Short communication

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Statistical musicology with therapeutic applications

Abstract

Scientists through their studies have revealed the healing powers of music in controlling blood pressure, negative emotions and stress. Statistics and probability have been used to analyze music successfully both in western and non-western (including Indian) music. This short communication gives what we are planning to do in our ongoing project titled Hindustani Raga Analysis Using Statistical Musicology with therapeutic applications for stress management sponsored by IDEA: Technology Innovation Hub@Indian Statistical Institute, Kolkata. The work done so far in the past few months is briefed.

Keywords: statistical musicology, Hindustani music, raga, music therapy, perceived stress scale

Volume 8 Issue 2 - 2023

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Received: February 23, 2023 | **Published:** April 12, 2023

Abbreviations: PSS, perceived stress scale; EEG, electroencephalogram

Introduction

The aim of the project is to study the great Indian raga tradition, especially Hindustani ragas, using statistical musicology. Several areas of statistics including time series modeling, applied probability and statistical inference will be used in the study. There is no unique way of analyzing a music performance and hence statistics and probability have a big role to play. In fact, a melodic analysis of a one-page composition can easily imply billions of comparisons of motivic units. *This suggests a future musicology that might move in the direction of* ***big data science*** *when it comes to understanding major works in music, be it in the Western classical score-driven tradition, in the Indian raga tradition, or in free improvisation.* Music softwares have been developed to calculate quantitative results that reflect the theoretical models of computational/statistical musicology. In the present study, only Hindustani raga structure and performances will be covered. *It is proposed to build a music transcriber which, apart from helping the learner and the analyst of Hindustani classical music, will also be useful in therapeutic applications especially in stress management.* Music helps to combat negative emotions, enhances creativity and has been found to give positive results in stroke patients and patients with other neurological disorder by improving the supply of oxygen and blood to the brain. Music therapy has the power to stimulate brain functions involved in emotion, cognition, speech and sensory perception. We also intend to build a music therapy app as a part of this project. The work done so far has been briefed in the subsequent sections.

Statistics and probability have been used to analyze music successfully both in western and non-western (including Indian) music. For details refer to the books by Beran,[1] Chakraborty et al.,[2] Temperley.[3] For the processing of music in the brain, the books by Thaut[4] and Patel[5] may be consulted.

Indian classical music has two forms: Hindustani or North Indian classical music and Carnatic or South Indian classical music. In both the forms, the nucleus is the raga which is a melodic structure with fixed notes and a set of rules that characterizes a particular mood conveyed by performance see Chakraborty et al.,[2] Raga and probability have a direct link because a raga note can be *vadi* (most important), *samvadi* (second most important), *anuvadi* (important but not *vadi* or *samvadi*, *alpvadi* (unimportant but permissible in the raga) or *vivadi* (not permissible in the raga) and the probability varies accordingly being high for the first three categories, low for the fourth one and zero for the fifth category. It is important to assess this probability both unconditionally and conditionally. The unconditional probability of a note is the ratio of how many times that particular note appears to the total number of notes in the musical piece. As music always has patterns, the notes are dependent. The probability of the next note say Y depends heavily on the current note say X (technically, this means a Markov chain of first order) and this probability is obtained by keeping in the denominator the number of times X appears in the musical piece and the number of times X is followed by Y is kept in the numerator. However if the last note is X, then we need to subtract one from the denominator as we do not have information of the note transition for the last note!

It should be carefully remembered that probability theory does not directly influence the decision process of the artist as music is always planned and hence deterministic and not random. But we are analyzing it from an analyst's point of view or a listener's point of view from which the deterministic response may be realized as the outcome of a stochastic process. It should also be remembered that musical data reflects a time series as the pitches of the notes can be listed in chronological order. The progression of the notes can be successfully captured by a suitable time series model. For simulating raga notes, Markov chain Monte Carlo method is recommended as we need to use Monte Carlo method to simulate the raga notes exploiting the transition probability matrix of a Markov chain to simulate the dependent notes. Had the notes being independent (Markov chain of order zero), ordinary Monte Carlo would suffice but in that case we would not generate music (imagine pressing the piano keys randomly)!

Material and methods

In addition to the probabilistic analysis and time series modeling of the notes, as discussed in the previous section, several other statistical features would be studied for the musical performance recordings. These include note duration (to capture restfulness or restlessness in the note rendition) , inter onset interval (arrival time differences for successive notes, notes in rhythm will have equal peaks in the IOI graph). Rate of change of pitch (to depict pitch velocity) and pitch movement between the notes where the musical emotions are embedded. These pitch movements can be rising *(arohi),* falling *(awarohi),* no transition implying stay of the note *(sthayi)* and a mixture of upward and downward movement *(sanchari).* We also record the hats (a hat is interpreted as a rise followed by immediate fall) and valleys (a valley is interpreted as a fall followed by immediate rise). Further the rising and falling transitions can be further grouped

into convex, concave or linear while the hats and valleys may be grouped into shallow, moderate or deep. See Chakraborty et al.,[2] for further reading.

Perceived Stress Scale[6] is used for the assessment of stress at baseline and after music therapy intervention.

Other tools used in the study include statistical musicology[7] and brain imaging through EEG signals.

Results

a. Using PSS (Perceived Stress Scale) baseline data have been collected on 28 participants so far, 14 for control group (Non Music Intervention group) and the remaining 14 for case group (Music Intervention Group), the allotment of a participant to one of the groups being done using Randomized Control Trial (RCT) to prevent bias in allocation (first follow-up after music intervention would be carried out after two months).

b. Kafi, being a joyful raga, is one of the Hindustani ragas being chosen for Music Intervention. The project Fellow, who joined this project has analysed Raga *Kafi* in detail, as summarized below:

Unconditional note probabilities has confirmed the multinomial model using Chi-square goodness of fit test while the conditional probabilities are useful in simulating *Kafi* notes using Semi Natural Composition Algorithm (SNCA), developed by the first author and his PhD scholar Dr. Swarima Tewari.[2,7] which uses Markov Chain Monte Carlo method. Further, using time-series modelling, the note progression of a *bandish* on raga *Kafi* (a *bandish* is a song like raga composition that maintains the raga correctly) has been successfully captured by Simple exponential Smoothing [$F_{t+1} = \alpha Y_t + (1-\alpha)F_t$, $0<\alpha<1$ where F_t is the predicted pitch of the note and Y_t is the observed pitch of the note at time t with $F_0=Y_0$] with a smoothing factor α= 0.868947. Simple Exponential modelling works well when there is no trend, no seasonal fluctuations and no missing data as in our case. If trend is present, double exponential smoothing is recommended. Chi- Square goodness of fit test is necessitated to verify whether the note probabilities are maintaining themselves over the instances of their realization as otherwise, the model is quasi multinomial instead of multinomial! Multinomial model is a generalization of Binomial model for more than two possibilities for an outcome; here the possible notes in the musical piece are more than two. Suppose a musical piece in raga *Kafi* has n notes. Since Kafi has seven notes Sa (the tonic, let us agree to keep it at natural C), *Sudh* (natural) Re (D), *Komal* (flattened) Ga (E-flat), *Sudh* Ma (F), Pa (G), *Sudh* Dha (A) and *komal* Ni (B-flat), each of the n notes can be one of the seven possibilities. The multinomial model gives the probability as to which note appears how many times out of a total of n notes. If the note probabilities of the seven notes are p1, p2….p7, and if they are maintained, then the probability that Sa appears x1 times, *Sudh* Re appears x2 times etc is given by $[n!/(x1!x2!...x7!)]\ (p1)^{x1}(p2)^{x2}….(p7)^{x7}$ where the probabilities p1-p7 are real numbers between 0 and 1 and x1+x2+…x7=n. You may compare this with throwing an imaginary die having seven faces and you want to know, in n throws, which face appears how many times. Note importantly that your die is unfair as the seven probabilities are unequal in raga *Kafi*. What is important is that your throws should be uniform as otherwise the probabilities would not be maintained and the model becomes quasi multinomial. Chi Square goodness of fit is carried out by testing the significance of the difference between observed frequencies O and expected frequencies E of the notes, where the latter is obtained assuming multinomial model. The statistic $\Sigma(O - E)^2/E$ which follows Chi Square distribution with k-1 degrees of freedom, k being the number of classes, is computed. Here in our example k=7 as there are 7 notes. One degree of freedom is lost because of the linear restriction that the sum of the observed frequencies should equal that of the expected ones. If any class frequency is less than 5, adjacent classes will have to be pooled resulting in loss of degree of freedom. Multinomial model is acceptable at α% level of significance if calculated chi-square is less than table chi-square at k-1 degrees of freedom and α% level of significance. Otherwise the model becomes quasi multinomial implying that the note probabilities are varying!

Some other Hindustani ragas and other genres of music to be used in the study would also be analysed.

This research work is being carried out in our department as a part of a project sponsored by IDEA: Technology Innovation Hub@Indian Statistical Institute, Kolkata. The title of the project is *Hindustani Raga Analysis Using Statistical Musicology with Therapeutic Applications for Stress Management*. Ms. Nimisha Katyayan, a Project Fellow in this project did the analytical work under the guidance of Dr. Soubhik Chakraborty, professor and ex-Head. Department of Mathematics, Birla Institute of Technology, Mesra who is the Principal Investigator (PI) in this project.

The data using PSS scale are being collected by Ms. Apoorva Chakraborty who is a certified music therapist from NADA Centre for Music Therapy, India. In this endeavour, she is being assisted by Mrs. Sushmita Mukherjee. Both of them interviewed the participants personally and filled scores (0,1, 2, 3, 4) for the 10 questions in the questionnaire of the PSS scale. The questions in the PSS scale are such that, for some questions, less score is desirable while for others, more score is better. To induce uniformity, the scores are reversed for the latter type of questions so that after reversing, for all questions, less score is deemed as better. Now the scores from the 10 questions are added and the rating is 0-13 implying low stress, 14-26 implying moderate stress while 27-40 implies high stress. As per PSS rule, those having stress level below 13 are dropped from the study. Thus the actual number of participants in both groups would be less than those interviewed (<14 for each group).

The project has two co-PI's, Dr. Shashi Bhushan Singh from the Preventive and Social Medicine Department, Rajendra Institute of Medical Sciences, Ranchi and Prof. Omar Farooq from the Department of Electronics Engineering, Zakir Hussain College of Engineering, Aligarh Muslim University who would be helping the project with hospital data and EEG signal analysis respectively. The present data being collected pertain to students of the institute.

The project has other collaborators including professional doctors, notably, Dr. Satish Chandra, retired professor of medicine and ex-Dean, Rajendra Institute of Medical Sciences, Ranchi and mathematicians, notably, Prof. Niladri Chatterjee from Department of Mathematics, Indian Institute of Technology who is collaborating with the PI Prof. Chakraborty in a study on the influence of Hindustani ragas on Tagore songs [8] which, in due course, would be put to therapeutic use, given the wide variety of human emotions covered by Tagore songs.

Previous successful work on therapeutic intervention of music done by this team on patients with brain injury (CVA and DHI) are detailed in Singh SB et al.[9] It is also briefed in a review article published in this journal earlier.[10]

Discussion

We are planning to do the aforesaid study in three phases:-

Citation: Chakraborty S, Katyayan N. Statistical musicology with therapeutic applications. *MOJ Biol Med.* 2023;8(2):50–53.
DOI: 10.15406/mojbm.2023.08.00183

Phase 1: Assessing the impact of music especially Hindustani ragas in reducing stress

Phase 2: Assessing the musical properties of the Hindustani ragas and raga based songs (e.g. Tagore songs), helpful in reducing stress, through statistical musicology

Phase 3: Brain imaging study through EEG signals to explore the emotional changes caused in the brain by Hindustani ragas and raga based songs and how they are actually helping the in reducing the stress

Remark: What kind of physical stimulus leads to what kind of emotional changes in the brain is a subject matter of psychophysics which is branch of psychology. The interested reader is referred to the book by Roederer.[11]

Although the project focusses on Hindustani music, the choice of the participants will also be taken into consideration and other genres of music may also be experimented with provided only the concerned musical pieces are so chosen that they are soothing to the sympathetic nervous system to be judged by the music therapist.

Music therapy session begins

The first music therapy session was held on 31st March, 2023 in the music room in our institute in both offline and online mode. The PI addressed the participants and briefed them about the objectives and the plan of the project. He then gave a popular talk on the science of music linking with the art of music. He gave a live demonstration with extempore singing to convince the participants that all musicians are subconscious mathematicians in the sense that when a singer or an instrumentalist is moving from one (musical) note to another note (or one beat to another beat in a percussion instrument), he/she can either move straight or in a curve. In the former case, the melodic structure of the note (or beat) assembly can be captured by Euclidean geometry involving integer dimension which holds for objects with well defined shapes (like point having zero dimension, a line having one dimension, a plane having two dimensions, a cube having three dimensions etc.). In the latte case, the melodic structure becomes complex and requires fractional dimension (examples of complex structure include cloud, cauliflower and ragas in Indian classical music).

The PI also linked music and statistics by arguing that music has patterns and statistics is the science of exploring and studying patterns in numerical data (e.g. by a statistical model). He first struck the piano (Casio) keys randomly and, creating a musical pattern in raga *Bhairavi*, argued. why pattern is necessary to generate music. He further argued that musical data are numerical in character and that whenever music is created, the corresponding pattern gets embedded in the data which can be extracted by a statistician.

He also pointed out the difference between a raga *bandish* and a raga based song arguing that the strength of a raga *bandish* lies in expressing the raga in a way that establishes the raga mood well enough while the beauty of a song actually lies in hiding the raga so that the listener feels that he/she is listening to a song rather than a something of serious nature. As such a song is not obliged to follow the raga rules correctly unlike a raga *bandish* where the raga rules are mandatorily followed.

The PI compared the contrasting aspects of music research going on in his institute on computational musicology, musical signal processing and music therapy, highlighting the books and research papers in peer reviewed journals of national and international repute published by mainstream publishers (Springer, Nova Sc. Sanctum Books etc.), the significant contributions of his PhD scholars and postgraduate students, the projects undertaken and research collaborations with other institutes in the country and abroad.

He jokingly concluded describing himself as a statistician by profession and a music therapist by choice arguing that the former makes him a commonality expert as the philosophy of statistics is to summarize and average while the latter projects him as a diversity specialist in that in music, being a work of art, what is special is more vital than what is common.

The music therapist then started the session with an interactive conversation. She explained that music therapy is a process or therapy using music to treat psychosomatic diseases, negative emotions and giving symptomatic relief in other physical maladies. It was cleared that music involves a particular pattern or arrangement of notes or beats otherwise it could be an annoying noise. Music is created through sound which is created from vibration. Both speech and music have their own alphabets but while for speech, which conveys a message, it is necessary to know the language, one can enjoy music, which primarily conveys emotion, without knowing the language thereby giving it a universal appeal.

One can hear a particular range of sound frequencies known as sonic sounds (20 Hz to 20,000 Hz). It is held that those who do meditation through music reach a certain stage known as *pritambara pragya* in which he/she attains the ability to hear infrasonic (<20 Hz) and ultrasonic sounds (>20,000 Hz). According to the Upanishads, the human system has five layers, namely, *annamaya kosh, manomaya kosh, pranamaya kosh, vigyanamaya kosh and anadamaya kosh*. Among these, *pranamaya kosh* is the most important layer which contains 72,000 nerves that divide and meet at different points with 114 meeting points of which two are spiritual and the rest are physical. Of the 112 meeting points, 4 are inactive and the rest 108 are called energy centres. These 108 centres correspond to the 108 *dhwanis* (sounds) in Sanskrit. Therefore Indian classical music has the ability to activate these 108 energy centres or chakras of our body that leads to enlightening our spirit and finally leads us to *moksha* (salvation). This very activation process is what is called *nada yoga*. Next we had meditation through chants which has great impact on our body. This was followed by breathing exercises, some light music solo, duet and chorus. Instruments like guitar, Casio were played and the participants enthusiastically joined the same.

Conclusion

It is hoped that this study will enlighten us on the specific ragas in Hindustani music that are helpful for stress management. Comparison with other genres of music and sub genres such as Tagore songs would also be very rewarding. This exploration of ragas and songs through statistical musicology with confirmatory EEG signal analysis would help us in building the music therapy app. The music transcriber would help us know the statistical features of the musical pieces used in the study and in subsequent studies.

Acknowledgments

The authors are grateful to IDEA: Technology Innovation Hub@ Indian Statistical Institute, Kolkata (ref: letter no. DRIE/ RDC/ NM-ICPS/ ISI Kolkata/2022-23/3971 dated 23rd Sept, 2022) for sponsoring this research. The PI would like to thank the Vice Chancellor of BIT Mesra, Prof. Indranil Manna for encouraging and supporting this research. He would also like to thank all the participants for their cooperation, and the artists Mr. Manish Kumar Sharma (vocal), Mr. Harsh Gautam (vocal and Casio), Mr. Sandeep Hazra (vocal

and guitar), Ms. Aditi Singh (vocal) and Ms. Apoorva Chakraborty (vocal). Finally, he would like to thank Mrs. Sushmita Mukherjee and her husband Mr. Animesh Mukherjee for coordinating the program and Mr. Mrinal Pathak for providing the music room for music therapy intervention. .

Conflicts of interest

The author declares no conflict of interest.

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