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Abstract

The concept of creativity and perception of a raga is revisited in this work from the end economic a professional Hindustani musician. EEG was done to record the rescue where a integring a professional Hindustani musician. EEG was done to record the rescue where a integring a line of the magery of a raga is revisited in this work from the end to reate the magery of a raga is revisited in this work from the end to reate the magery of a raga is revisited in this work from the end to reate the magery of a raga is revisited in this work from the end to reate the magery of a raga is revisited in this work from the end to reate the magery of a raga is revisited in the second where a line of the end to reate the magery of a raga is revisited in the second where a line of the end to reate the magery of a raga is revisited in the second where a line of the end to reate the magery of a raga is revisited in the second where a line of the end to reate the magery of a raga is revisited in the second where a line of the rest were the magery of a raga is revisited in the second where a line of the rage where a line of the rage of the brain during these two experimental conditions using a position of order (PFC) in case of the brain during these two experimental conditions using a position of order (PFC) in case of the rage of the brain during these two experimental conditions using a position of order (PFC) in case of the rage of the brain during these two experimental conditions using a position of the professions [10] reveal called multifractal detrended cross-correlation analysis (MFDXA). With this method, we have seen that poting during imagination and perception the degree of cross-correlation is very high in the occipital lobe, purported y due to the revision of the rage of the rage of the profession is dependent of the rage of the profession of the profession of the rage of the profession of the profession of the profession of the profession of the profesion of the profession of the profession of the profession of the visualization of the raga by the musicians. In other electrodes also, inter/intra-lobe cross correlations have been found

of-the-art techniques to assess brain response. e e ect of mentally composing a musical piece was studied in this work with the help of a Hindustani classical raga. e performers of Hindustani raga music insist that while performing or composing a musical piece, they have a visual imagery of that particular composition in their mind which helps them to improvise and reach to the audience better. We strive to quantitatively assess the proposition and several other unanswered questions in regard to musical imagination and perception by using latest state-of-the-art techniques to assess brain response.

Creative thinking has been one of the predominant issues of neuroscience that provided contradictory results in the past. Most of these works make use of coherence properties between the lobes using linear power spectral analysis in various frequency ranges to assess the amount of interdependence.

Coherence, a parameter obtained from spectral analysis of the EEG, is the normalized cross-spectrum of two signals and re ects the correlation between them with respect to frequency. Applied to EEG analysis, the value of coherence lies in its providing data on the relationships between the electric oscillations recorded from two locations on the skull [1]. Musical training can have strong e ects on the structural and cognitive development of brain [2-6]. No previous study, to our knowledge has studied the non-linear aspects of EEG to study creative musical imagery on trained musicians with Hindustani raga music.

Musical improvisation by far the most challenging task that an artist has to undertake, requiring the real-time generation and production of

novel melodic and rhythmic sequences in line with an ongoing musical performance, us, understanding musical improvisation is crucial to understand how in general creative processes are conducted in human being. A recent neuro-imaging study [7] reports increased surface area for subjects reporting high levels of musical creativity which suggests that

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while performing expresses the raga according to his mood. us there are di erences from one rendition to another. Even if an artist sings or play same Ragand same Bandishwice then there is supposed to be some dissimilarity in between the two performances. ese di erences in the rendition of a raga several times on di erent days are generally called improvisation. Unlike symphony or a concerto, Raga is unpredictable; it is eternally blooming, blossoming out into new and vivid forms during each and every performance which is the essence of "improvisation" [14]. e performers of Hindustani raga music insist that while performing or composing a musical piece, they have a visual imagery of that particular composition in their mind which helps them to improvise and reach to the audience better. e literature regarding perception and imagination of a musical stimuli involving Hindustani raga music is quite scarce, though it is quite rich and diverse when it comes to the variety of emotions induced by it [15-18]. Simply put, a raga

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considered. A sound system (Logitech R Z-4 speakers) with high S/N e gth order detrended covariance Fq(s) is obtained a er ratio was used in the measurement room for giving music input to theveraging over 2Ns bins.

> $F_{q}(s) = \{1/2N_{s} / \frac{2NS}{v-v-1} [F(s,v)]^{p/2}\}^{1/q}$ (4)

> > $F_{a}(s) \sim s^{(q)}$.

Experimental protocol

subjects.

where q is an index which can take all possible values except zero e subject was prepared with an EEG recording cap with 19because in that case the factor 1/q blows up. e procedure can be electrodes (Figure 1) (Ag/AgCI sintered ring electrodes) placed in the peated by varying the value of s. Fq(s) increases with increase in value international 10/20 system. Impedances were checked below 5 kOhrafs. If the series is long range power correlated, then Fq(s) will show e EEG recording system (Recorders and Medicare Systems) wasower law behavior

operated at 256 sample/s recording on customized so ware of RMS.

e data was band-pass- Itered between 0 and 50 Hz to remove DC Zhou found that for two time series constructed by binomial dri s. Each subject was seated comfortably in a relaxed condition in a measure from p-model, there exists the following relationship [22]: chair in a shielded measurement cabin. ey were also asked to close $(q = 2) [h_x (q = 2) + h(q = 2)]/2.$ (5)

their eyes. A er initialization, a 20 min recording period was started, and the following protocol was followed:

- 1. 2 min 30 seconds "Before imagination"
- 2. 2 min 30 seconds "While imagination raga Jay Jayanti
- 3. 2 min 30 seconds "A er imagination"
- 4. 5 min resting period
- 5. 2 min 30 seconds "Before Listening"
- 6. 2 min 30 seconds "With listening raga Jay Jayanti"
- 7. 2 min 30 seconds "A er listening".

We divided each of the experimental conditions in three windows of 45 seconds each and calculated the cross-correlation coe cient for where each window.

Method of Analysis

Multifractal detrended cross correla

We have performed a cross-corre between two non-linear signals originating from di erent lobes of the (q) derived from x = 2 - 2 (q = 2) [28]. For uncorrelated data, has hore correlated is the data. brain fo

$$x_{avg} = 1/N / \sum_{i=1}^{N} x(i) \text{ and } y_{avg} = 1/N / \sum_{i=1}^{N} y(i)$$
 (1)

s mentallv same raga y(i) as

X (i)
$$\{ \begin{bmatrix} j & i \\ k & 1 \end{bmatrix} x(k) - x_{avg} \}$$
 for i = 1 . . . N (2)

Y (i)
$$\{ \begin{bmatrix} j & i \\ k & 1 \end{bmatrix} x(k) - x_{avg} \}$$
 for i = 1 . . . N (3)

and $\ensuremath{_{\rm x}}$ are the auto-correlation and cross-correlation e

power-law cross correlation with a speci c exponent [29]. According to auto-correlation function given by:
C () =
$$x[x(i +) xxc][x(i) xc] c \sim$$
 (6)

ARFIMA processes, each of both is autocorrelated, but there is no

Podobnik and Stanley have studied this relation when q = 2 for

In case of two time series generated by using two uncoupled

monofractal autoregressive fractional moving average (ARFIMA)

$$C_{x}() = \mathscr{X}[x(i +) \quad \mathscr{X}x c][y(i) \quad \mathscr{X}y c]_{x} c \sim$$
(7)

xponents, respectively. Due to the non-stationarities and trends uperimposed on the collected data direct calculation of these xponents are usually not recommended rather the reliable method calculate auto-correlation exponent is the DFA method, namely
$$2 - 2h$$
 (q = 2) [29]. Recently, Podobnik et al., have demonstrated the

to calculate auto-correlation exponent is the DFA method, namely
=
$$2 - 2h$$
 (q = 2) [29]. Recently, Podobnik et al., have demonstrated the
elation analysis of correlation between cross-correlation exponent and scaling exponent

signals and EEG time series [28].

bllowing the prescription of Zhou [7]. a value 1 and the lower the value of and
$$\frac{1}{N} x(i)$$
 and $x = 1$ and the lower the value of and $\frac{1}{N} x(i)$ and $\frac{1}{N} x(i)$ a value 1 and the lower the value of and $\frac{1}{N} x(i)$

$$x_{avg} = 1/N / i_{i-1}^{N} x(i)$$
 and $y_{avg} = 1/N / i_{i-1}^{N} y(i)$ (1) In other words, we want to have a quantitative estimate of how the di erent lobes of the brain are correlated when a performer is mentally creating the imagery as well as during the perception of the same raga

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both during imagination and perception of the musical piece indicates the creation of a visual imagery of that particular musical piece in the performer's brain. at the two occipital electrodes are strongly correlated during the listening part also is an important revelation of this study, and strengthens the claim of creation of visual imagery of a particularraga by the musicians. e strong cross-correlation between the frontal and fronto-temporal electrodes might be evidences of involvement of higher order cognitive thinking and auditory skills involved in the processing of musical stimuli. Interestingly, the crosscorrelation between the electrodes decreases to a great extent a er the removal of stimuli, pointing to enhancement of neural activity during creative imagery of a musical composition. Also, the combination of electrodes for which rise is signi cant, the fall a er removal of stimuli is also signi cant, indicating that in the absence of any creative task diminishes the cross correlation between di erent lobes of the brain. Some of the features of this interdependence between inter as well intra lobes of brain during mentally creating as well as perceiving a musical composition, obtained from the degree of cross correlation are revealed for the rst time from our new data. us, with this we have tried to obtain a quantitative de nition of creativity, which till now was considered more of a philosophical term rather than a scienti c one. e increase or decrease of the degree of cross-correlation between the di erent lobes of brain during a variety of cognitive tasks can now be related to creativity involved in each of the tasks. e obtained data thus, may be of immense importance when it comes to studying the neurocognitive basis of creativity and alertness to a certain cognitive function. An extension of this work is being carried out in our laboratory, where artistes of the same and di erent gharaoáslindustani classical music are being taken and the neural responses corresponding to the musical creativity and improvisation are being studied to get a robust knowledge about the general paradigm of musical improvisation.

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