Analysis of the data was performed using power of EEG in the alpha band. Analysis of Variance (ANOVA) was done on the natural log transformation of EEG in the alpha band using valence, intensity and hemisphere factors. The results revealed higher relative left frontal EEG activity and less absolute frontal EEG power for positively valenced music. Also there was lower frontal EEG power in the left hemisphere across both valence and intensity. It was noted by the EEG activities that positively valenced music like joy and happy induced less frontal EEG power which means that there is more activity in those regions and less activity when the music is negatively valenced. This supports the fact that, in general, emotions induced in the brain activate the frontal regions. Also, with increase in intensity of music, the overall activity in the frontal region was found to increase. It is to be noted that the negative emotions are termed as non communicative primary emotions exhibited during self defense and anxiety whereas positive emotions are termed as secondary learned emotions and are exhibited in social contexts. There are chances that the subjects listening to music process the language parts of the music along with the emotional content. This might be a reason for activation of the language areas in the left hemisphere of the brain [16].

Another study tried to examine if the style of music would cause any difference in the brain activation patterns while processing emotions induced by music. A wide range of music stimuli including environmental sounds were used for the study. ANOVA measures were used for analysis of brain activity based on valence and music style along with laterality, electrodes and gender. The results clearly indicated changes in the activation patterns in the cortical regions. Musical stimuli that were rated to produce positive effects induced more localized patterns towards the left fronto-temporal cortices and stimuli that were designed to produce negative effects induced symmetrical bilateral fronto-temporal activation. Also, it was noted that positive emotions generated due to music stimuli showed patterns more localized towards the left hemisphere whereas negative emotions did not show the same amount of localizations towards the right hemisphere [17].

Power spectral analysis is yet another major technique to determine the electrophysiological correlates of music and associated emotions in the brain. It is known that the EEG frequency bands are related to mental activities and neuronal states. A study was carried out to know which frequency bands of EEG are correlated with the processing of pleasant and unpleasant music. Joyful excerpts of instrumental dance music tunes formed the consonant or pleasant stimuli and the dissonant or unpleasant stimuli were derived by playing the same pleasant version simultaneously with two of its pitch shifted variants. Welch's power spectral averaging technique that computes the power spectra using the Fast Fourier Transform was used for analyzing the power spectrum. Analysis of Variance (ANOVA) measures were employed for further statistical analysis of the power in the frequency bands. The results showed a significant increase in the theta power over the mid frontal regions while listening to pleasant music. Unpleasant music failed to induce any increase in the theta power. Also, a linear correlation was observed between the pleasantness ratings of the music given by the subjects and theta power. Among all the frequency bands of the EEG, theta rhythm ranging between 4 - 8 Hz can be observed during two different conditions; one is during drowsiness and the other type is when the brain is involved in different tasks like mental calculations, working memory, meditation, learning and error processing.

This type of theta rhythm is also known as the Frontal midline theta or 'Fm theta'. It is known from previous studies that Fm theta is generated due to activities in the dorsal anterior cingulate cortex which is a part of the limbic system involved in emotional processing. Thus, it can be inferred that an increase in Fm theta power while listening to pleasant music can be associated to the emotional processing in the brain. Also, because of the already induced pleasant emotions, the subjects listened to pleasant music more attentively making the Fm theta rhythm dependant on both emotional and attention processes. This supports the fact that anterior cingulated cortex is associated with both emotional processing and attention and Fm theta can be used effectively as an indicator of emotional modulates of music [18].

Yet another study investigates the effective brain networks during listening to music using Multivariate Autoregressive and Directed Transfer Function analysis. The results indicated an increase in connectivity in frontal and fronto-parietal regions while listening to joyful music. A positive correlation was seen between the behavioral results and frontal inter-hemispheric activity [19].

In another study based on Indian Music the researchers analyzed the effects of Hindustani Classical Music on brain activity under normal relaxing conditions using EEG. Nonlinear analysis of different EEG rhythms was performed using the detrended fluctuation analysis technique. The results indicated that arousal based activities enhanced when listening to music of contrasting emotions in case of alpha bands and there was evident residual arousal after the music stimuli was removed. This also indicated the retention of memory corresponding to alpha band [20].

As brain is a nonlinear system, it can produce complex behaviours which cannot be analyzed effectively using linear methods. In order to analyze signals produced from nonlinear systems, nonlinear signal processing algorithms can be used in time, frequency or spatio-temporal domains. Therefore, based on the literature, it would be interesting to analyze the effects of music on the brain using advanced nonlinear signal processing algorithms. The study of literature has shown that while many studies have been carried out to analyze the effects of music on brain and its responses, there are not many studies involving modern signal processing techniques. Moreover, the number of studies based on Indian classical music is significantly less and more so using modern signal processing techniques. This research aims to analyze the brain correlates of happy and sad musical emotions induced during listening to ragas of NICM by using a modern signal processing technique i.e. nonlinear processing of EEG signals.

## II. MATERIAL AND METHODS

The current study had two main objectives: The first objective was to compare the effects of listening to happy and sad excerpts of North Indian Classical Music (NICM) on same regions of the brain and the second one was to compare the effects of happy and sad musical conditions across right and left hemispheres of the brain. EEG was recorded from a group of subjects while listening to excerpts from NICM that were known to induce happy and sad emotions.

### A. Selection of Subjects

Twenty musically untrained subjects (10 Males, 10 Females) were recruited for the current study. The subjects were right handed with their average age being 29 years. No left handed subjects were recruited owing to their probable difference in hemispheric specialization for emotions [21].

### B. Stimuli and EEG Recording

The musical stimuli used in this study consisted of excerpts of six ragas based on North Indian Classical Music theory. These excerpts were classified as ragas capable of inducing happy and sad emotions in the person listening to them based on the classical music literature of NICM. Three ragas were known to induce happy emotions and three were known to induce sad emotions. All the raga excerpts were played on the Bansuri, a musical instrument, by the same artist in a slow pace without any percussion support. The tonic note for all the excerpts was same.

Continuous EEG signals were recorded from the participants using a 32 channel Neuroscan recording system at the Music Cognition Lab, National Institute of Mental Health and Neurosciences (NIMHANS), Bengaluru, India and were sampled at a rate of 1KHz. The electrodes were placed according to the international standard 10-20 electrode placement system [22]. The subjects were informed about the EEG recording procedure and were instructed to feel the emotion that each raga excerpt elicits in them. The participants were made to listen to raga elaboration phases of these six ragas for an average duration of 129±16 seconds. EEG was also recorded during eyes closed rest condition. Behavioral ratings from the participants were also recorded. Based on the results of the previous studies on music and emotions, the EEG signals recorded at the frontal and front-temporal regions were considered for analysis.

### C. Signal Processing

Initially the recorded EEG signals were analyzed for eye blink artifacts, eye movements and other motion artifacts using the Neuroscan software. The artifacts and noisy channels were removed using this software and the filtered signal was retained for further analysis. Application of signal processing algorithms to investigate neuronal correlates of various features of music like timbre, rhythm etc., have shown better results than the conventional spectral analysis and behavioural studies. Owing to the nonlinear dynamics of the brain, it was decided to apply a nonlinear signal processing technique to analyze the effects of listening to NICM on the brain.

### D. Representation of Recurrence Plots

The signals obtained from the nonlinear system are used to obtain the phase space trajectory. Any discrete signal can be mapped into a phase space using the following method. If we have a signal with 'N' terms, a vector $y_i$ of D dimensions and delay d can be calculated using (1).

$$\boldsymbol{y}_i = \begin{bmatrix} x_k \\ x_{k+d} \\ x_{k+2d} \\ \vdots \\ x_{k+(D-1)d} \end{bmatrix} \quad (1)$$

Where x is the discrete signal and $D \geq 1$, $d \geq 1$, $i$=1 to N, $k=i$ mod N - ($D$ - 1) $d$ [23]. The number of vectors is equal to the number of terms of the signal. A recurrence occurs when points $y_i$ and $y_j$ occur close to each other.

The recurrence plot, a graph representing the times at which a nonlinear system recurs to a former state, can be used to investigate the m-dimensional phase space trajectory through a two dimensional representation of its recurrences i.e. the phase space trajectory of the system visits approximately the same area in the phase space. It is the graph of a square matrix whose elements correspond to those times at which the state of a dynamical system recurs [24]. The values of the elements of the square matrix are either 0 or 1. It has also been shown that at specific conditions, the original signal can be reconstructed from the recurrence plot. The advantage of a recurrence plot is that it can detect hidden patterns and similarities in these patterns. Information about the underlying signal characteristics can be extracted through a recurrence plot.

Though recurrence plot is a graphical method of visualizing the patterns of the signal, the qualitative analysis alone is not sufficient to detect the small-scale patterns. To overcome this, Recurrence Quantification Analysis (RQA), a method that quantifies the number and duration of recurrences of a dynamical system was introduced [25]. The RQA technique has been used in this study to analyze the brain responses to NICM. Several parameters were extracted using the RQA technique in the current study which is discussed below.

Recurrence Rate: The recurrence rate is the density of recurrence points in a recurrence plot. It specifies the probability that a specific state recurs and is mathematically calculated by considering the ratio of the number of recurrence points to the total number of points in a recurrence plot.

Determinism: It is the percentage of recurrence points that form the diagonal line of minimal length in a recurrence plot. Determinism specifies the predictability of the dynamical system.

Laminarity: The amount of recurrence points which form the vertical lines in a recurrence plot is represented by Laminarity. The vertical lines represent the amount of laminar phases in the system.

Diagonal Line Length: The average diagonal line length in a recurrence plot is related to the predictability time of the dynamical system. The lengths of the diagonal lines correspond to the time duration during which the segments of phase spaces stay parallel to each other or the divergence behavior of the trajectories. Similarly, the trapping time measures the average length of the vertical lines and represents the laminarity time of the system i.e. the duration that a system can stay in a specific state.

Divergence: Mathematically, divergence is the reciprocal of the maximal length of the diagonal lines excluding the line of identity. It corresponds to the KS entropy of the dynamical system.

Entropy: The probability that a diagonal line has a specific length can be estimated by using the frequency distribution of the lengths of the diagonal line length. The measure of the complexity of the system can be determined by calculating the Shannon entropy of the probability.

All the parameters were determined by implementing the mathematical equation of those parameters using the Matlab software (Mathworks Inc.). The results obtained are discussed in the following section.

## III. RESULTS AND DISCUSSION

The primary agenda of the study was to know how the brain processes music internally. Recurrence Quantification Analysis (RQA) techniques were applied on the EEG signals acquired to determine the effects of listening to North Indian Classical Music on brain activity. Emotional processing in the brain has been observed to be carried out in the frontal regions of the brain. Specifically, positive emotions are processed in the left frontal region and negative emotions are processed in the right frontal regions of the brain. Also, previous studies have suggested that the left fronto-temporal cortex is involved in processing the emotions elicited by music known to produce positive effects. Due to these reasons, EEG signals from the frontal and fronto-temporal regions were considered for analyzing the effects of NICM. Recurrence plots and different RQA parameters such as the recurrence rate, divergence, entropy, laminarity and determinism were extracted from the signals. The parameters were compared for happy and sad musical stimuli. The results showed significant differences in the recurrence plots and parameters extracted from the right and left frontal regions of the brain while listening to happy and sad musical excerpts of NICM.

Fig 1.a and 1.b show the variations in the recurrence plots of EEG signals acquired at the left and right frontal regions for both happy and sad musical conditions. Since, by mere visualization of recurrence plots, it is not possible to conclude about the variations during different conditions, we have adopted the recurrence quantification analysis measures to quantify the recurrence plot and extract relevant parameters from them.

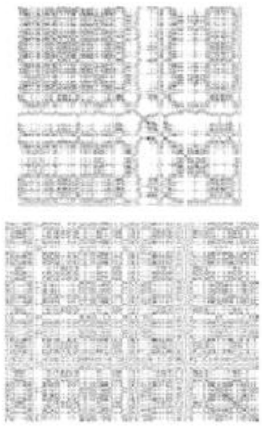

**Fig 1.a: Recurrence plots of happy and sad music conditions at the left frontal region**

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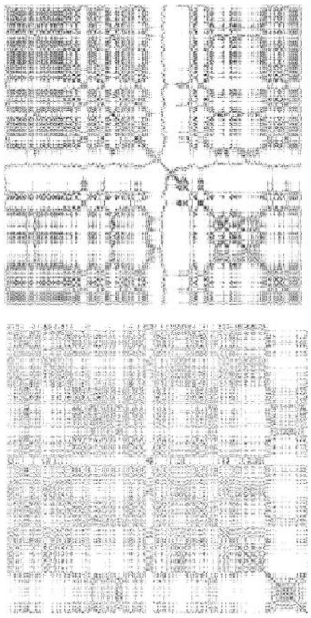

**Fig 1.b: Recurrence plots of happy and sad music conditions at the right frontal region**

Specifically, the results show a significant increase in the average divergence in both left fronto-temporal and left frontal regions for music stimulus that induces happy emotions. During sad musical conditions, there was a prominent decrease in the average divergence at the right frontal and fronto-temporal regions as seen in Fig 2.a and 2.b.

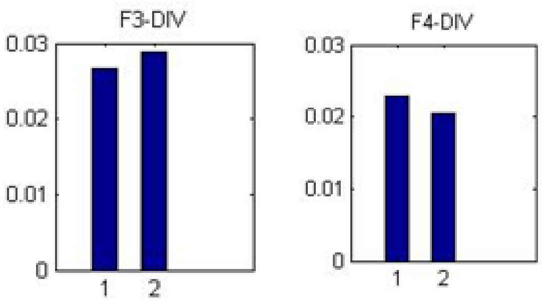


**Fig 2.a: Average divergence in the left and right frontal regions. 1 - Happy, 2 - Sad music**

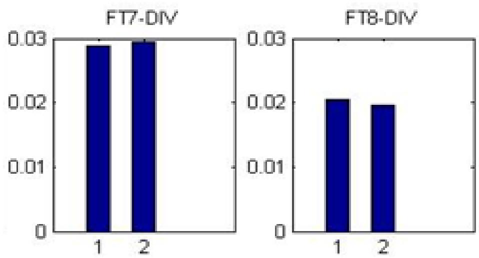


**Fig 2.b: Average divergence in the left and right fronto-temporal regions. 1 ; Happy, 2 - Sad music**

Also, during sad musical stimuli, there was a significant decrease in average divergence and a similar increase in average entropy in the right hemisphere when compared to the left hemisphere as seen in Fig 3 and Fig 4.

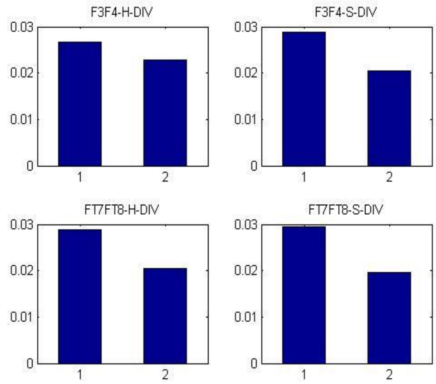


**Fig 3: Hemispherical differences: Average Divergence due to happy and sad music. 1 - Left, 2 - Right hemisphere**

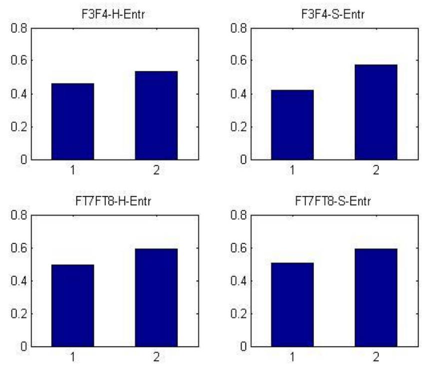


**Fig 4: Hemispherical differences: Average Entropy due to happy and sad music. 1 - Left, 2 - Right hemisphere**

The changes in average divergence in the left frontal and fronto-temporal regions endorse the fact that the emotions elicited by happy musical conditions are processed in the left frontal and fronto-temporal regions of the brain. Also, the significant changes in divergence and entropy in the right hemisphere indicate active emotional processing in those regions of the brain.

## IV. CONCLUSION

Music, from ancient times, is known to modify the emotions produced in the listener's brain. It is also known to alter the behaviour of the listener based on the type of music being listened. This basis has led many neuroscientists to study the effects of music on the listener's brain and understand the variations in emotional experience induced through music. Even though many studies have been carried out to analyze the effects of music on brain and its behaviour using frequency domain analysis methods, the number of studies using signal processing techniques, more so with Indian Classical Music as a stimulus is significantly less. Thus, this paper is concerned with determining the brain correlates of listening to happy and sad music, particularly listening to the ragas of Indian classical music. Nonlinear signal processing technique has been used instead of the conventional linear techniques. We expect nonlinear processing of EEG to be more appropriate since brain is inherently a nonlinear biological system.

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The results clearly indicate that the emotions induced by happy and sad music stimuli are processed differently by the brain in different regions. The left frontal region is found to be active in processing happy emotions and right frontal region is active for sad conditions. The results also show that the frontal regions are active in overall emotional processing as compared to other regions of the brain. Therefore, in future, it may be useful to extend the study for analyzing the effects of NICM on brain networks to determine connectivity as music processing involves coordination between different regions of the brain. Further, it would also be advantageous to explore the possibilities of using the results obtained for treating psychological disorders.

## CONFLICT OF INTEREST

None

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