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Indian Journal of Physiology and Pharmacology

Article in Press

Original Article

Electroencephalographic power spectrum and intersubject correlation on acoustic stimulation with modes of Indian music: A randomised controlled trial

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Received: 27 June 2024
Accepted: 20 November 2024
EPub Ahead of Print: 05 February 2025
Published:

DOI
10.25259/IJPP_337_2024

Quick Response Code:

Supplementary data available at:
https://dx.doi.org/10.25259/IJPP_337_2024

ABSTRACT

Objectives: There is variation in the level of engagement among individuals during any sensory experience, including listening to music. This current randomised controlled triple-blind study employed Indian music to understand electroencephalogram (EEG) based inter-brain synchronisation.

Materials and Methods: Four groups (three music interventions: mode or raga Miyan ki Todi, Malkauns and Puriya and one control group) were compared, with 35 participants in each group. EEG power spectrums before intervention (BI), during intervention (DI) and after intervention (AI) acoustic were analysed for correlated components (C1, C2 and C3), and scores of Inter-subject correlation (ISC).

Results: Left frontal gamma power increased with raga Malkauns DI. Raga Miyan ki Todi showed a frontal increase in beta1 power, and raga Puriya showed a decrease in right frontoparietal delta power AI. The raga Malkauns and Miyan ki Todi groups showed decreased C1 (globally distributed low-frequency activity) and increased C2 (posteriorly dominant alpha-beta1 activity) power. Raga Puriya showed a weak decrease in C1 and ISC scores and a marginal drop in C3 (peripherally dominant broad-band activity) AI.

Conclusion: The findings demonstrate specific mode-dependent correlated EEG components that persist after the listening period. The short-term effects were postulated due to default-mode network activity and autobiographical memory. Overall, this study adds to our understanding of the effects of Indian music on the brain.

Keywords: Indian music, Melodic modes, Electroencephalogram, Intersubject correlation, Correlated component analysis

INTRODUCTION

Human connects with the environment through engagement, which is defined behaviourally as a commitment to attend to the stimulus. Similar to other sensory experiences, acoustic stimuli, especially music, engage a person and help to induce and perceive different emotions.[1-5] Music not only entertains an individual but also affects cognition [6,7] and reduces stress.[8-11] These responses can be recorded using subjective (questionnaires)[12] and objective measures [electrocardiogram (ECG), electroencephalogram (EEG) and functional magnetic resonance imaging (fMRI)].[9,13]

Studies on EEG power spectral changes on passive listening to music show the impact of the genre of music and the features of music, including tempo, rhythm and scales.[14-16] For example, listening to Indonesian Gamelan music increased EEG beta power,[17] indicating music-evoked memory recall or visual imagery;[18] listening to instrumental music (*raga Desi Todi*) reduced anxiety and increased EEG alpha power;[19] listening to a drone instrument (*tanpura*) increased the complexity of the frontal alpha and theta power;[20] music therapy increased posterior theta power and decreased mid-frontal beta and posterior alpha power, along with a reduction in the degree of anxiety.[21] The duration of the music stimulus in most studies ranged from a few seconds to about 3 min. A digital music study examined music consumption across people aged 16–64 years and concluded that Indians consume approximately 25.7 h per week (~3.5 h a day).[22] There are significant temporal differences within short bins of time intervals (every 2 min) in the EEG power spectrum while listening to different modes of Indian music.[14] Therefore, while studying music engagement, a time-based stimulus, it is important to intervene with longer time durations, until the completion of the melody. Exposure to complete musical pieces, inducing different emotions [23-25] can assist in comprehending the functions of specific neural regions spatially and temporally.

The level of engagement of every individual in a group and comparison of EEG variability across groups employing inter-subject correlation (ISC) analysis is relatively recent and has yet to be thoroughly studied. When a set of individuals are exposed to the same sensory stimulus, a few individuals have typical experiences (engaged) while others remain atypical due to the uniqueness of their brain activity.[26] ISC evaluates the similarity of an individual's brain over a duration with that of another individual or a group (reviewed,[27] and for a tutorial, see[28]). ISC is often used with fMRI or EEG when visualising a moving stimulus, such as a movie clipping or listening to a speech [26,29-33] during natural as well as emotion-inducing music stimuli.[34,35] It is interesting to understand music-based engagement and ISC through the recording of EEG for two reasons: Music is a time-based stimulus, and EEG is well suited to investigate the time-locked brain responses as the temporal resolution is high. Two, the melodic modes or scales of music are made up of a set of organised tones at frequencies implicated to induce specific emotions. These emotions, in turn, result in specific EEG responses.

ISC of neural responses is said to be well-suited for measuring musical engagement [36] and used to identify the unmodelled neural patterns in response to listening and playing music.[37-41] Although the previous studies have investigated the brain responses during continuous listening to relatively simple musical stimuli or controlled auditory paradigms,[15,42,43] to the best of our knowledge, very few studies examine how the human brain processes the multitude of musical features present in naturalistic musical stimuli. Observation of such synchronised responses in a group of participants for music indicates a socio-behavioural response to musical stimuli, which will have implications in the management of neuropsychiatric conditions generating atypical socio-behavioural network responses.

To date, there has been little attention on changes in EEG power and ISCs on receptive listening to Indian music. Like Western music, the Indian musical system has several scales or modes,[44,45] which are made of a given set of tones or frequencies, presented in an orderly manner to generate an emotion of their own. The previous studies have used Indian music modes in Western listeners and showed that despite being culturally unfamiliar with the tones and the combination of tones, the listeners could perceive the intended expression of the respective modes.[23,46,47] To the best of our knowledge, it is still unknown if ISC varies with different musical/melodic modes within a particular genre, and none of the studies have used different modes of Indian music.

In this study, the engagement of participants while listening to different modes of Indian music as acoustic stimuli is evaluated through the recording of EEG changes. This study is part of a larger study where cardiovascular and other physiological parameters were recorded after intervention (AI) with three modes of North Indian Classical music (Hindustani music) named *raga Miyan ki Todi, raga Malkauns* and *raga Puriya*.[48] In this manuscript, the detailed EEG findings, using correlated component analysis (CorrCA) on spectral data to show the differences in terms of spectral components and ISC scores, are reported. Since the three music interventions led to a reduction of the state anxiety levels (see[48]), the main objective of the present study was to further elucidate the brain mechanisms (correlated spectral components and their scalp distribution) and the levels of engagement of individuals (ISC scores) to the intervention. It was tested if the effects lasted beyond the intervention period. The hypothesis was that different modes of music would induce different electroencephalographic changes and would produce specific correlated spectral components of cortical frequency. Due to the repetition of the phrases during the elaboration of a given melodic mode, the overall ISC may be reduced. The findings of this study can serve as preliminary evidence to choose musical modes appropriate to target cognitive deficits in patients with schizophrenia, autism and dementia for music-based cognitive remediation.[49] It can also extend the knowledge of neural underpinnings and neural mechanisms underlying music and attention. Based on previous studies,[30,38] an exploratory approach was taken, and ISC was calculated using maximally correlated spectral components.

MATERIALS AND METHODS

Study design

This was a prospective randomised controlled trial with a triple-blind design with 140 participants who were randomly divided into four groups, with 35 participants in each group. Each group received one of the acoustic interventions: Group A received *raga Miyan ki Todi*, Group B received *raga Malkauns* and Group C received *raga Puriya*, with Group D as a Control Group. The music sessions were comprised of 10 min of listening to pre-recorded musical clips. EEG was recorded during three periods: Silence, music listening and silence (each lasting 10 min) and compared with the control (no music).

Ethical approval

The study protocol was approved by the Institutional Scientific Committee on Human Research and Ethical Review Board. The study was conducted between 2019 and 2021, with the first recruitment in June 2019 and the final recruitment in February 2021. The data presented in this report were part of the larger experiment (full trial protocol: NCT03790462 on clinicaltrials.gov.in). The research was conducted following the Declaration of Helsinki guidelines.

The basis for sample size

The sample size was calculated using nMaster 2.0 software. Based on a study conducted by Okada *et al.* [50] assuming that the (root mean square standard deviation of normal-to-normal - NN intervals on ECG), a parasympathetic index on Heart rate variability (HRV) would increase after music therapy. An effect size of 0.83 (medium to large effect) was considered for this study, and a confidence interval of 95% and calculated the minimum sample size of 32 would be sufficient to achieve 90% power of the study. Another study[51] where the change in State-Trait Anxiety Inventory-6 (STAI-6) anxiety median and interquartile range scores was from 33.3 (23.3–41.7) before music intervention and to 30 (20–40) after music intervention was also considered. Taking the minimum difference of 4 units in the STAI score, with an effect size of 0.7, power of 85% and an alpha error of 5%, the sample size was calculated to be 35 in each group. Thus, in the current study, a minimum sample size of 35 participants in each group was planned.

Recruitment

Participants were recruited from various educational institutions in Bengaluru, Karnataka, India. Healthy individuals were invited through an open call for participation, which was posted online through social media and advertised on notice boards across the institutions. To align with the study's objectives of the study and to avoid cultural familiarity differences, only Indian nationals were eligible to participate. Those who responded to the invitation received an online questionnaire through Google Forms (explained in[48]).

Inclusion and exclusion criteria

Inclusion criteria were participants volunteering for the study, aged 18–30 years, of either gender, right-handed, medically and surgically healthy individuals (initially self-reported in the online questionnaire and confirmed on visiting the laboratory). They had to be fluent in English, with normal hearing, and without cognitive or decisional impairments and those who were not smokers or alcoholics were invited to participate in the study. Pregnancy positivity was one of the exclusion criteria. Participants with any past or current medical or surgical disorders and a body mass index of over 30 kg/m^2 were excluded from the study [Figure 1]. The rest of the participants were invited to the laboratory for further recordings.

Randomisation

A simple randomisation technique was used to select participants into four groups [Figure 1]. The random numbers (four sets of 35 each) were generated using Microsoft Excel and placed in an opaque envelope. The participants' serial numbers were written on the envelope. After each participant's baseline assessment, the research assistant opened them and assigned them to their respective groups. Participants understood that they were part of the music intervention group once the intervention started, although the specific mode was unknown to them. All investigators conducting outcome assessments were blinded to the interventions [Figure 1].

Interventions

All participants listened to the acoustic intervention through headphones, following a published protocol,[52] from a laptop, at a volume of 50% at a level of <65 decibels as measured using a National Institute for Occupational Safety and Health (NIOSH) Sound Level Meter app.[53] The acoustic stimuli were randomly coded as A, B, C and D. Participants were instructed to listen to this with their eyes closed and minds relaxed for the duration it played (10–11 min). As repetition is said to reduce ISC values,[30-32] the acoustic stimuli were not repeated.

Music intervention

Three melodic scales (modes/*ragas*) of Hindustani music: (*Ragas) Malkauns* (pentatonic: C, E♭, F, A♭, B♭), *Puriya* (hexatonic: C, D♭, E, F#, A, B) and

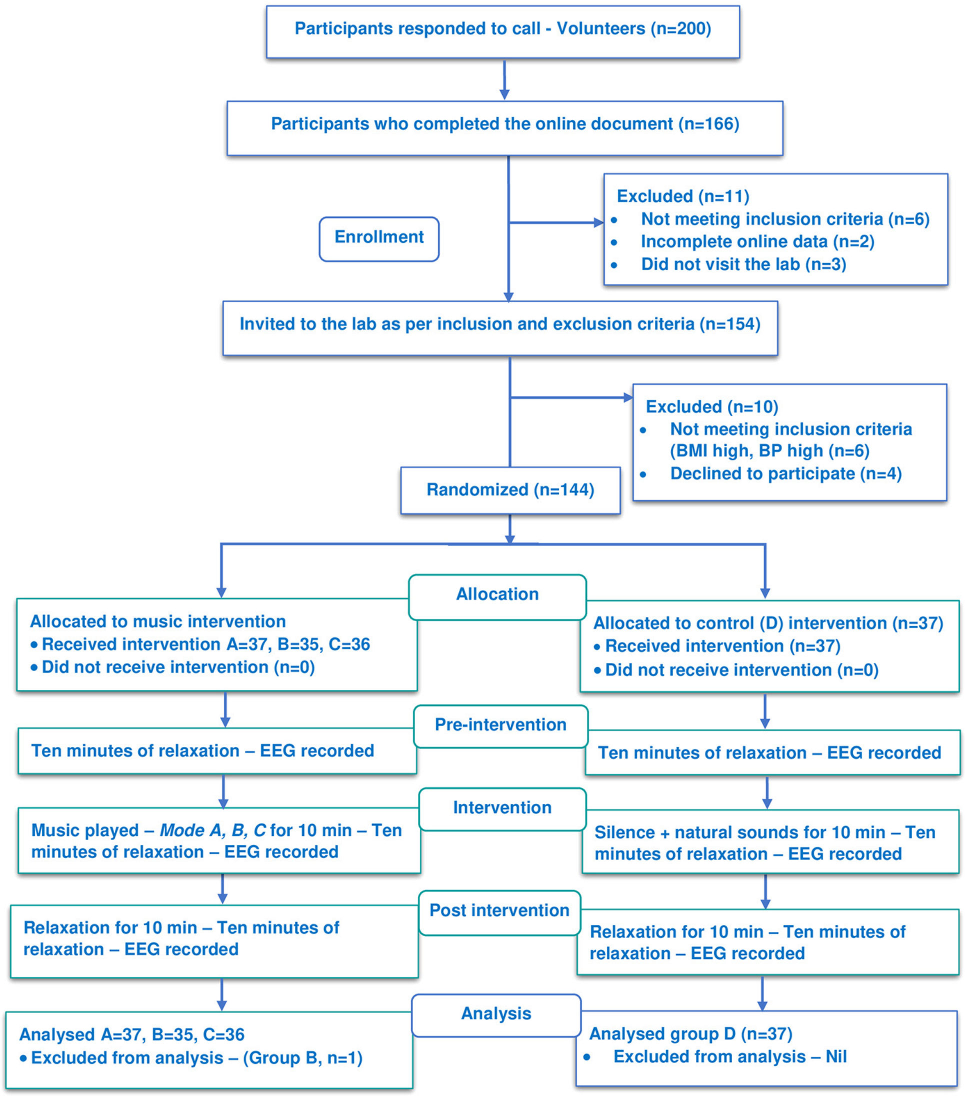

Figure 1: CONSORT flow diagram showing participant flow through each stage of the randomised controlled trial (enrolment, intervention allocation, intervention and data analysis). BMI: Body mass index, BP: Blood Pressure, EEG: Electroencephalogram.

Miyan ki Todi (heptatonic: C, D♭, E♭, F#, G, A♭, B). [Table 1 and Figure 2] were chosen as interventions based on Indian music literature.[44,45,54-56] Although it is possible that the participants were familiar with modes and tones due to their cultural background, none of them had been exposed a priori to the specific musical pieces. The music was tuned to a frequency of 329.63 Hz (the tonic or '*Sa*' at pitch E). The musical piece was of a duration of 10–11 min of flute/*Bansuri* instrumental music. The music was recorded by an eminent musician (exclusively for the study) by playing the improvisation in the respective scales (named *alaap* in Indian music[5,48]). The flute was chosen as it comprises only pitch, intensity, rhythm and timbre, without the lyrical and percussion components.

Control group intervention

Participants in Group D (the control group) listened to an audio clip that was mostly silent for over 10 min. However, since they were required to lie down in a supine position for over 30 min, they may have felt sleepy. Sleep, being anxiolytic, could have led to EEG changes, potentially affecting the study's objective. To prevent this, natural sounds (birds chirping and a flowing river) were played for 10 s every 2 min during the 10 min, totalling 50 s overall.

Process of recordings

Recordings of EEG were done in a supine position with eyes closed, with the first 5 min utilised for attaching EEG

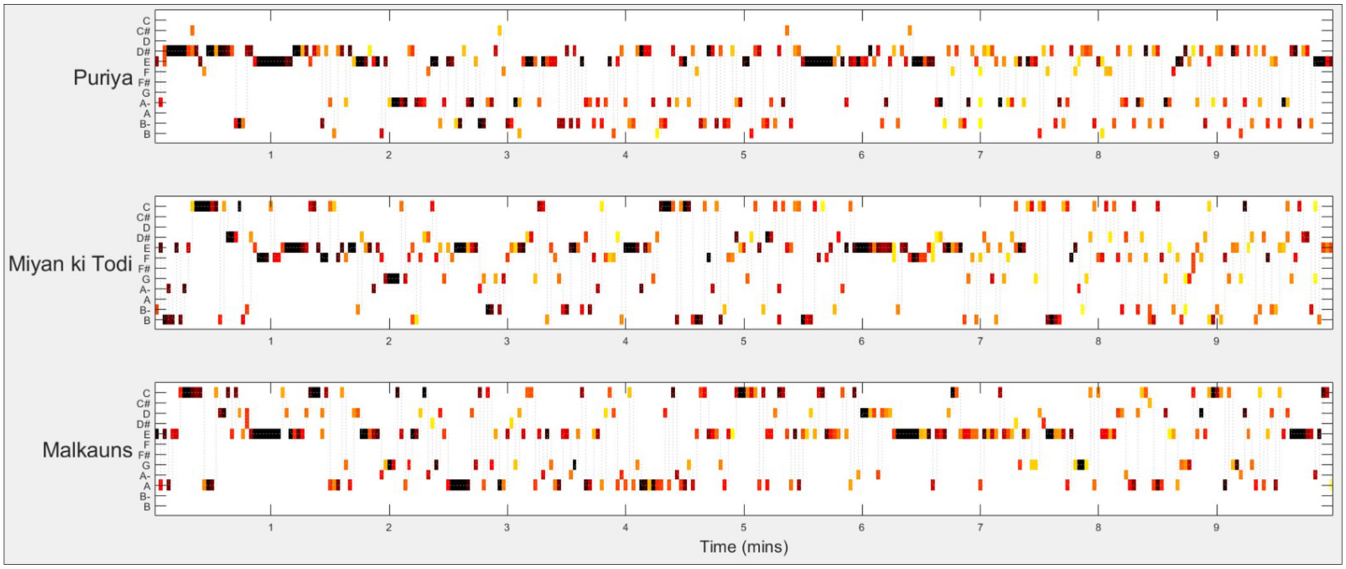

Figure 2: Note distribution in each pitch class in the three music interventions shown in the chromagram. This is a time-frequency representation, where the frequency content of the music is binned into the 12 pitch spelling attributes ('chroma') as used in Western music notation. The warmer colours represent the intensity of that pitch at each time point in the clip. The chromagarm is thresholded for better visualisation (only the dominant pitch at each time point is shown). Here, the 10-min clips of the three Indian music clips are displayed to highlight their differences in terms of spectro-temporal variations (low-level musical features).

Table 1: The three chosen Indian musical scales, the names of the notes/svaras in Hindustani music, the equivalent staff note and Western scale intervals.

Svara/ note	Hindustani name	Staff note	Western scale Interval name
Raga Miyan ki Todi (Scale A) (heptatonic, G appears in descent)			
S	Shadja	C	Perfect unison
r	Komal Rishab	D ♭	Minor second
g	Komal Gandhar	E ♭	Minor third
M	Tivra Madhyam	F#	Augmented fourth
P	Pancham	G	Perfect fifth
d	Komal dhaivat	A ♭	Minor sixth
N	Shuddha Nishad	B	Major seventh
Raga Malkauns (Scale B) Ascent and descent same – pentatonic			
S	Shadja	C	Perfect unison
g	Komal Gandhar	E ♭	Minor third
m	Shuddha Madhyam	F	Perfect fourth
d	Komal Dhaivat	A ♭	Minor sixth
n	Komal Nishad	B ♭	Minor seventh
Raga puriya (Scale C) C, D ♭ , E, G ♭ , G, A/A ♭ , B (hexatonic)			
S	Shadja	C	Perfect unison
r	Komal Rishab	D ♭	Minor second
G	Shuddha Gandhar	E	Major third
M	Tivra Madhyam	F#	Augmented fourth
D	Shuddha Dhaivat	A	Major sixth
N	Shuddha Nishad	B	Major seventh

Note: Sharp symbol (#) raises the note by a half step; Flat symbol (♭) lowers the note by a half step.

electrodes. The participant was asked to relax with eyes closed for the next 30–35 min when the EEG was recorded [Figure 3]. The artefacts were marked as events throughout the recording, which aided during data analysis. The event marked were eye movement, jaw movement, sleep onset and other muscle movements. In the mid 10 min of this 30 min, the acoustic intervention was carried out through the headphones [Figure 3]. This study concentrated on the effects that would naturally occur during acoustic stimulation without the participation of the participants in any cognitive task.[57] Subsequently, the participant's heads were cleaned and relieved. The recordings were made using a 19-channel EEG system (Galileo Mizar Lite, EB Neuro, Italy), with silver chloride electrodes (Ag-Cl) placed on the scalp after the 10–20 international system of electrode placement (active electrodes were placed in Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1, O2 and the reference electrode in the ear lobes [A1 and A2]).

Electroencephalographic data analysis

Raw recordings of three conditions were marked before intervention (BI), during intervention (DI), and AI and stored in GalNT software (EB Neuro, Italy). These were then converted to the standard European Data Format (EDF). EDF exported EEG data did not have markers; a researcher manually recorded the timings for each of the three study conditions (i.e. BI, DI and AI) in the device software. These timings were carefully corrected for data clipped off during acquisition pauses (there was at least one pause per subject). Using custom code written in MATLAB software, event marker files (.evt files required for the next step) were

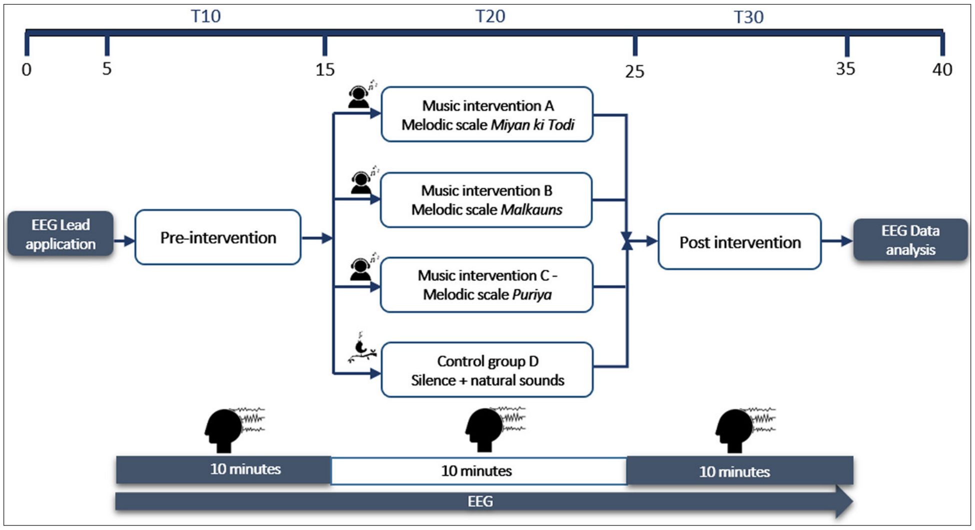

Figure 3: Study protocol; T5, T10, T20, T30, and T35 is the time in minutes; Flow chart describing the process of recording. EEG: Electroencephalogram.

generated for each EEG file, denoting the 7-min continuous segments within each of the three study conditions (skipped the initial 1 min of each condition to avoid artefacts during transitions). These data were then subjected to pre-processing using EEGLAB,[58] version: 2021. This included 0.5–40Hz bandpass filtering, automated bad channel and bad segment removal by Artifact Subspace Reconstruction (ASR) approach,[59] bad channel spline interpolation, and average re-referencing – all done with custom-written codes in MATLAB software (version: 2021b). Bad segment removal by ASR resulted in discontinuities in the EEG data. Hence, to make sure that the subsequent segmentation of EEG data for power spectral analysis does not contain discontinuities within each segment, boundary markers were added using EEGLAB. Furthermore, these were further visually inspected, and the data from participants with at least 3 min of good quality EEG for all three portions were considered for further analysis.

Band power was evaluated using fast fourier transformation (FFT)-based power spectral analysis on each of the EEG segments (with 2 s non-overlapping Hanning windowed sub epochs giving 0.5Hz resolution) and grouped into standard frequency bands (delta: 1–4Hz, theta: 4–7Hz, alpha: 8–13Hz, beta1: 13–20Hz, beta2: 20–30Hz and gamma: 30–45Hz), for all 19 EEG channels, across all files. The gamma power was limited to <45Hz) due to the low sampling rate (128Hz) and potential filter effects in this frequency band.

As multi-channel EEG captures spatially distributed activity of prominent brain networks, instead of analysing individual electrodes, this study used a linear combination of electrode-level spectral activity capturing EEG spectral activity most correlated among participants. CorrCA is based on canonical correlation analysis helped in achieving this. This approach has been used in prior studies on time-domain data to extract multi-electrode EEG components related to music listening and video viewing.[30,39] Here, frequency domain data, that is, the average power spectral data within each 10-min condition, was used for CorrCA. CorrCA also gives the forward model topography and time series of the components, which could be used for spectral and other analyses that are typically done on single electrode data. For CorrCA, the code available at http://www.parralab.org/isc/ was used. For the current analysis, CorrCA was performed on compiled spectral data (frequency × channels × subjects) to capture the components most prominent to each intervention and selected the first three components per group with the highest ISC values at the group level. The subject-level total power across the spectra of each component was examined for the intervention effect between the groups. Furthermore, the ISC values at the subject level were compared between the groups as a measure of engagement within the conditions. For the key steps followed for computing the CorrCA and ISC, see [Supplementary Figure S1].[60]

Statistical analysis

Data were analysed using the Statistical Package for the Social Sciences (SPSS) (SPSS Inc. Released in 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.). The continuous variables were analysed using descriptive statistics, and the qualitative/categorical variables were analysed using frequency and percentage. For statistical analysis of electrode-level EEG spectral data, a hierarchical general linear model with cluster statistics was applied to the electrode-level data using functions of the LInear MOdelling (LIMO) toolbox in MATLAB software. Briefly, the condition codes were used as a within-subject category variable in the first-level analysis and group code as a between-subject category variable in the second-level analysis. The first-level analysis applies linear regression within each subject to generate beta values for each condition and electrode, which helps to minimise the between-subject variability. These beta values (instead of raw power values) were then subjected to robust *t*-tests (yuen's *t*-test) for between-group comparisons in the second-level analysis. The multiple comparisons of multi-electrode data were done using the clustering statistic of the LIMO toolbox (threshold-free cluster enhancement or tfce).[61-65] Briefly, this is achieved by performing a permutation test (500 permutations), wherein each electrode value is locally scaled based on its 'clusterness' potential (tfce value) in each permutation, thereby generating an empirical distribution of max tfce values (under the null hypothesis). If the observed tfce value is unlikely to be in this null distribution, then conditions can be significantly different and driven by those high tfce clusters. For statistical analysis of component-level spectral data and ISC scores, robust one-way repeated measures analysis of variance was applied, followed by *post hoc* Yuen's trimmed mean test (20% trimming)[66] and *P*-values adjusted using Holm's correction,[67] using Jamovi software written in R language. Two-tailed $P \leq 0.05$ was considered statistically significant at a 5% level of significance.

RESULTS

Sociodemographic data

All the sociodemographic characteristics were comparable among the groups as we reported in,[48] except for educational status, which was adjusted during physiological parameters analysis. There were no differences in familiarity with music or training between the groups [Supplementary file, Table S1, Table S2, Figure S2].

Electrode-level band power changes relative to baseline

Power changes were calculated across the scalp for each subject, relative to the baseline power BI, for each frequency band. These power changes were obtained as first-level beta values of a hierarchical general linear model approach described in the methods section. DI, the most prominent changes were a global decrease in alpha power for all intervention groups (most prominent in control) and a frontal increase in beta1 for *raga Miyan ki Todi* [Figure 4]. AI, the most prominent change was a frontal decrease in delta power in *raga Puriya* and a frontocentral increase in beta1 power in the *raga Miyan ki Todi* group [Figure 5].

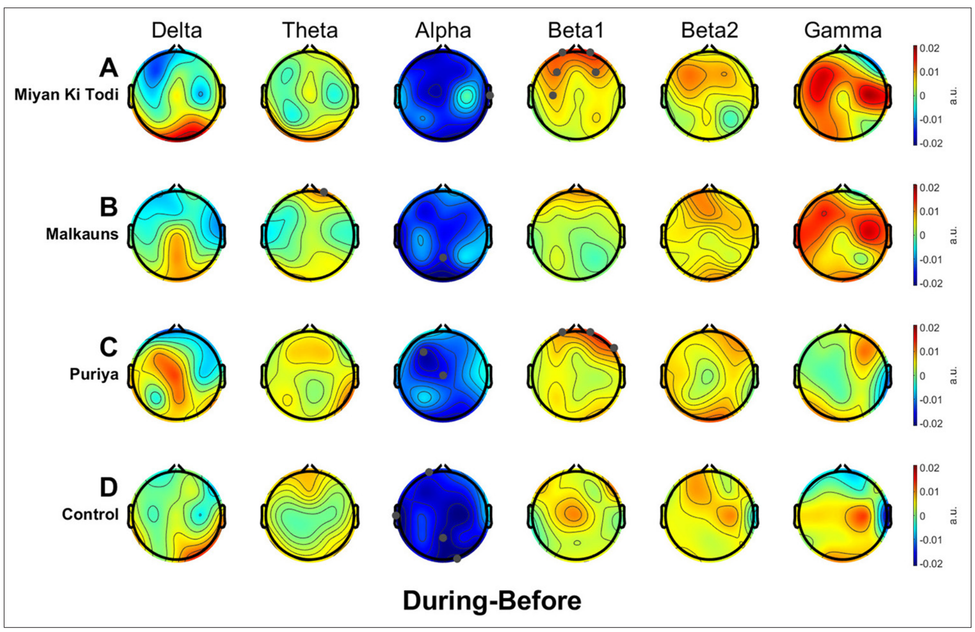

Figure 4: Scalp maps representing the average changes in electrode-level band power during intervention relative to before intervention, within each group (First-level analysis). Negative values (indicated in cooler colors) would mean a decrease in power spectral values and positive values (indicated in warmer colors) mean an increase relative to the Before Music condition. Statistically significant electrode sites after robust *t*-test with cluster-based multiple comparison correction (tfce) are denoted by grey dots. The clean data (at least 3 min per subject) from the middle 7 min of the intervention period were used for this analysis.

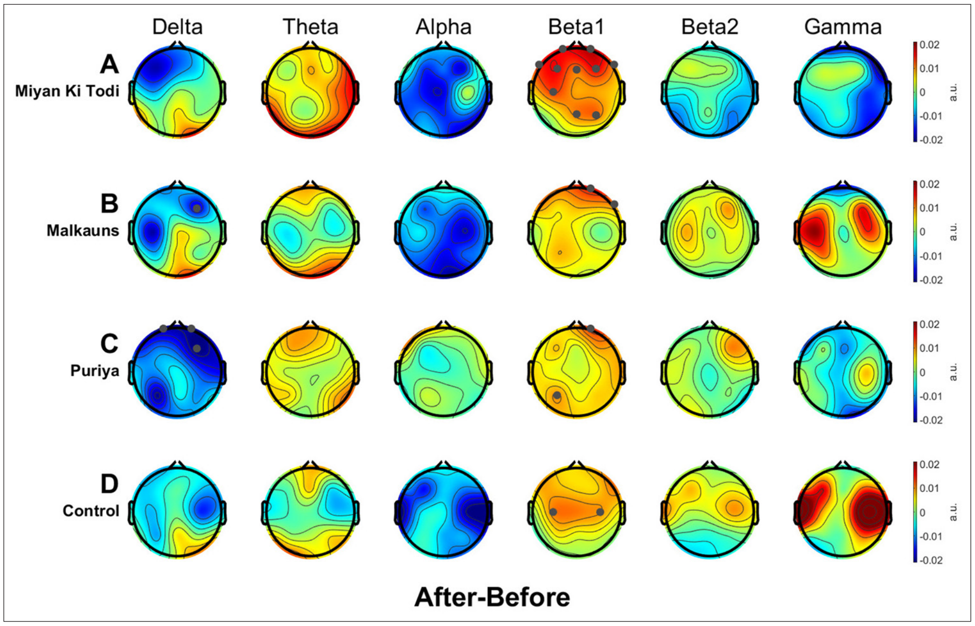

Figure 5: Scalp maps representing the average electrode-level band power changes after intervention relative to before intervention, within each group (First-level analysis). Negative values (indicated in cooler colors) would mean a decrease in power spectral values and positive values (indicated in warmer colors) mean an increase relative to the before music condition. Statistically significant electrode sites after robust *t*-tests with cluster-based multiple comparison corrections (tfce) are denoted by grey dots. The clean data (at least 3 min per subject) from the middle 7 min of the intervention period were used for this analysis.

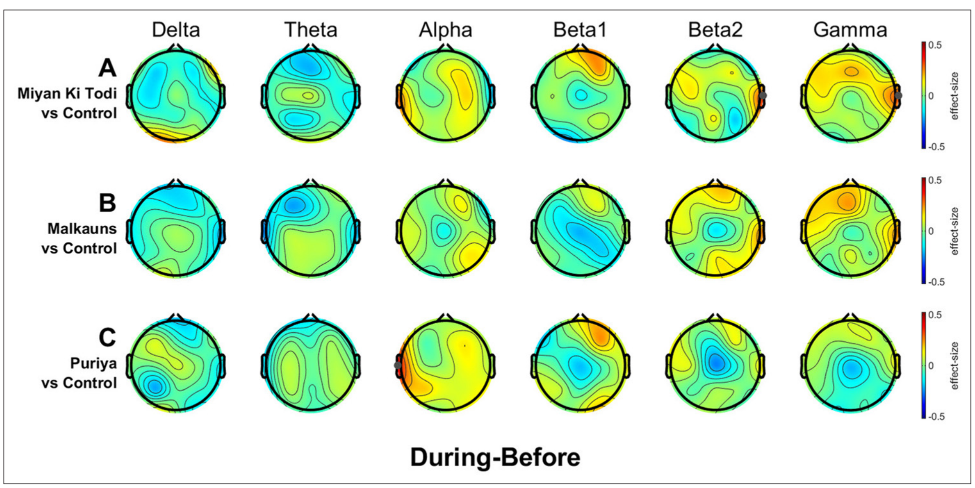

Figure 6: Scalp maps showing the differences between the groups in electrode-level band power between the intervention and control groups (Second-level analysis) during the intervention relative to before the intervention. Negative values (indicated in cooler colors) would mean a decrease in power spectral values and positive values (indicated in warmer colors) mean an increase relative to the control group. Statistically significant electrode sites after robust *t*-test with cluster-based multiple comparison correction (tfce) are denoted by grey dots. The clean data (at least 3 min per subject) from the middle 7 min of the intervention period were used for this analysis.

To evaluate the group differences, a second-level analysis was done where each music intervention group was statistically compared with the control group, and cluster-based multiple comparison correction (tfce) was employed to determine the significant changes. Based on this analysis, the group listening to *raga Miyan ki Todi* showed a significant right temporal increase

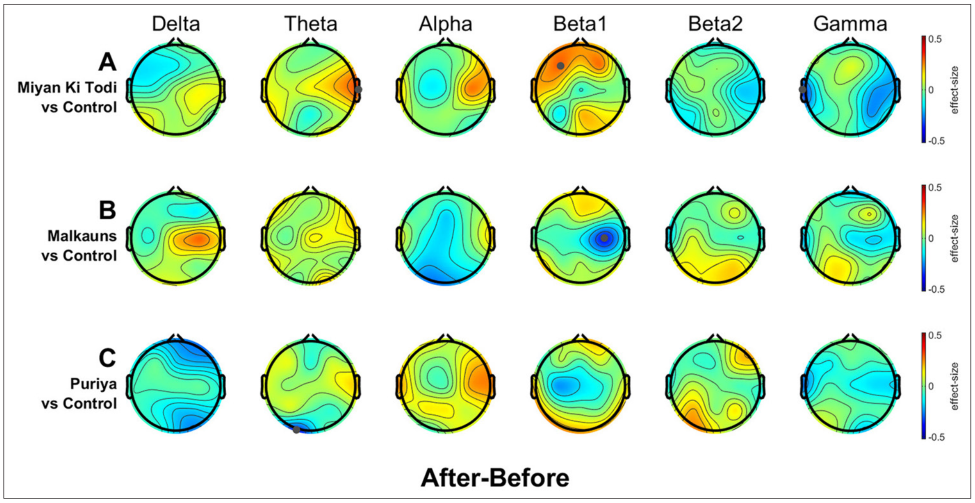

Figure 7: Scalp maps showing group differences in electrode-level band power between the intervention and control groups (Second-level analysis) after intervention relative to before intervention. Negative values (indicated in cooler colors) would mean a decrease in power spectral values and positive values (indicated in warmer colors) mean an increase relative to the control group. Statistically significant electrode sites after robust *t*-tests with cluster-based multiple comparison corrections (tfce) are denoted by grey dots. The clean data (at least 3 min per subject) from the middle 7 min of the intervention period were used for this analysis.

in beta 2 and gamma power, and the *raga Puriya* group showed a left temporal increase in alpha power, DI in comparison to controls [Figure 6]. Whereas, AI, the group listening to *raga Miyan ki Todi* showed a significant right temporal theta power increase, frontal beta1 power increase, and left temporal beta power decrease, while *raga Malkauns* group showed right central beta 1 power decrease and *raga Puriya* group showed posterior theta power decrease [Figure 7].

Correlated component-level band power changes relative to baseline

To explore intervention-related changes in spectral patterns unconstrained by typical individual frequency bands, CorrCA was performed. This extracted the spectral components correlated between subjects for a particular condition from average power spectral data within each 10-min condition. For each component, this also gave the amount of similarity of each subject's component to that of all others as a score called ISC. The spectral distribution of the first three most correlated components was as follows: the first component is a globally distributed low-frequency activity (C1), the second component represents posterior dominant alpha-beta1 activity (C2) and the third component represents peripherally dominant broad-band activity (C3) [Figure 8].

In terms of the dynamics of the CorrCA spectral components, both *raga Malkauns* and *raga Miyan ki Todi* groups showed a similar pattern of significant decrease in C1 power ($P < 0.001$) and increase in C2 power ($P < 0.001$) DI relative to baseline when compared to the control group [Figure 8]. Even AI, this decrease in C1 power ($P < 0.001$) and increase in C2 power ($P < 0.001$) was strong for *raga Malkauns* but *raga Miyan ki Todi* group only showed a weak increase in C2 power ($P < 0.05$), whereas *raga Puriya* showed only a decrease in C1 AI ($P < 0.001$), compared to the control group [Figure 9].

ISC scores of C1 and C2 were comparable between groups, except for *raga Puriya,* which showed a marginal drop in C1 ($P < 0.05$) AI [Figure 10]. ISC scores of C3 were significantly lower for the *raga Miyan ki Todi* and *raga Puriya* groups ($P < 0.01$) DI.

DISCUSSION

In this study, the spectral effect of EEG during 10 min of acoustic intervention with three different modes of North Indian classical music and one control stimulus in healthy young participants, using the conventional electrode-level power spectrum and correlated component-level power spectrum, was evaluated.

The intervention

The three musical stimuli consisted of instrumental music based on different modes or *ragas* of Indian classical music (*raga Miyan ki Todi, raga Malkauns and raga Puriya*) that were chosen based on Indian music literature.[44,45] In a previous study, passive listening to music without rating it (unrestrained music listening), followed by a listening and rating task (L→LR) increased the power values of all the frequency bands, that is the alpha, beta and theta bands, as

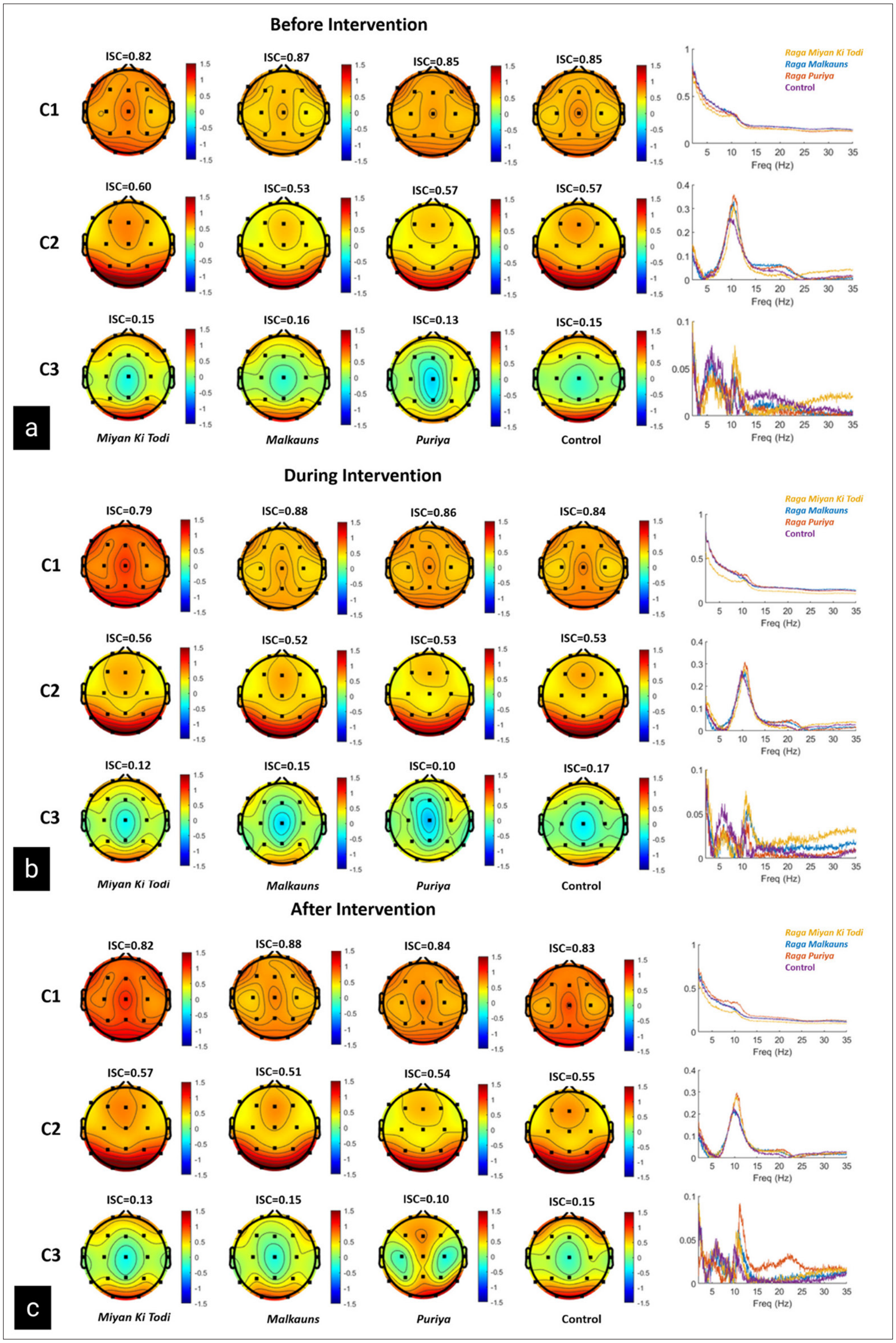

Figure 8: (a) Before, (b) During, and (c) After intervention - scalp distribution and spectral pattern of the first three components (C1, C2, and C3) based on CorrCA. Lower values (indicated in cooler colors) would mean a lower weightage and higher values (indicated in warmer colors) mean a higher weightage for a particular scalp location. The clean data (at least 3 min per subject) from the middle 7 min of the intervention period were used for this analysis. ISC: Inter-Subject correlation.

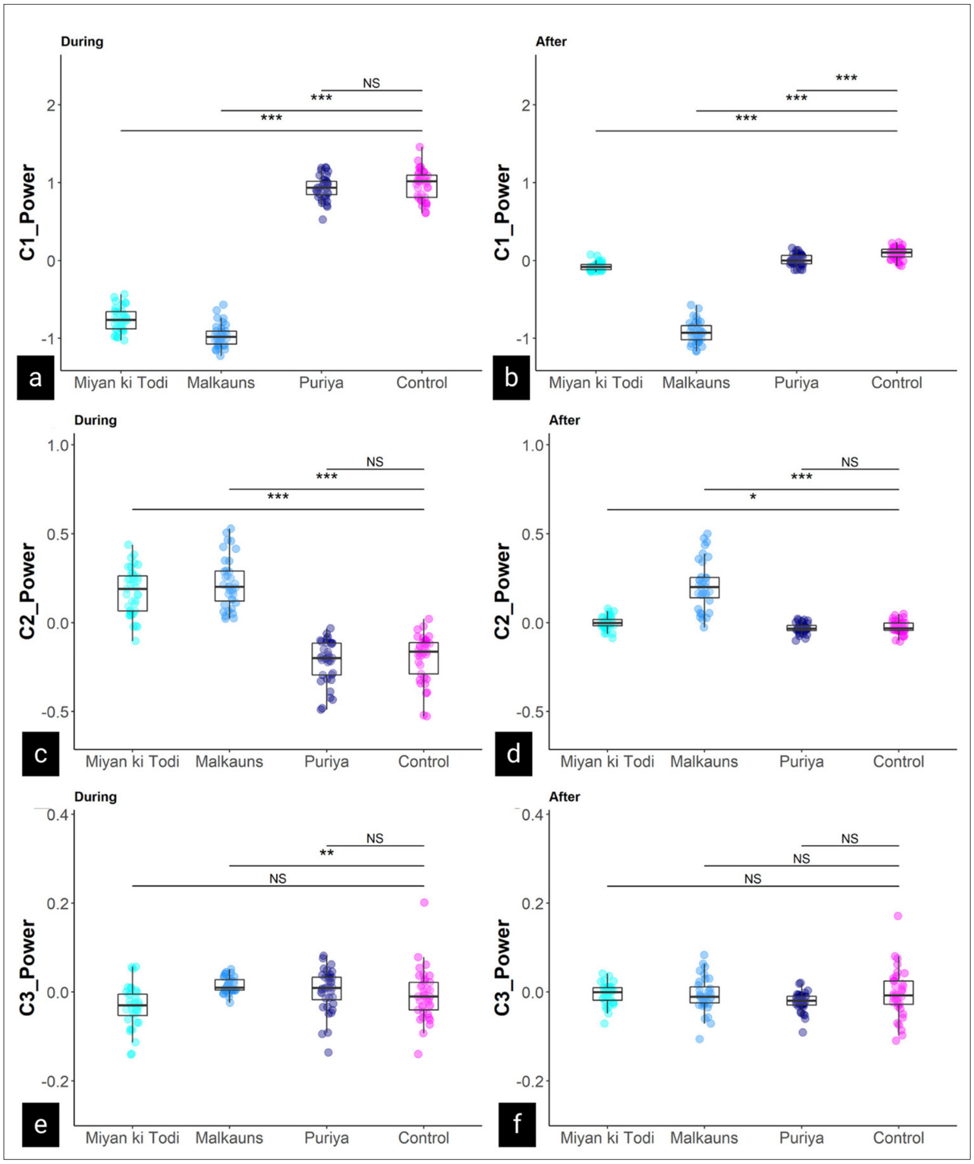

Figure 9: Change in (a) C1 during, (b) C1 after, (c) C2 during, (d) C2 after, (e) C3 during, (f) C3 after intervention. Figure depicting the change in the total spectral power of the components (C1, C2, & C3) between the four groups during and after the intervention, relative to before the intervention. $^{*}P \leq 0.05$; $^{**}P \leq 0.01$; $^{***}P \leq 0.001$; NS: Not Significant.

compared against participants who first rated the music with simultaneous listening (LR→L). The authors also observed a rise in heart rate (HR) in the L→LR condition (emotional arousal response), while the LR→L had a drop in HR,[68] probably due to the boredom introduced by the long-lasting rating task.[68,69] This was the basis of the current study where only a passive listening intervention was implemented without concurrent rating.

Electrode-level band power analysis

In within-group (first-level) analysis, power spectral changes were observed in multiple frequency bands and scalp locations for each of the different intervention groups. The fact that there are very few studies interpreting EEG findings concerning Indian music intervention per se, compelled us to depend on previous music intervention research based on Western or global music. An initial approach for the discussion is the interpretation of each altered frequency band as an indicator of cortical and subcortical network activity. Several EEG studies report conflicting evidence of electrode-level power spectral changes (decrease, increase or null responses) when listening to music. Listening to Mozart's K.448 music[70] resulted in a significant drop in global alpha power during listening, which persisted in the posterior sites post-music. This study also observed a significant decrease in theta and

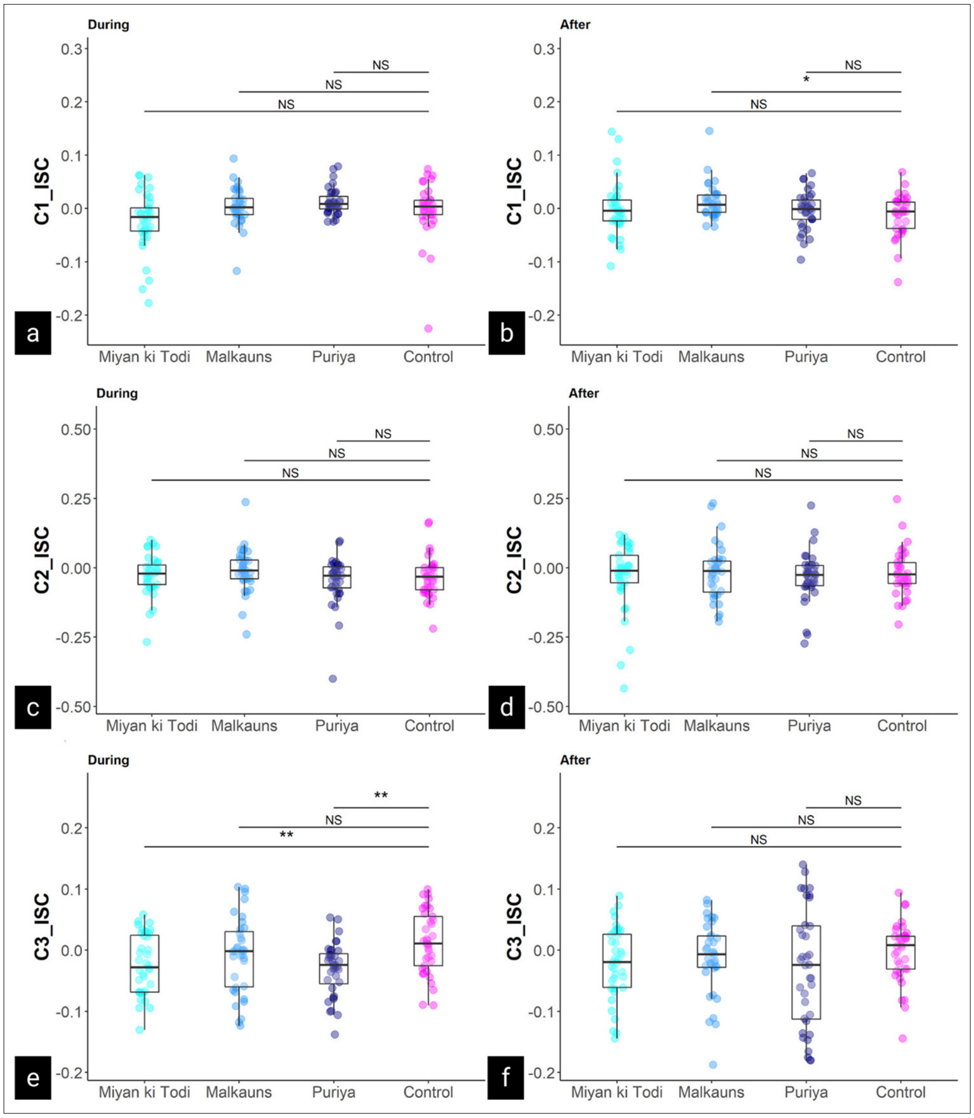

Figure 10: Change in (a) C1 during, (b) C1 after, (c) C2 during, (d) C2 after, (e) C3 during, (f) C3 after intervention. Figure depicting the change in the inter subject correlation scores of the components (C1, C2, & C3) between the four groups during and after the intervention, relative to before the intervention. * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS represents 'not significant.'

beta power during listening, which partially persisted after music. Alpha power is often associated with active inhibition, especially of task-irrelevant brain areas, and therefore, a drop in alpha power could indicate an overall increase in the level of brain activation (or disinhibition) that occurred when listening to the acoustic stimulus[71] or processing or anticipating a stimulus.[72] However, since alpha power drop co-occurred with a drop-in the nearby spectral bands (theta and beta) while listening to music, the above-mentioned spectrally specific explanation becomes questionable. These power spectral variations contrast with the work where the L→LR paradigm led to an increase in most frequencies, due to the mind-wandering effect of music.[68] Listening to popular classical symphonic pieces led to an increase in EEG alpha power in the parietal and occipital areas of both hemispheres during the listening and the peak frequency of the alpha band was significantly reduced.[16] The authors concluded that the level of brain activation was reduced on listening to music. It has also been argued that the alpha band oscillations involve an optimal excitation-inhibition level of neural networks, wherein there is suppression of networks that might interfere with the processing of relevant information including information conveyed during unrestrained music listening.[68,73] An increase in alpha power is seen when attention is driven toward internal thoughts rather than external events. In the present study, a drop in alpha power was observed in all the groups on first-level analysis probably showing the attention drawn toward the external acoustic stimulus.

The beta rhythm is usually associated with increased alertness, and stress-related cognitive processes[74,75] and is shown to predict listener-specific neural signatures in naturalistic music listening.[76] The increase in EEG beta power positively correlated with the regional cerebral blood flow during music listening,[17] probably due to active cognitive sound processing, within the premotor-posterior parietal framework. Like beta, an increase in gamma activity is associated with selective attention, and conscious stimulus recognition[77,78] implicated in the perceptual binding of musical features at the sensory level and the matching of external acoustic information to internal thought processes to form meaningful concepts.[79,80] Gamma is also found to be higher in trained musicians, reflecting improved binding of musical features[81-83] and may be related to musical expectations.[84] The rise in gamma and beta power during music listening has been postulated to be due to familiarity with music, which increases emotional provocation.[85] This study also showed a significant decrease in alpha activity on listening to their expertise-related music, probably due to inhibition release.[86] Based on the available literature, in the present study, one may comment that *raga Malkauns*, a pentatonic scale, and a commonly used raga in Indian Bollywood or regional music,[87] probably led to higher familiarity and anticipatory prediction effects resulting in higher beta 1/gamma on EEG power spectra DI. With *raga Miyan ki Todi,* a significantly increased frontal beta 1 power during and frontocentral beta 1 AI was observed. An increase in the right temporal beta 2/gamma DI, an increase in the right temporal theta, frontal beta 1 and a drop in the left temporal beta AI with cluster statistics probably indicated the higher attention or arousal response to music. This partially correlates with previously published findings[48] on the anxiety questionnaire and autonomic functions data in the group listening to raga Miyan ki Todi where the least reduction in anxiety levels was observed in comparison to *raga Malkauns* and *raga Puriya* and an HRV arousal response noted. Listening to natural music has been found to drive the beta, theta and delta activity,[88] especially when the rhythm of the music falls in these frequency ranges. Using Magnetoencephalogram, it was found that preferred music reduced delta power in the cingulate gyrus, while entrainment music led to changes in gamma power in the somatosensory regions.[89] The drop in delta was attributed to alertness or divergent thinking after stopping the intervention.[90] In the present study, the drop in delta power AI and an increase in alpha power DI with *raga Puriya* could be due to a higher preference for this music, corroborated by the highest reduction in anxiety levels and greater parasympathetic responses[48] along with probable divergent thinking. Since no objective measures of preference or scores of valence and arousal were obtained for the interventions that were used in the present study, it is difficult to confirm the preference findings.

Correlated component-level power analysis

As discussed above, it is clear from the findings and existing literature that the spectral changes associated with music listening span multiple frequency bands and scalp locations. This may indicate the presence of complex spectral interactions that may not be well captured in the electrode-level power spectral results in standard frequency bands conducted. For this, CorrCA was explored, extracting three spectrally and spatially distributed components (C1, C2 and C3) that are consistently repeating within each condition across subjects. The components were visibly similar between groups. But on quantitative comparison of component-level average power within the groups, a decrease in C1 power (globally distributed low-frequency activity) and an increase in C2 power (posterior dominant alpha-beta1 activity) were observed with *raga Malkauns* (strong both DI and AI) and *raga Miyan ki Todi* (strong during and weak AI), whereas *raga Puriya* showed a decrease in C1 (AI), compared to the control group. These components reflect a new dimension to the electrode-level band power analysis and the interpretations of the findings. The component-level analysis findings align with the multi-frequency complex spectral patterns often attributed to default mode network (DMN) activity and its relation to imagery or self-referential thoughts. Supporting this notion, a high-density EEG study where the attention of participants intermittently switched from internal (autobiographical remembering) to external (GO-NO-GO task) processing, found that autobiographical remembering was associated with an increase in spectral power in alpha and beta and a decrease in delta power.[91] At the source level, the alpha power increase was localised to regions of DMN. The decrease in delta power is more pronounced when the autobiographical contents have positive emotions. Furthermore, the more posteriorly distributed alpha increase would suggest a relatively higher activity in the anterior DMN hub, which is involved in mostly conscious modelling, planning and control functions, and relatively lower activity in the posterior hub, which is involved in mostly unconscious processes that include self-representation, emotion and salience detection.[92] As these results are analogous to the prominent component level changes in the group that heard *raga Malkauns,* they may also indicate attention modulation toward predicting the notes and may also serve as a reliable indicator of liking to music.[93] The previous studies have also made interesting observations about the co-occurrence of power changes in multiple frequency bands. Low-frequency brain waves increased in the auditory cortex with a gradual increase in theta and alpha power in the amygdala and orbitofrontal cortex (probable higher analysis of music) with time along with an increase in the power of alpha, theta and beta1 waves in the orbitofrontal cortex while listening to consonant sounds.[15] A uniform reduction of alpha power and an increase in the gamma high power localised was observed in the electrodes over or nearby the auditory-cortex brain regions during music listening.[57] This may be captured by the slight increase in C3 power during listening in the *raga Malkauns* group. A globally distributed alpha reduction along with other frequency bands (such as delta and theta) and an increase in posterior dominant alpha activity might indicate listening to engaging music. This is the probable explanation for component-level analysis captured as C1 power decreases and C2 power increases during and after music listening. Nevertheless, these patterns indicate that increasing levels of engagement reduced the stimulus-driven exogenous components of EEG, with decreased peripheral responses and increased correlation across participants.

This type of component-level analysis of EEG was initially explored[30] using multiple presentations of short film clips and found that the peak arousing moments in the movie resulted in peak correlations of neural activity with increased frontal theta, reduced alpha and beta in the parieto-occipital regions across the viewings. A repetition of viewing or a disrupted sequence of scenes resulted in reduced correlation. This study refers to the correlation to be due to 'emotion-laden attention'. A highly correlated response is said to be typical of physiological arousal. Assessment of physiological synchrony in the audience during concert performances of classical, contemporary and romantic music indicated that faster tempo in classical and romantic concerts (more familiar) led to higher arousal and ISC and that it correlated with the music features of transitions, boundaries and phase repetitions.[94] The strength of the present study objective was comparable to this previous work where full-length naturalistic music was used as an intervention to understand the relevant physiological changes rather than cut music pieces or phase scrambled music pieces. However, this also indicates that the structural phase variations in the musical piece need to be analysed in future works to understand the exact features that result in altered correlation and ISC. In the present study, as the EEG segments were not very well time-locked to intervention stimuli, frequency domain data were used for CorrCA, based on the spectral distribution of the first three most correlated components, with the highest ISC values in each group, and showed that the ISC values were statistically comparable and showed similar patterns. Thus, this study captured the spatiospectral components that showed comparable engagement during the session and their spectral pattern might better represent the intervention-related changes.

ISC

Although the ISC scores were mostly comparable between the groups, the group listening to *raga Puriya* showed a drop in C3 power (peripherally dominant broad-band activity) DI and a marginal drop in C1 AI. ISC examines shared brain responses between participants and the degree to which the music is gripping their brains.[39] The ISC of EEG has been used as an objective index of engagement with naturalistic stimuli such as movies, stories, speeches and music. The ISC has both lower-level processes, such as sensory processing, and higher-level processes, such as memory retention.[29,31] The ISC is shown to be affected by attention[30,95] and is capable of tracking musical engagement even though the behaviour is not recorded. When attention is diverted away from sensory processes, the resulting ISC is shown to be smaller among participants.[95,96] Furthermore, ISC reduced after repeated listening to familiar music and that slower music led to mind-wandering.[39] Slow music reduces the focus on the music, greater differences in physiological responses among individuals and ultimately lower ISC.[29,94,97] Since there is very little literature available currently on Indian music intervention and ISC computation, the present findings of similar ISC scores across groups could be due to the slow tempo of the music. Although the music was exclusively recorded for the present study (not familiar with the clippings used), familiarity with the tones or combinations of tones cannot be fully excluded as all the participants were Indians. Phase-scrambled Indian Bollywood music significantly increased ISC, along with peak ISC seen during periods of escalated tension, unexpected transitions or boundaries of original music.[38,40] The hypothesis that repetition of the phrases may reduce ISC was partially true only for the group that listened to *raga Puriya*. Further, the music used in the present study did not have peaks, tension or emotionally charged variations as in the previous studies.[35,38] The music was created to produce an overall relaxing effect which might have resulted in more groupwise comparable results of ISC. It will be interesting to conduct future experiments to understand if the frequency of occurrence of notes within these modes leads to these correlated components and cross-frequency coupling variations on EEG.

Study limitations

Here are some methodological limitations in this study. Due to the lower density of the EEG electrodes, the relation of our finding to the DMN activity through source localisation analysis cannot be verified. Furthermore, phenomenological reports AI sessions that could be subjected to structured analysis and correlated with the EEG findings were not collected. These limitations need to be addressed in subsequent studies. Since the findings of EEG corroborate with autonomic changes and anxiety levels,[48] it would be interesting to understand whether these autonomic changes also exhibit ISC[94] and are modified after controlling for baseline data from the control group, as seen in the current EEG analysis. One other group, if added, would have further confirmed the findings concerning the musical scales/modes specifically, that is one group listening to the drone instrument (*Tanpura*) DI. This would have made the argument stronger with the second-level analysis where each music intervention group was statistically compared with the control group and cluster statistics (tfce) was employed. Although musical transitions are associated with typical change in EEG activity[98] in this study, as the onset of music intervention was manually marked, they are not temporally precise for studying the temporal dynamics of brain activity in association with the temporal dynamics of the respective musical clips. These will need to be addressed in a future study.

Implication of the findings

To the best of our knowledge, this is the 1st time that three acoustic stimuli in the form of Indian melodic modes have been studied scientifically as acoustic interventions for their short-term neuroplastic effect on the EEG power spectrum, with ISC-based component-level analysis, among a larger sample of healthy young individuals. The study of Indian music is important for several reasons: (a) To begin with, most of the music intervention studies have concentrated on using Western classical music, or other genres of music as an intervention. There are no studies to date that have analysed the changes in the level of engagement using EEG with CorrCA or ISC using Indian music. As the effect of music depends on the cultural background and music features, it was interesting to study more about the effects of using Indian music as an intervention, and among the music features a study of the musical scales, analysing the effect of listening to a systematic combination of tones on EEG was chosen; (b) intervention with culturally familiar tunes or melodies is shown to have a better effect than non-familiar tunes. Thus, Indian music was appropriate for the study conducted on Indians; (c) the tones and subtones of Indian music are unique compared to Western music as it is more often based on melody than on harmonic components. As explained in the introduction section, only a few modes of Indian music have been explored scientifically to understand the induced emotional and physiological responses. However, an objective measurement of the physiological changes during listening to Indian music is significantly lagging. The present study is therefore novel in the inclusion of Indian musical scales to understand the physiological effects of the same; (d) music intervention is now commonly included in the management regimens to prevent and treat neurological diseases such as stroke, dementia, schizophrenia, autism, depression and pain. Considering its beneficial effects on modifying the cognitive and emotional behaviours of a person, it is important to exploit all the possibilities of using different music features to come up with personalised music intervention options for neuropsychiatric conditions in the future. Thus, research implications of Indian music intervention add to the broad knowledge available currently on the neuroplastic effects of music therapy, learning, playing, and listening.

CONCLUSION

The observation of a reduction in globally distributed low-frequency activity and an increase in posterior dominant alpha-beta1 activity may be characteristic of passive listening to relaxing Indian modes, which may persist even after 10 min of the listening period. Among the modes, *raga Malkauns* showed this effect most prominently, followed by *raga Miyan ki Todi* and least by *raga Puriya*. As the increase in posterior alpha and low beta power is associated with DMN activity and a decrease in delta power with positive emotional memory, the complex correlated spectral pattern observed in both electrodes-level and component-level analysis in this study may indicate the observation of positive autobiographical memory while listening to musical modes and thus contribute to a relaxing experience. Further studies may need to include detailed phenomenological reports to support the findings and build a stronger scientific foundation for the use of music in medicine. As ISC-based brain activity is modulated by training, studies may try to explore the effect of musical training, exposure to different genres, correlation with music features and genre familiarity aspects. Emotionally stimulating musical stimuli need to be studied, as ISC is said to vary with time-based emotional stimuli such as stories or movies. To understand the exact neural substrates activated, it is better to use higher-density EEG or fMRI data. Finally, the points that understanding the differential effect of culturally relevant music modes and using inter-subject correlated measures for evaluation will help develop more powerful music therapy modules needs to be emphasised. Such short-term neuroplastic changes can benefit multiple mental health issues as well as improve personal and social well-being.

Ethical approval: The research/study approved by the Institutional Review Board at M S Ramaiah Medical College, number MSRMC/EC/2017, dated 25 July 2017.

Declaration of patient consent: The authors certify that they have obtained all appropriate patient consent.

Financial support and sponsorship: The project was funded by the Indian Council for Medical Research (ICMR) (2017–0174/F1), Government of India.

Conflicts of interest: There are no conflicts of interest.

Use of artificial intelligence (AI)-assisted technology for manuscript preparation: The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

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How to cite this article: Kunikullaya KU, Sasidharan A, Muradi V, Kunnavil R, Goturu J, Murthy NS. Electroencephalographic power spectrum and intersubject correlation on acoustic stimulation with modes of Indian music: A randomised controlled trial. Indian J Physiol Pharmacol. doi: 10.25259/IJPP_337_2024