Music Induced Brain Functional Connectivity using EEG Sensors: A Study on Indian Music

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Abstract—Music is promoted in all traditions for the well-being of the listener. The two-dimensional emotion models and their effects on the brain were analyzed while listening to selected raga and at Rest. The present study visualized the functional connectivity of emotional responses to Indian Dharmavathi raga thereby locating the similar regions across the electroencephalogram (EEG) sensor pairs. The international 10-20 sensor placement system was followed for recording EEG signals. The stimulus based functional associations were noted which help in investigating the neuronal synchronization.

The body and mind relaxes according to music, the hormone system reacts positively, and allows our brain to act effectively in no time [3]. Listening to music helps the neurons and synapses to be in active state [4]. Music listening activates various region of the brain area. The processing of music is closely associated with different cortices in brain such as the cerebral, auditory, motor and frontal [5]. The primary auditory cortex manipulates pitch, loudness and harmonic, melodic and rhythmic patterns which are processed by secondary cortex and tertiary auditory cortex. This harmonizes all these patterns into the level of music [6]. The sensorimotor cortex is also involved, where the left and right areas are engaged in the preparation, execution and termination of the musical array [5].

The functional connectivity provides the direct measure to understand how cognitive progressions are comprehended in the brain as this gives the strength and weakness of the connected regions [7, 8]. The time based temporal correlation across various activated brain regions while processing specific cognitive task is termed as Functional brain connectivity [9, 10, 11]. This will also help in studying the neurobiological disorders of the brain [12, 13].

The functional magnetic resonance imaging (fMRI) BOLD correlations give less information about the neuronal communication and directionality [13, 14]. As EEG has high temporal resolution, it is suitable for classifying the synchronization across different EEG bands in significant functional connections [15, 16]. The functional connectivity indicates the coupling across each EEG sensor locations in particular EEG bands. Thammasan [17] recognized music-induced emotion using electroencephalogram (EEG) as it gives a high sequential decision with low expenditure when compared with imaging studies.

Music has been known to alter or evoke emotions [18] and these emotions depend on the valence (pleasing / unpleasing), arousal (peaceful / agitated) and dominance (independent / dependant) of the played music. These observations were replicated in the physiological changes. Alluri [19] stated that an increased functional coupling was noted between the regions that process musical emotions. Musical training accelerates the reinforcement of functional connections [20].

Music has the potential to induce changes in the EEG which can possibly be related to the emotional responses generated. The frontal asymmetry indexes reflect the notable activity of the left frontal lobe, which is related to positive approach and elevated engagement [21], and the right lobe holds good for the withdrawal/ negative approach [22]. The pleasantness/unpleasantness was measured by calculating the theta band. The frontal midline (Fm) theta power increases when listened

Index Terms—Music, Dharmavathi raga, emotions, sensor placement, mood, electroencephalogram.

I. INTRODUCTION

India is a diverse country where music is an integral part of the communal and spiritual life. Indian classical music consists of various ragas. Bhatkhande [1] defines raga as melodic style and it is structured into a sequence of five to nine musical notes [2]. The selection of raga is based on individual’s choice that exaggerates their mood. Human physiological systems eventually reflect these modulations clearly.

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to pleasant music [23]. While most of the studies on Indian raga concentrated on cardiovascular parameters, the current work focuses on the effect of participants-preferred Indian raga, and its effect on brain activation using EEG. Moreover, extracting the EEG frequency bands and preserving the time localization becomes more crucial. Hence, the present work focuses on wavelet packet decomposition to evaluate the effect of Indian raga on various brain regions. The objective of this study is to visualize the functional connectivity at various EEG sensor locations for different EEG bands as this will facilitate the dissimilar regions across the sensor pairs. The study thereby enables to pin point the possible stimulus specific information processing in brain.

II. METHODS AND MATERIALS

A. Participant Details

Sixteen participants were recruited for the study based on their interest in listening to Indian musical raga. They do not have any formal musical training. The experimental protocol was followed by Mini Mental Test (MMT) [24]. The participants were checked whether they are mentally competent to sit for the experiment. The process of recording was performed only on those participants who scored 25 out of 30 as these scores were considered normal. All the participants were made to sit on a chair at a relaxed position in a soundproof room during the entire study. The experiment was conducted in congruence with the Institutional Ethics Committee for research. The participants furnished written informed consent prior to the experiment.

B. Musical Stimuli Selection

The participants selected the choice of musical stimuli based on their interests. Two sets of Indian musical stimuli (Nat Bhairav raga and Dharmavathi raga) were presented to the participants. The self-reported Positive and Negative Affect Schedule (PANAS) was used to evaluate mood of each participants before and after listening to the selected raga. The participants were asked to rate ragas using PANAS which consists of two 10-item scales to measure both positive and negative affect.

![Time-domain representation of the Dharmavathi raga and Time-frequency spectrum of the Dharmavathi raga.](image)

Fig. 1. Selected Dharmavathi raga: (a) Time-domain representation of the Dharmavathi raga and (b) Time-frequency spectrum of the Dharmavathi raga.

Valence (varies from pleasant to unpleasant) and arousal (varies from calm to excite) of the participants were quantified using Self-Assessment Manikin (SAM) scale. All of them listened to both the ragas. According to the participants’ rating, the Dharmavathi raga was perceived as high valence and low arousal (HVLA) whereas Nat Bhairav raga was rated as low valence high arousal (LVHA). Hence, only Dharmavathi raga was considered for EEG recording and analysis. The time-domain and frequency distribution of the selected Dharmavathi raga are shown in Fig. 1.

The Dharmavathi raga has maximum frequency distribution up to 7 kHz and identical frequency distribution in low frequency (0 to 2500 kHz). The EEG signals were recorded for 12 minutes, consisting of a baseline of 2 minutes, followed by the listening condition that lasted for 5 minutes and then a 5 minutes rest period.

C. Sensor Placement

The 10–20 standard EEG sensor placement configuration system (Fig. 2) was used to place the sensors on all the brain lobes (sixteen locations): central (C3 and C4); frontal (F3, F4, F7 and F8); front polar (Fp1 and Fp2); occipital (O1 and O2); parietal (P3 and P4) and temporal (T3, T4, T5 and T6). The left and right ear lobes (A1 + A2) were the reference and the ground sensor was placed on the forehead. The monopolar montage was selected. The impedance between the sensor and the scalp was kept below 5 kΩ. EEG machine with 32 channel (RMS, India) was utilized for recording EEG signals (Fig. 3). The sampling frequency was set to 256 Hz/channel. A low-pass filter and a high-pass filter having 0.1 to 50 Hz as cut-off frequencies were used to filter unprocessed EEG signals. Acquired EEG signals were stored in the computer, and an offline analysis was performed. The time base and sensitivity for the EEG recording device were set to 30 mm/s and 7.5 µV/mm respectively.

D. EEG Feature Extraction

The entire 5 minutes of data from each of the conditions (epoch) was analyzed. The acquired EEG signals were generally corrupted with muscle and eye movement artifacts [25, 26]. The slow sensor drift and eye movements were not recommended so that the delta band was not analyzed. The recorded EEG under three various circumstances (Baseline, listening to raga (Task) and silence (Rest)) were analyzed offline in Wavelet Analysis Tool Kit of LabVIEW®2017 where wavelet packet decomposition was performed on EEG signals.

Electroencephalographic signals are finite energy time-domain signals that are decomposed and expressed in Equation (1).

$$ψ_{jk}(t) = 2^{j/2}ψ(2^{j}t - k), \ j, k \in \mathbb{Z} \quad (1)$$

Where, $\psi(t)$ is the mother wavelet and $\phi(t)$ is the scaling function. The mathematical expression of a signal $S(t)$ in terms of the wavelets ($\psi$) at level $j$ is given in Equation (2) [27].

$$S(t) = \sum_{k} s_{j}(k) \phi_{jk}(t) + \sum_{k} d_{j}(k)ψ_{jk}(t) \quad (2)$$

Where, $s(k)$ corresponds to approximate coefficient, $d(k)$ relates to detailed coefficients at level $j$ and $S$ is the summation of extracting signal for a particular EEG frequency band in each sensor location. Initially, the original signal $S(t)$ is...
filtered by a high pass and a low pass filters. The approximate signal is represented by the low frequency components while the residuals among real and proximate signal are represented by the high frequency components.

The EEG signals recorded under various conditions were decomposed into different frequency EEG bands (alpha, beta and theta) using consecutive half band digital low pass and high pass filter banks (wavelet packet decomposition) [28]. The frequency decomposition at each stage obtained from filter banks is depicted in Fig. 4. The recurrent pattern and the dominant frequency components of the signal decide the selection of optimal mother wavelet and number of decomposition levels. The Daubechies family of wavelets is shown as optimal candidate for signal characterization and there is also a local similarity between the signal obtained and the mother wavelet. By repeated iteration, it was found that orthogonal Daubechies (db4) wavelet was chosen for optimal time-frequency localization. The bandwidth of the EEG signal was set from 4 to 32 Hz, and the band energy ($E$) represents the extracted wavelet packet coefficients. The relative energy $P_j$, which was normalized energy density derived from a set of wavelet packet coefficients at resolution level $j$, provides exhibiting power in corresponding EEG frequency band. The energy calculation using wavelet transform provides more high frequency resolution and less spectral leakage compared to conventional power estimation using Fourier transform [29] and it is well suited for analysis of non-stationary signals like EEG. Hence, the relative wavelet band energy was calculated at all sensor locations that were designated, for all three conditions.

The energy $E_j$ at a particular level of decomposition $j$ that belongs to any of the band can be represented in Equation (3).

$$E_j = \sum_{k=1}^{L} [C_j(k)]^2$$  \hspace{1cm} (3)

Where, $C_j(k)$ represents the wavelet coefficient and $L$ denotes the total number of wavelet coefficients. Thus the relative energy $P_j$ of a particular band represented by $j^{th}$ level of decomposition is specified in Equation (4) [22].

$$P_j = \frac{E_j}{\sum_j E_j}$$  \hspace{1cm} (4)

The distribution of calculated relative alpha, beta and theta band energies of EEG signals recorded at sixteen locations under three conditions was found not normal. Hence, the Friedman test was selected as a substitute for ANOVA test with repeated measures to obtain the overall differences among measured parameters. The significant value was set at $p=0.05$. The Wilcoxon signed-rank test was applied for Post-hoc analysis on three conditions where $p$ is chosen as 0.017.

The participant’s choice of selected raga for listening and silence (Rest) were treated as independent variables. The relative alpha, beta and theta band energies along with the subjective ratings of SAM Scale and PANAS were considered as dependent variables. Apart from that, the correlation among sensor locations, different conditions, different EEG bands were measured using Spearman correlation coefficient. The

Fig. 2. The international 10-20 EEG sensor placement system (C = central, P = parietal, F = frontal, Fp = frontal polar, T = temporal, O = occipital, A1, A2 = references).

Fig. 3. Recording of EEG signals and experiment set up.

Fig. 4. shows the wavelet packet decomposition stages for each EEG frequency band.

E. Statistical Analysis

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This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2873402, IEEE Sensors Journal

statistical study was accomplished in IBM SPSS® software platform.

III. RESULT

The authors observed statistically significant differences in relative band energies among three conditions (Baseline, Task and Rest), $\chi^2(383) = 1290.138$, $p=0.0001$.

A. Behavioral Data

Based on SAM scale rating, the participants perceived Dharmavathi raga as high valence and low arousal. At the same time, they rated Nat Bhairav raga as low valence and high arousal (Fig. 5). Significant differences ($p=0.004$) were found between two ragas in terms of valence and arousal.

The positive affective scoring results revealed an alteration in mood before and after listening to both ragas. The positive affective scores were increased significantly ($p=0.003$) after listening to Dharmavathi raga while the scores were decreased after listening to Nat Bhairav raga (Fig. 6a).

The negative affective scoring results revealed an alteration in mood before and after listening to both ragas. While the negative affective scores were decreased significantly ($p=0.004$) after listening to Dharmavathi raga; on the other hand, no significant changes were noted for Nat Bhairav raga (Fig. 6b). The behavioral data showed that Dharmavathi raga stimulated mood changes and it was rated as high valence and low arousal. Hence, the Dharmavathi raga has been selected for the present study.

B. Brain Activation Task (Listening to Dharmavathi raga)

The relative energies at alpha band were considerably low ($p=0.005$) at F3 and F7 (left frontal) sensor locations during Task as compared to Rest whereas the relative energies were appreciably high at right frontal sensor locations (F4 and F8) during Task when compared to Rest (Fig. 7).

C. Frontal Asymmetry Index Score

Affective stimulus along with emotion was quantified by frontal asymmetry index: logarithm value of the ratio of alpha band energy at right frontal location to the alpha band energy at left frontal location [30]. There was significantly high ($Z=-2.801b$, $p=0.005$) frontal asymmetry index observed at frontal lobe while listening to Dharmavathi raga (Task) compared to silence (Rest). The elevated frontal asymmetry index shows positive approach [22, 30] which is associated with positive emotion.

D. Relative Theta Band Energy

Significantly high relative theta band energy were found at frontal sensor locations (F3($p=0.002$), F4($p=0.002$), F7($p=0.005$) and F8($p=0.002$)) during Task as compared to Rest (Fig. 8). This was not observed at other sensor locations.
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E. Brain Connectivity Analysis

In graph theory, any network consists of nodes that are interrelated with edges. In the present study, the nodes denote cortical region (EEG sensor locations) and the edges signify the functional interaction between the nodes [31]. The Spearman correlation coefficient calculated across all sensor locations at different EEG bands were considered as edges for those nodes.

A 14x14 Spearman correlation coefficient matrix was obtained for conditions (Task and Rest) at different EEG bands. The computed Spearman correlation coefficient varies between -1 and 1, where -1 indicates negative association and +1 represents positive correlation. Dissimilarity score index confines the correlation coefficient scores between 0 and 1. This represents the functional connectivity maps of relative band energies of alpha, beta and theta.

Dissimilar score index \( D \) is given by the Equation (5),

\[
D = 1 - \frac{r_s}{2}
\]

Where, \( r_s \) is the Spearman correlation coefficient. This similarity represents the strength of association between two sensor locations. By calculating the similarity score index, the sensor pairs that are synchronized during Task (listening to raga) and Rest (silence) can be obtained. From the dissimilarity score, the similarity index was obtained.

Similar score index \( S \) is given by the Equation (6),

\[
S = 1 - D
\]

The similarity score of 1 represents high association/positive correlation (similar regions) and 0 indicates low association/negative correlation (dissimilar regions) [32]. These generated functional connectivity maps were visualized using BrainNet Viewer of MATLAB®.

F. Beta Similar Index

Figure 9 shows the brain functional connectivity at beta band during Task and Rest. The relative energy of beta band at the right front planar sensor location FP2 was highly associated \((p<0.05)\) with parietal (P3-P4) and occipital (O1, O2) lobe sensor locations during Task (listening to raga). A higher interdependency was noted at left frontal location (F7) was highly correlated \((p<0.05)\) with temporal locations (T3, T4). The similarity was observed between the right temporal location T6 \((p<0.05)\) and left occipital location (O1) and left parietal location (P3) whereas left temporal sensor location T5 \((p<0.05)\) was same as right occipital location (O2). The right frontal location (F4) was highly correlated with FP2 and the left and right parietal sensor pairs (P3-P4) during Rest (silence). This was not noted during Task. In addition, Fp1 \((p<0.05)\) was highly associated with Fp2, P3 and P4. The F3 \((p<0.05)\) had interdependency with F4, Fp1-Fp2 and P3-P4.

G. Alpha Similar Index

The brain functional connectivity at alpha band during Task and Rest is shown in Fig. 10. The relative energies of alpha band at the left frontal sensor pairs (F7-F3) were highly associated and the right frontal sensor pairs (F8-F4) were highly correlated whereas F7-F8 and F3-F4 were highly dissimilar \((p<0.05)\) during Task. The right front planar location Fp2 was highly correlated with Fp1, T6-T5-T3-F8. The location F7 \((p<0.05)\) was highly dissimilar with F8, T3, T4, T5 and Fp1. The pair locations F7-F8 and F3-F4 were
similar during Rest. The location F3 was also correlated with Fp2 and P3. The location F7 was identical with T3 and T4. The left temporal location T3 was highly associated with T5 and F8. And FP1 was correlated with P3 and O1.

![Fig. 10. Brain functional connectivity at alpha band: (a) Task (listening to raga) and (b) Rest (silence).](image)

H. Theta Similar Index

During Task, the relative energies at theta band were highly interdependent ($p<0.05$) with frontal sensor locations (F3, F4, F7 and F8), which was not noted during Rest (Fig. 11). The left frontal sensor location (F3) exhibited higher interdependency ($p<0.05$) with FP1, P3 and O1 whereas F7 was correlated only with F4. Likewise, the right frontal location (F8) was similar with F3 and F4. High level of dissimilarity was noticed between the temporal (T4, T5 and T6) and frontal (F3, F4, F7 and F8) locations. The locations F7 and T6 were highly correlated ($p<0.05$) at Rest. The location F3 was identical with T3, FP1, P3 and P4. The left temporal location T3 was correlated with T5, T6, FP1, P3, P4 and O2 during Rest. Also FP1 was highly related ($p<0.05$) with P3, P4 and O2. The occipital sensor location O2 shared similarity with the parietal locations (P3 and P4).

![Fig. 11. Brain functional connectivity at theta band: (a) Task (listening to raga) and (b) Rest (silence).](image)

IV. DISCUSSION

Music varies across culture and expresses emotion. Bennet and Bennet [4] suggested that the Indian music has unique characteristics of performing raga melodies at particular times of the day and night and it seems to be more melodious only in this period. Some ragas will appeal only during early morning; others during evening, and some at midnight hour. Human beings react to each raga or ragini with a particular aura. The present work allows recruited participants to decide their choice of musical raga stimuli based on their liking. The emotion induced by positive valence raga with varying arousal level was considered in this study. The participants were presented with Nat Bhairav and Dharmavathi ragas (Indian musical stimuli) and their perception of valence and arousal was rated using SAM scale. The mood of the listeners can have an impact on evoked emotion. Positive and negative affect schedule was used to measure the participant’s mood before and after listening to the selected raga. All the participants perceived Dharmavathi raga as high valence and low arousal, and hence, Dharmavathi raga was selected for the experiment.

Thammasan et al. [17] reported that the valence-arousal emotion model is a highly consistent model in assessing music induced emotion and it’s calculated in two-dimensional anatomical space [17, 33, and 34]. Based on their observation,
the current study focused on two-dimensional emotion models for the participant favored musical raga stimuli. The induced emotion was measured using Electroencephalograph (EEG) and visualize the functional connectivity across the sensor locations when listen in to the selected stimuli and rest.

Blood and Zatore [35] addressed intense emotional response to the participants selected music in their research. The brain activity changes when listening to most preferred music as it induces strong emotional experiences [36, 37]. Participants’ preferred familiar musical stimuli made profound emotional experiences than unfamiliar ones [38]. Music fulfillment is extremely biased and it varies across culture [39]. The existing studies focus on the consequences of Indian raga on Indian participants. The human body reacts to each raga in carnatic music; if it is listened during particular period of day on a specific scale as the outcome of the effect would be more fruitful. Based on this fact, the current study focused on Dharmavathi raga which was played using violin and other instruments. Dharmavathi raga can be played at any time [40] so keeping this in mind the entire experiment was conducted in the morning. The results for SAM Scale revealed that the participants who preferred listening to Dharmavathi raga alone rated it as pleasant, low arousal (high valence and low arousal) when compared with Rest and Baseline. This clearly indicates the selected musical stimuli (Dharmavathi raga) induced positive emotion. There were no changes in parietal, central and occipital sensor locations for the participant favored musical raga was evaluated using EEG technique.

Sackeim et al. [41] established the result that induced emotions changes the asymmetric frontal activity in alpha band. In this EEG study, the results supported the findings of Tsang et al. [42] and Schmidt and Trainor [43]. Listening to Dharmavathi raga produced an asymmetric decrease in alpha component energy in F3 relative to F4 and F7 comparative to F8. In addition, the alpha frequency power at F4 and F8 were significantly higher only while listening to the selected raga when compared with the Rest and Baseline. This clearly indicates the selected musical stimuli (Dharmavathi raga) induced positive emotion. There were no changes in parietal, central and occipital sensor locations for the participant favored musical raga was evaluated using EEG technique.

Earlier studies have also shown that the frontal midline (Fm) theta power enhances by listening to pleasant music [44, 23]. The relative theta band energies were appreciably elevated at all the frontal sensor locations during Task (listening to the Dharmavathi raga) as compared to Rest. No significant changes were observed in parietal, central and occipital sensor locations. The increases in theta band energy reveals that listening to Dharmavathi raga gives pleasant mood, which was corroborated by Sammler et al. [23]. The relative energy of alpha band was high at all right frontal sensor locations (F4 and F8) during Task.

The functional connectivity analysis gave the insight music processing in the brain. The alpha similar index scores, the left frontal sensor pairs F7-F3 was highly associated and this was also noted between right frontal sensor pairs F8-F4 while listening to music. However, during Rest, the alpha similarity scores were similar at F7-F8 and F3-F4. But this was not eminent as listening to music. The other sensor locations were moderately correlated (synchronized) during Rest, which indicates the pleasant effect of the music continued during Rest. This result further supports that the reduced alpha energy reveals excitement in activity with augmented commitment (approach/ positive) and the reverse holds (increased alpha energy) for the decreased commitment (withdrawal/ negative) [22]. High functional connectivity at theta band energy was highly interdependent with frontal sensor locations during Task but not observed during Rest. High level of dissimilarity was noticed between the temporal sensor locations (T4 (<0.05), T5 and T6) and frontal sensor locations during Task. This further emphasis frontal midline theta increase as proposed by Sammler et al. [23]. An elevated functional association at sensor pairs, the right front planar sensor FP2 is highly associated (p<0.05) with parietal (P3-P4) and occipital (O1 and O2) lobe sensor locations at relative beta band energy during Task. However, during Rest, F4 is highly correlated with FP2 whereas; the left and right parietal sensors P3-P4 were not correlated. The activation of arousal component of emotion was reflected in beta band, as the participants rated the music played as low arousal; this was reflected with less activation (correlated) in beta band across the sensor locations.

There is an asymmetric decrease in F3 and F7 (left frontal locations when compared to F4 and F8 (right frontal locations). Along with the frontal midline (Fm), theta band energy was found to be increased only at frontal sensor locations, which specifies the interested raga was pleasant and induced positive emotions which match the participants’ perceived emotion. Even though, raga played was perceived as low arousal, no significant changes were observed in beta band energy.

V. CONCLUSION

Participants’ who preferred listening Indian raga were selected; the perceived emotion and mood were calculated using SAM Scale and PANAS. The participants perceived the music listened to, with high valence and low arousal and the positive affective scores increased after listening. The induced emotion was measured using EEG. In the right frontal lobe sensors, activation at alpha band was high when compared with left frontal sensor locations. The frontal sensor pairs F7-F8 and F3-F4 are highly dissimilar while listening to music but they are similar during rest (silence). This suggests that the selected Dharmavathi raga listened to, induced positive emotion. An increase in the frontal theta revealed that the played music was pleasant and no changes in beta component energy although it was perceived as low arousal. The relative beta component was highly correlated with F4, FP2, P3-P4 during Rest, this was not noted while listening to music. Listening to Dharmavathi raga increased the positive affective scores and induced positive emotion along with mood changes after listening. Therefore, this raga was recognized which induces happiness and safeguard against depression. In order to support this further the sample size should be increased and a neutral stimulus such as noise should be used to re-emphasize the statement.

VI. ACKNOWLEDGEMENTS

Authors thank all participants for their voluntary involvement in this study.
VII. CONFLICTS OF INTEREST

No conflicting interests in this study

VIII. FUNDING AND GRANT-AWARDING BODIES:

Not applicable

REFERENCES


This article has been accepted for publication in a future issue of this journal, but has not been fully edited. Content may change prior to final publication. Citation information: DOI 10.1109/JSEN.2018.2873402, IEEE Sensors Journal

IEEE Sensors Journal


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