Full-Length Article

Temporal changes in electroencephalographic power spectrum on listening to melodic scales of Indian music on healthy individuals - *a randomized controlled trial*

Kirthana Kunikullaya U[1], Arun Sasidharan[2], Rakshith Srinivasa[3], Jaisri Goturu[4], Nandagudi Srinivasa Murthy[5]

[1] *Institut de Recherche en Santé, Environment et Travail (IRSET), University of Rennes, Rennes, France*
[2] *Center for Consciousness Studies (CCS), Department of Neurophysiology, National Institute of Mental Health & Neuro Sciences (NIMHANS), Bangalore, Karnataka, India*
[3] *Department of Neurosurgery, M S Ramaiah Institute of Neurosciences, M S Ramaiah Memorial Hospital, MSR Nagar, Bangalore, Karnataka, India*
[4] *Department of Physiology, International Medical School, MSR Nagar, MSRIT Post, Bangalore, Karnataka, India*
[5] *Department of research and patents, Gokula Education Foundation, MSR Nagar, MSRIT Post, Bangalore, Karnataka, India*

Abstract

Music is said to affect the brain in different ways. To the best of our knowledge, research on the effect of passive listening to different melodic scales of Indian music on Electroencephalogram (EEG) power spectrum is rare to find. In this randomized control trial, 138 healthy subjects were randomly divided into 4 groups (A to D, n~32 in each group), of which A (raga Ahir Bhairav), B (raga Kaunsi Kanada), C (raga Bhimpalas) received music intervention while group D was the control arm. 19 channel scalp EEG was recorded for 30 minutes [10 min for each condition, before (BI), during (DI) and after intervention (AI)] and conducted power spectral analysis of waveforms in standard frequency bands. Two-way ANOVA was performed across conditions and groups, to determine the scalp regions showing significant changes, for each frequency band separately. Music seemed to induce a relaxation effect with scales B and C causing maximal effect. In line with existing literature, it may be concluded that listening to these melodic scales was associated with mind wandering effects and probable visual imagery/recall.

Keywords*: Music; electroencephalography; passive listening; brain waves; melodic scales*

multilingual abstract | **mmd.iammonline.com**

Introduction

Listening to music is an aesthetic pleasurable experience, that is subjective, depending upon individuals' choices, experience, and mood at that moment. Music has the ability to improve cognition, memory, sensory-motor responses, and communication[1,2]. According to the American Music Therapy Association "…music is used within a therapeutic relationship to address physical, emotional, cognitive, and social needs of individuals"[3]. Music may be used as medicine (passive listening) or as a therapy (active music-making)[4]. Music has been incorporated as an adjunct therapy to treat various neurological and psychiatric disorders[5]–[8]. The neuroscientific approach to music medicine peaked since the time it was shown that dopamine release in certain regions of the brain is increased at the moment of peak emotion to music, resulting in the chills response[9,10].

Studies using electroencephalogram (EEG) show that the power of most of the brain waves increases, indicating a 'mind-wandering effect', during passive listening to music[11]. Particularly, power in the alpha-band in the parietal and occipital areas of both hemispheres are shown to rise during listening to the music (popular classical symphonic pieces), with decrease in the peak frequency of the alpha-band. However, on repeated listening, these changes were attenuated[12,13]. Music being a complex combination of various features that include, pitch, tempo, dynamic contrasts, melodic scales, and so on, it is important to understand the effect of systematically combined musical features, in order to create the music that best suits one's need, for therapeutic purposes. Importantly, how the brain responds to passive listening to different melodic scales, irrespective of training, remains to be elucidated in detail. To the best of our knowledge, not many studies have assessed the effect of passive listening to specific melodic scales on the EEG power spectrum, and scientific studies on Indian melodic scales are meager, despite of the rich repertoire of melodic scales in the Indian music system.

India has a rich culture of music. Indian music is classified into Hindustani (North Indian) and Carnatic (South Indian) music[14,15]. Similar to western music melodic scales, Indian music is made up of 7 basic tones (*Saptaswara – represented as Sa, Ri, Ga, Ma, Pa, Dha and Ni,* equivalent to *Do, Re, Mi, Fa, So, La, Ti of western music)*[14]. *Raga /*

PRODUCTION NOTES: Address correspondence to:

Kirthana Kunikullaya U, E-mail: kirthana.rguhs@gmail.com

| COI statement: The authors declared that this article was funded by Rajiv Gandhi University of Health Sciences (RGUHS), Government of Karnataka, India (Unique ID: 15M009) and Indian council for Medical research, Government of India (ICMR) (2017-0174/F1). The authors have no conflict of interest to declare.

Clinical Trials identifier: NCT02691585, NCT03790462 (full trial protocol can be accessed from clinicaltrials.gov.in)

Melodic scales are a set of tones, in various combinations and permutations that in turn produces a specific melody, which can be improvised upon[16]. Indian melodic scales are associated with unique physiological effects, as conceptualized in ancient Indian music literature[. Further, as per recent studies, similar to western music, major modes of a melodic scale (>200 cents) tend to cause happy emotions while the minor modes cause sad emotions[17-20]. Based on these studies and the outcome of our previous study[14,21], the present research was taken up, where the effect of passive listening to three Indian melodic scales/ *ragas* on spectral power of EEG was evaluated, among healthy young individuals (as part of a larger study - clinicaltrials.gov)[24,25]. The hypothesis of the present study was passive listening to different melodic scales produces specific power spectral changes on EEG.

The primary objective of the present study was to evaluate the effect of passive listening to three selected melodic scales, on the EEG power spectrum. The secondary objective was to compare early versus late changes in EEG power on a time scale, during passive listening to the elaboration of the scale.

Research approach and methodology

A prospective, parallel-group, triple blinded, randomized controlled trial was conducted with an experimental study design, with a total sample of 140, randomized into 4 groups (n=32 participants in each group). Group A-C were subjected to music intervention [Hindustani melodic scale elaboration (*alaap*)], while group D was the control group. The 4 interventions were coded by a person uninvolved in the present study (stored as .mp3 files in a laptop, coded as A, B, C, D). The study protocol was approved by the institutional scientific committee on human research and ethical review board (Submission reference: MSRMC/EC/2016; Dated: 11/02/2016; MSRMC/EC/2017; Dated: 25/07/2017). The study period ranged from 2016 to 2019 (October 2016 - first recruitment and December 2019 - last recruitment). The research was conducted according to all aspects of the Declaration of Helsinki, apart from registration via an online questionnaire, where an informal consent, to answer the online questionnaire and further participation in the study was taken. Participants later provided written, informed consent to volunteer for the study in the lab.

Basis for sample size

The sample size was calculated (using nMaster 2.0 sample size software, Department of Biostatistics, CMC, Vellore) based on heart rate variability change after music therapy[which increased from a value of 17.4 (7.2) ms to 24.1 (15.5) ms. With an effect size of 0.59 and power of 90% and confidence interval of 95%, the minimum sample size (two-tailed test) was estimated to be 32[.

Recruitment, Inclusion and Exclusion criteria

The data was collected from a group of institutions with people from medical, dental, pharmacy, physiotherapy and engineering backgrounds in India. Healthy participants aged 18 – 30 years were invited to participate in the study via advertisements on the notice boards and social media posts[27]. Participants who responded to the call were sent an online questionnaire via google forms. Inclusion criteria were healthy individuals, aged 18-30 years, of either gender and who were non-smokers or alcoholics. Existence of any medical disorder (cardiovascular, renal, respiratory, endocrine, hearing problem, psychiatric disorders, stroke, epilepsy), pregnancy, body mass index (BMI)>30 kg/m^2; intake of drugs for any reason, other impairments that would prevent the subject from performing few experimental procedures were considered as exclusion criteria.

Baseline demographic data recording

About 200 individuals volunteered to participate, of which 171 answered the online questionnaire. Of this, we excluded 15 participants due to incomplete online data or high self-reported BMI. Thus, 156 participants were invited to the lab for further data collection of which n=6 declined (reason quoted - gel used for EEG recording on the hair). The participants (n=150) were explained about the study, the protocol, and the co-operation expected from them on visiting the lab. They were informed about their rights to withdraw their participation from the study. A general health check-up was done for all participants. The BMI was calculated and BP in the sitting position was measured twice with a five minutes' rest (Sphygmomanometer) in between[28]. Only normotensives were included as per inclusion criteria (12 more participants excluded based on lab recordings). The final total sample size was 138 (sample size in each group: A=36, B=33, C=36, and D=3).

Randomization

The total sample was randomized into four groups using a simple randomization technique wherein random numbers were generated using MS Excel (4 sets of 32 each) by the statistician. All the numbers generated and the group to which it belonged were written and kept in an opaque and sealed envelope. After baseline assessment of the participants, the envelope was opened by the research assistant who assigned the participants into one of the four arms. All investigators were blinded about the randomization and the participant allotment for intervention [Figure 1].

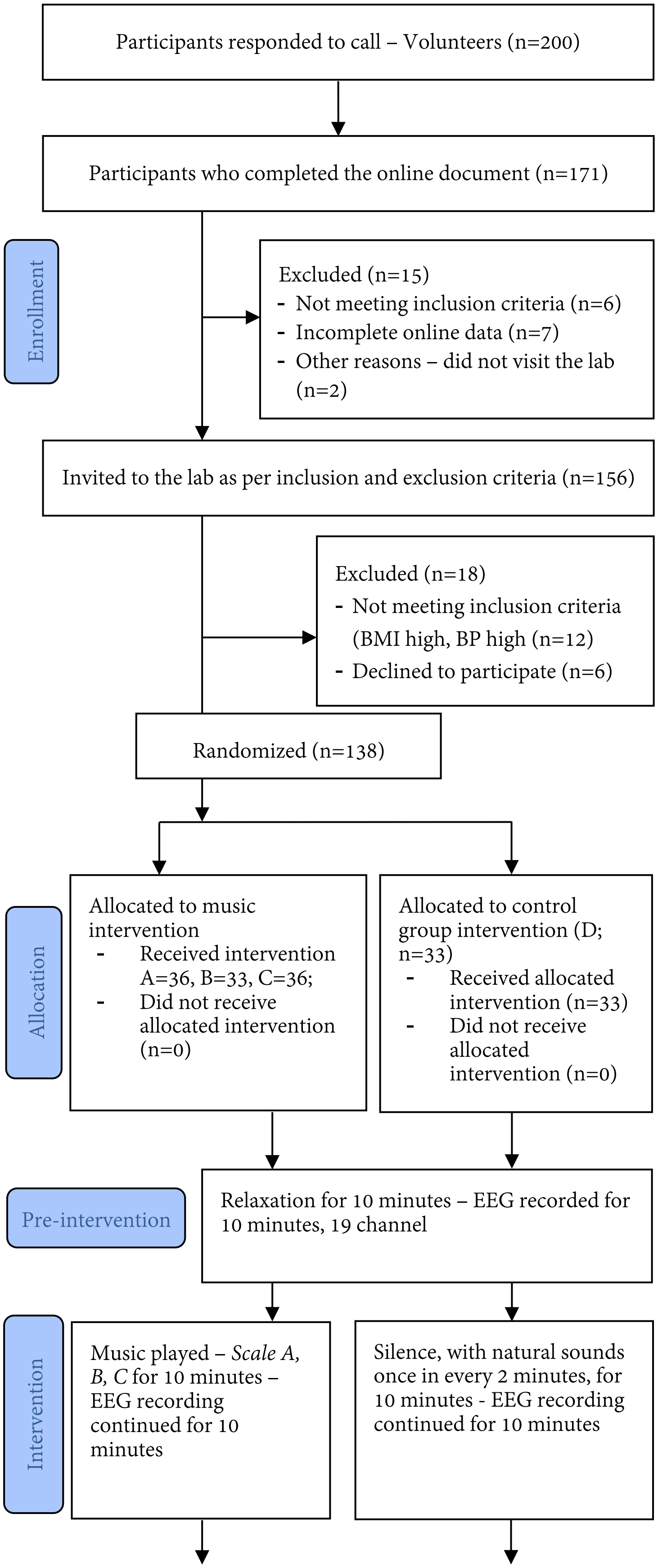
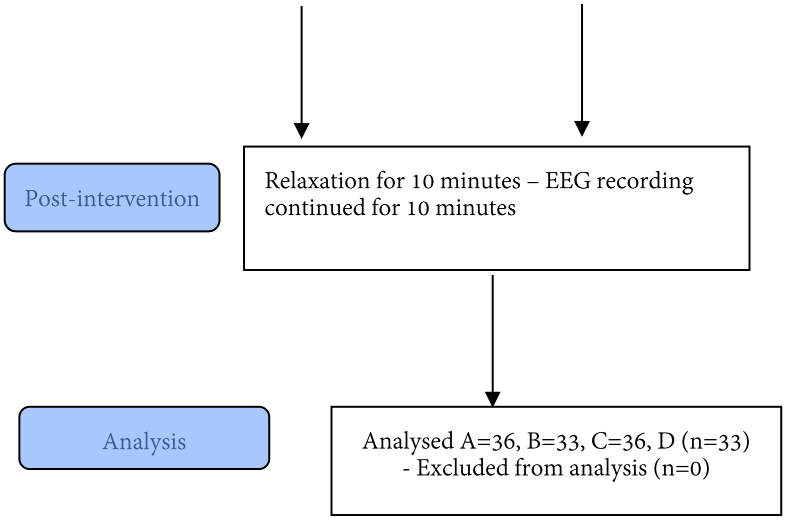


Figure 1: *Consort diagram of participant recruitment, intervention, and analysis. Note: n, sample size*



Baseline (Pre) and Post-intervention readings

Participants were asked to abstain from tea, coffee about 2 hours before the recording. All the recordings were carried out from 09:00 to 12:00 in an isolated examination room at a stable temperature (20 - 22°C), in a noise-free atmosphere. During the recording, the participants lay in a semi-darkened, electrically shielded, sound-attenuated room with their eyes closed[29]. It was ensured that no one entered the room once recordings began. In order to ensure proper connection of electrodes with the scalp, all the participants were asked take a head wash with shampoo without any conditioner or oil, prior to their visit to the lab. The scalp was cleaned with spirit and rubbed with skin preparing gel to achieve electrode impedance desirably less than 5 kilo-ohms. EEG signals were acquired using Galileo- NT BE Light (EB Neuro S.p.A., Italy) hardware and software under standard conditions. The EEG was recorded from the scalp by using silver-chloride (Ag-Cl) electrodes following the 10-20 international system of electrode placement guidelines[30]. The active electrodes were placed at 19 sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, C3, Cz, C4, T4, T5, P3, Pz, P4, T6, O1 & O2) and reference linked electrode at both ear lobes (A1 & A2). In addition, ECG leads were connected in Lead II arrangement, to detect ECG artifacts. A baseline EEG was recorded for five mins by minimizing eye blinks and movement to the best possible. All EEG recordings were done by the same technician. Pre-intervention EEG was recorded, when a person relaxed for about ten minutes, with their eyes closed. Intervention with respective audio clips as per the random group allocated was administered for the next ten minutes. At the end of ten minutes, the audio was stopped while the participants' post-intervention EEG recording continued, for another ten minutes. Participants were made to feel comfortable; the head was cleaned and then they were relieved.

Intervention

The participants recruited for the study were made to listen to the intervention through headphones (using headphones is considered ideal as per the review[31]), connected to the laptop, at uniform volume (50%). We instructed the participants to listen with eyes closed, mind relaxed, for the duration, it was played.

Control group (Group D) intervention
Since the complete recording lasted for 30 – 40 minutes duration, it was possible for the participants to feel sleepy or fall asleep, which in turn would modify the stress levels, altering the objective of the present study. Silence during the middle 10 minutes would not be an ideal for comparison, when the other group received music (audio stimulus). For these 2 reasons, natural sounds (birds chirping and flowing river) were played for 10 seconds once in every 2 minutes in the mid 10 minutes (intervention phase). This also ensured that the technician was blinded to the intervention given to Group D, who had to play an audio clip D.mp3 to this group.

Music intervention
Certain melodic scales/*ragas* have been said to normalize tension and BP, as per ancient music literature. They are *Ahir Bhairav, Bhimpalas, Bhupali, Hindol, Puriya, Kaunsi Kanada and Todi* [18,32]. In our previous study, *raga Bhimpalas* was shown to reduce BP after three months of music intervention specifically among pre-hypertensives[23]. Thus a study of other melodic scales was planned to understand acute changes in various electrophysiological parameters on passive listening to them (details in clinicaltrials.gov)[24,25]. In the current study, for music intervention, 3 randomly chosen melodic scales/ *ragas* [Group A - *raga* A (*Ahir Bhairav*), group B - *raga* B (*Kaunsi Kanada*), group C - *raga* C (*Bhimpalas*) were implemented. These scales were chosen as each differed from the other by 1 – 3 notes [More details of each scale – Supplementary file]. The music used for this study was pre-recorded instrumental (*Bansuri*) music playing *alaap* portion in the respective *raga* by an eminent flautist. Improvisation in Indian music has a specific set of rules and is called by specific names, as *alaap, jor, taan, neraval, swarakalpana,* etc [for a detailed review see reference[16,27]]. The *alaap,* is a type of improvisation done at the beginning of a composition or performance, that slowly introduces the notes/ *swaras* of a scale/ *raga*, within the framework of the scale, without a particular rhythm, with tempo rising as the scale is elaborated[16]. Passive listening to music was chosen, as active music making may not be an option for all participants and would introduce muscle artefacts.

Table 1: *Scale of Raga Ahir Bhairav, Kaunsi Kanada, Bhimpalas: the names of the notes in Hindustani music and Western scale, with their equivalent frequencies, Just intonations, and 12-TET*

Svara / Note	Hindustani name	Carnatic note	Staff note	Western scale Interval name	Freq	JI	12-TET
	Raga Ahir Bhairav (Raga A)						
S	Shadja	S	C	Perfect unison	1	0	0
r	Komal Rishab	R1	D♭	Minor second	16/15	112	100
G	Shuddha Gandhar	G3	E	Major third	5/4	386	400
M	Shuddha Madhyam	M1	F	Perfect fourth	4/3	498	500
P	Pancham	P	G	Perfect fifth	3/2	702	700
D	Shuddha Dhaivat	D2	A	Major sixth	5/3	884	900
n	Komal Nishad	N2	B♭	Minor seventh	9/5	1018	1000
	Raga Kausi Kanada (Raga B)						
S	Shadja	S	C	Perfect unison	1	0	0
R	Shuddha Rishab	R2	D	Major second	10/9	183	200
g	Komal Gandhar	G2	E♭	Minor third	6/5	316	300
M	Shuddha Madhyam	M1	F	Perfect fourth	4/3	498	500
P	Pancham	P	G	Perfect fifth	3/2	702	700
d	Komal Dhaivat	D1	A♭	Minor sixth	8/5	814	800
n	Komal Nishad	N2	B♭	Minor seventh	9/5	1018	1000
	Raga Bhimpalas (Raga C)						
S	Shadja	S	C	Perfect unison	1	0	0
R	Shuddha Rishab	R2	D	Major second	10/9	183	200
g	Komal Gandhar	G2	E♭	Minor third	6/5	316	300
M	Shuddha Madhyam	M1	F	Perfect fourth	4/3	498	500
P	Pancham	P	G	Perfect fifth	3/2	702	700
D	Shuddha Daivat	D2	A	Major sixth	5/3	884	900
n	Komal Nishad	N2	B♭	Minor seventh	9/5	1018	1000

Note: ♭ = Flat notes; Interval names, abbreviations, frequency ratios, and sizes in cents for just intonation (JI) as well as 12-tone equal temperament (12-TET) tunings are shown. The 12 intervals of the Western chromatic scale, comparably presented (More about JI and 12-TET in supplementary file).

EEG Analysis

Raw EEG data were converted to the standard European Data Format (EDF) (separate files for Before (BI), during (DI) and after intervention (AI) portions) using the free file converter tool of NPXLab[33]. BESS 6.5 software (Axxonet System Technologies, Bengaluru) was used for visual evaluation of the data for gross artifacts and overall signal quality. Participants with at least 1 min of good quality EEG (by visual inspection) for all the three portions, were chosen for further analysis. Twenty-one channel EEG data were imported into Gnu-Octave[34] for further pre-processing, power spectral analysis, and statistical evaluation (using custom scripts). Briefly, the data was band-pass filtered (FIR filter; 0.5-40Hz and 50Hz notch) using the functions of EEGLAB 15[35]. Noisy channels were automatically detected using routines of PREP Pipeline[36] if channels were bad for more than 40% of the data. Bad channels were deleted, splines interpolated and then the data were re-referenced to the average of all electrodes. The data was once more subjected to PREP Pipeline, and its segment level criteria were used to automatically determine artifactual data in segments of 1s. The non-artifactual portions were divided into non-overlapping 1s epochs and FFT-based power spectral analysis (single 1s Hanning window, 0.5Hz resolution) for each channel, and averaged across the epochs (values were log-transformed). Power values were binned into standard frequency bands (delta:1-4Hz, theta:4-8Hz, alpha:8-12Hz, beta1:13-20Hz, beta2:21-30Hz, and gamma:30-45Hz). For detailed evaluation of power spectral changes, power from frontal electrodes were used (Fp1, Fp2, F3, Fz, F4, F7 and F8). Midline frontal power (Fz), Frontal asymmetry (average power difference between right and left frontal electrodes) and temporal dynamics of average frontal power across time segments (2-minute non-overlapping time bins), were used for detailed evaluation.

Statistical analysis

Data were analyzed using SPSS software version 18.0 (SPSS Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.). The continuous variables were analyzed using descriptive statistics such as mean and SD or median and Interquartile Range as per skewness of data. The qualitative/categorical variables were analyzed using frequency and percentage. The normalcy of the data was checked by applying Kolmogorov-Smirnov Test.

Baseline comparisons were carried out using one-way Analysis of variance (ANOVA). For between-group comparisons, Kruskal Wallis Test was applied. At baseline, the categorical variables were tested for differences in proportion using the Chi/Square test of significance. Apart from tabulation, data was also depicted graphically using bar diagrams and line diagrams. P of ≤0.05 was considered significant.

For statistical comparison across all EEG electrodes, a permutation-based repeated measures ANOVA (1000 permutations/iterations) implemented using EEGLAB's 'statcond' function in MATLAB, was used. To take care of multiple comparisons for the 19 electrodes, false discovery rate (FDR) correction was applied to the p-values, and the alpha threshold was set to 0.05. Two-way ANOVA effects (condition, group/time, and interaction) followed by one-way ANOVA effects in band power between groups or conditions, were examined to identify the most prominent scalp regions and frequency bands.

To assess whole scalp changes normalised to BI (basline) period, the power spectral density values were also subjected to hierarchical general linear model analysis using the LIMO toolbox v2[37] as used in our previous work[38]. Here, 1st level analysis models multi-channel bandpower data at subject-level and generates beta values. As baseline normalisation, the beta values from AI condition were substracted from BI condition for each participant. For 2nd level between-group analysis, these baseline normalised participant-level power differences were done using robust statistics. Cluster statistics (threshold-free cluster enhancement or tfce)[39] with bootstrapping (500 iterations) was used to correct for multiple comparison effects across multiple channels and frequency bands. 95th percentile of bootstrapped tfce values was chosen to correspond to alpha threshold of 0.05.

Further statistical analysis on frontal power values (frontal asymmetry and temporal change within condition) was done using R software, using libraries like "dplyr" for data operations, "WRS2" for robust statistics, and "ggplot2" and "ggstatplot" for plotting. Robust one-way repeated measures ANOVA on trimmed mean followed by post-hoc Yuen's trimmed mean test (20% trimming) was used[40], and p-values adjusted using Holm's correction[41].

Results

The primary endpoint of this study was the change in the power spectrum of EEG waves at the end of the intervention. The 4 groups were similar concerning the sociodemographic characteristics, with statistically no significant difference seen. The baseline data and socio-demographic details are given in the supplementary file [S1 Table S1].

EEG Findings:

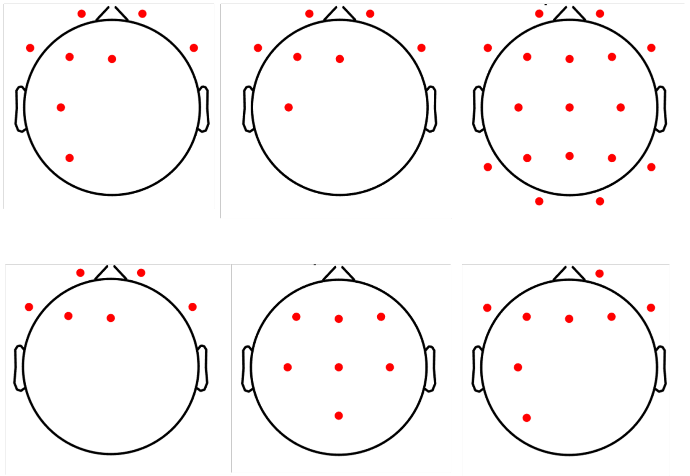
Scalp distribution of EEG power changes across conditions between groups

Both between-condition and between-group changes showed major changes in the frontal electrode sites [Figure 2]. Between-condition changes were significant for two music groups: Group B in alpha band and Group C in beta1 band.

Between-group changes were significant for AI condition in theta, beta1, and beta2 bands; however, BI condition also showed significant group difference in alpha band.

Figure 2: *Summary of power spectral changes for the between-group and between-condition comparisons. The shaded cells in the table highlight the statistically significant comparisons following one-way ANOVA with the corresponding unfilled head maps (a-f). The red dots in the head maps represent the electrodes with significant p-values. The p-values are FDR-corrected for multiple comparisons.*

	Between-Group			**Between-Condition**			
	BI	DI	AI	A	B	C	D
δ							
θ			(a)				
α	(b)				(c)		
β1			(d)			(e)	
β2			(f)				

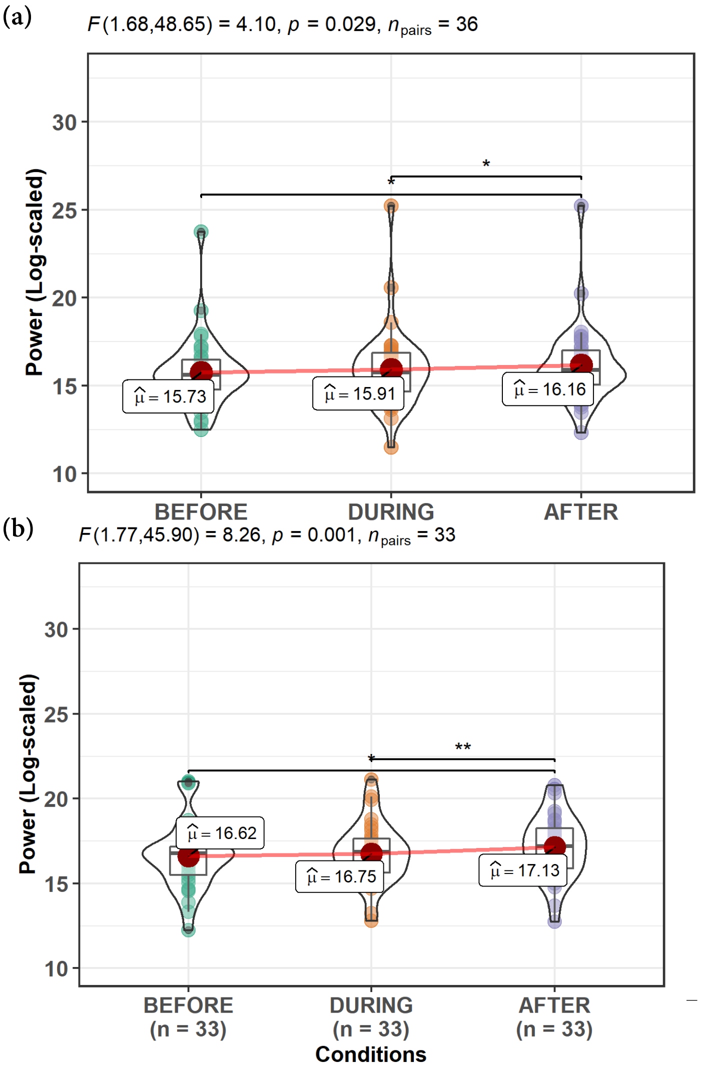


Between-Condition changes in Average Frontal Power within each group

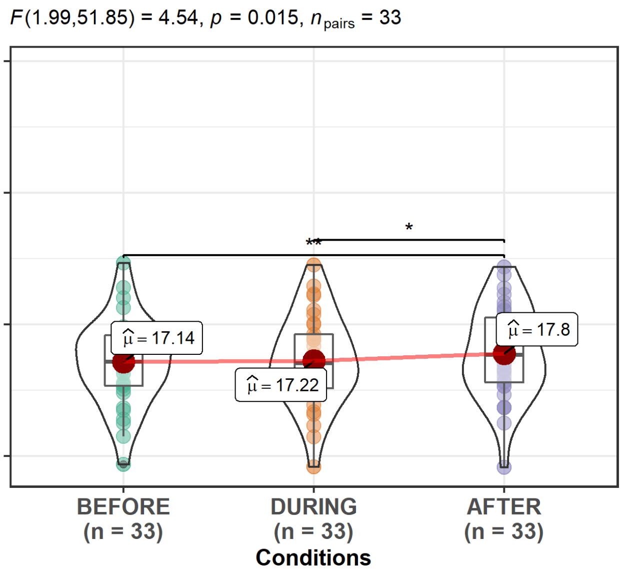
Using midline frontal electrode (Fz) as the representative site, power values were assessed between the three conditions for each frequency band and group [Figure 3]. Group B exhibited a significant increase in alpha and beta1 power, and Group C showed the increase for theta and beta1, across the intervention period (BI to AI). Group D (Control group) showed a significant increase in theta power by the end of the intervention period. Group A showed no such changes. Also, none of the groups showed changes in delta and beta2 power across the conditions.

Figure 3: *Between-Condition frontal power changes. The table summarizes the findings from delta, theta, alpha, beta1 and beta2 bands for each group. The arrows in the table show significant power changes and their sizes are proportional to the power difference between BI and AI conditions. The violin-cum-box plots (a-e) show details of the statistically significant findings. The horizontal lines with stars on violin-cum-box plots denote the significant post-hoc differences.*

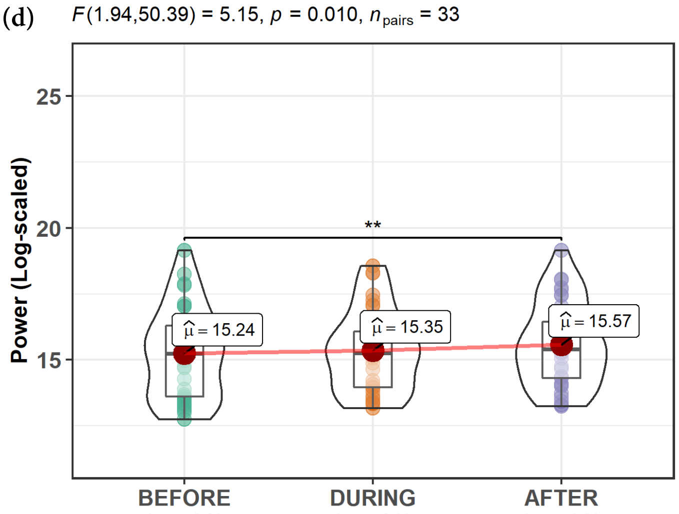
	Between-Condition			
	A	B	C	D
δ				
θ			↑(a)	↑(b)
α		↑(c)		
β1		↑(d)	↑(e)	
β2				



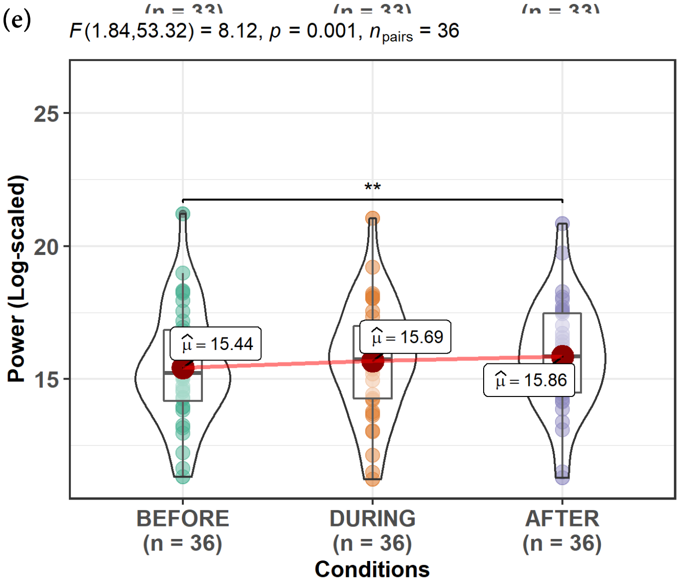
(c)



(d)



(e)



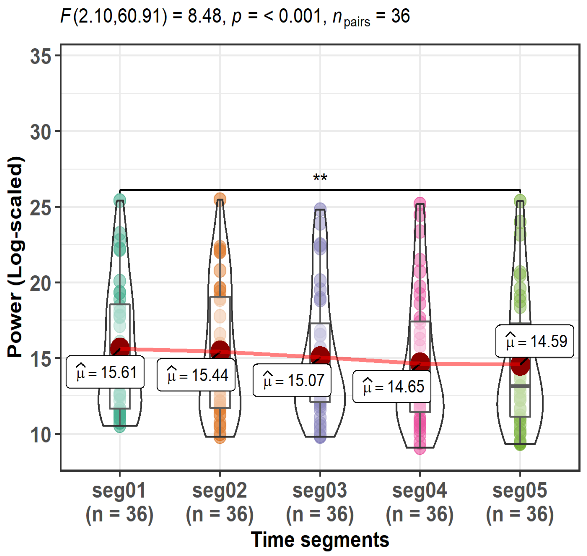
Between-Condition changes in temporal dynamics of Frontal band power within each group

This analysis was done to examine whether the between-condition changes seen in frontal band power are temporally consistent within each condition, by dividing the 10 mins period into 2 mins segments. Overall, in both alpha and beta1 bands, a decrease in power across the 2 mins segments was seen in all the music groups (groups A , B and C), but during different conditions. Drop in alpha band power across segments was significant BI in group A and C, and DI and AI in group B [Figure 4]. Drop in beta1 band power across segments was significant BI in group C, DI in group B and AI in group A [Figure 4]. Whereas, group D (control group) did not show such significant power drop pattern (except in theta band).

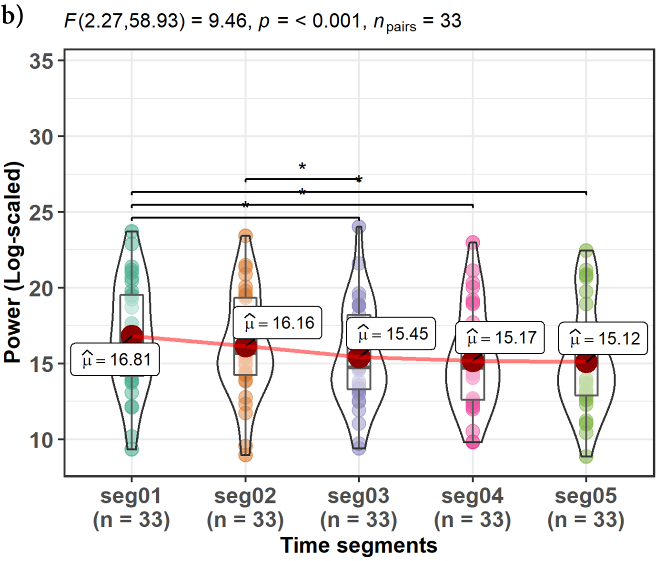
Figure 4: *Temporal dynamics of Frontal alpha power within each condition. The tables summarizes the findings from delta, theta, alpha, beta1 and beta2 bands. A representative violin-cum-box plot (a to e) for prominent power changes are shown. The arrows in the table show significant first versus last segment drop in power and their sizes are proportional to the power difference for each band. The horizontal lines with stars on violin-cum-box plots denote the significant post-hoc differences.*

	A					B					C					D				
	δ	θ	α	β1	β2	δ	θ	α	β1	β2	δ	θ	α	β1	β2	δ	θ	α	β1	β2
BI			↓								↓		↓	↓	↓					
DI			(a) ↓					(b) ↓	(c) ↓								↓			
AI				(d) ↓	↓			(e) ↓							↓					

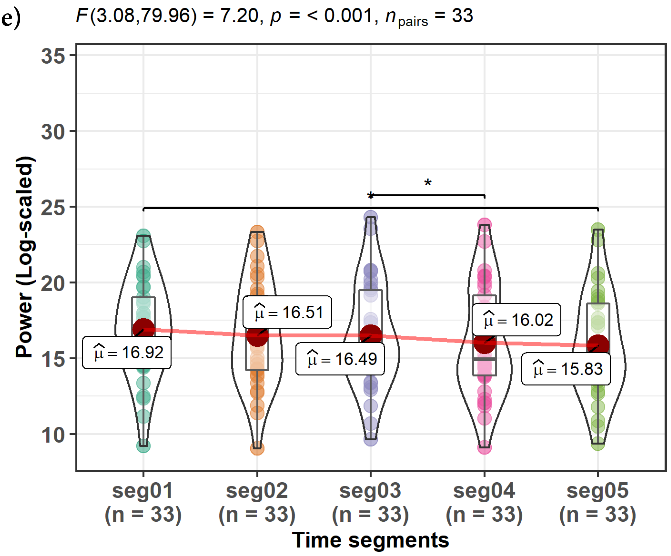
(a)



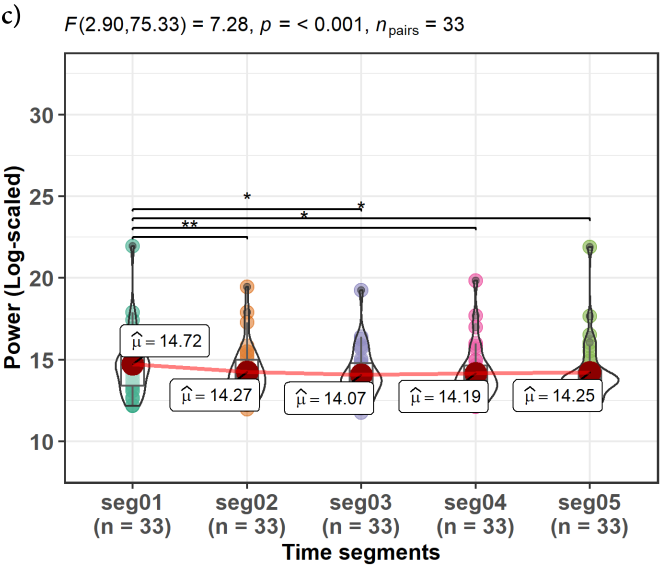
(b)



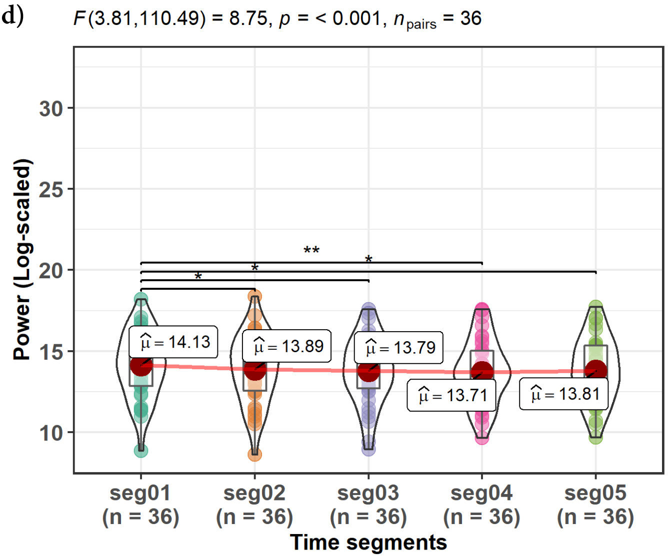
(e)



(c)



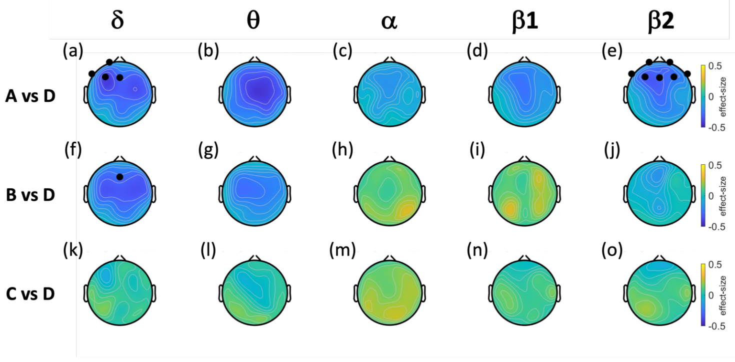
(d)



Between-Group changes in baseline-relative power

To handle the between-group changes in spectral power during the BI condition (i.e., baseline differences between groups), we used a hierarchical general linear model approach and subtracted BI data from AI data within each subject, for between-group comparisons across the scalp electrodes. In comparison to control group (group D), group A showed significant drop in delta and beta2 power across multiple frontal sites, and group B showed decrease in delta power in a single midline frontal site. Group C did not seem to differ from group D [Figure 5].

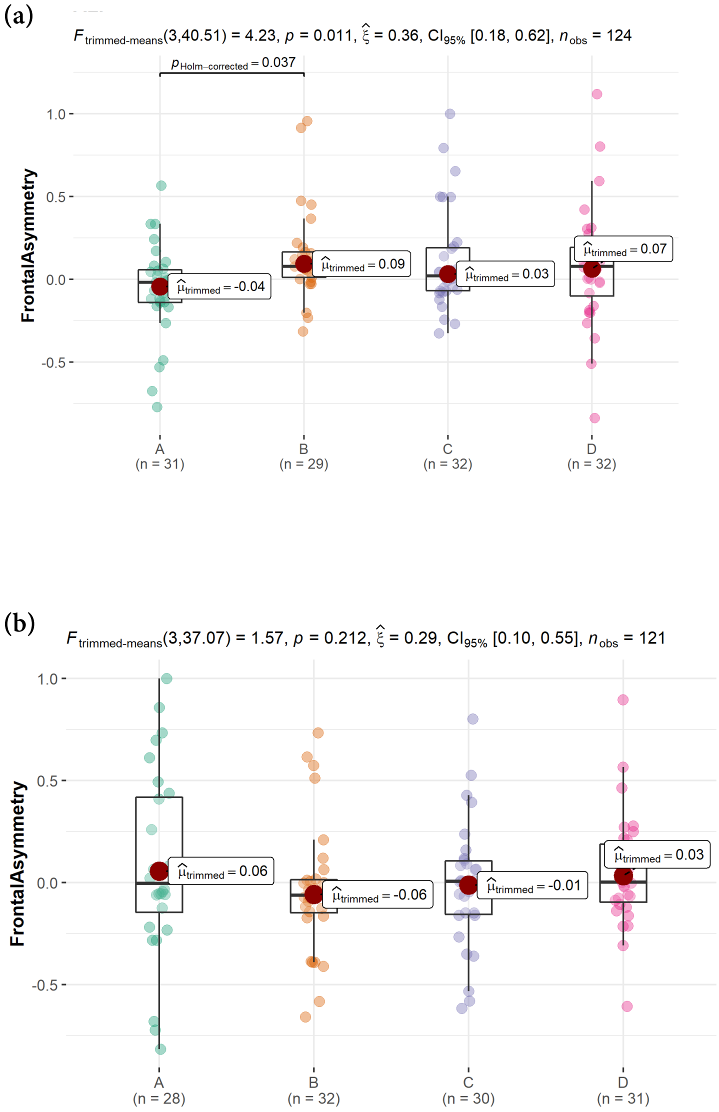
Figure 5: *Scalp distribution of Between-Group basline relative power changes. Different rows represent head maps of each music group (A, B & C), and different columns represent the different frequency bands (DEL-delta, THE-theta, ALP-alpha, BET1-beta1 and BET2-beta2). Blue shade indicates decrease and Yellow shade indicates increase in power relative to the control group (Group D), represented as effect-size (cohen's d). Black dots represent statistically significant electrodes based on clustering statistics (tfce).*



Between-Group changes in Frontal band power asymmetry across conditions

Frontal asymmetry was computed as the difference in band power (baseline normalized) between the right and left frontal electrodes, Group A showed significantly lower asymmetry value for alpha band (left > right) compared to Group B for DI condition [Figure 6]. No significant difference were observed in other bands and conditions.

Figure 6: *Change in Frontal alpha asymmetry across groups for (a) DI and (b) AI conditions. Horizontal line over the box plots denote significant post-hoc differences.*



Discussion

In this study, for the first time power spectral changes (recorded via EEG) on passive listening to three distinct melodic scales of Indian music, have been scientifically evaluated, among young healthy individuals. The intervention lasted for 10 minutes duration. The power of the five EEG oscillations - delta, theta, alpha, beta1, and beta2 were analyzed. Two-way ANOVA across scalp showed that both between-condition (AI) and between-group (Groups B and C) changes were significant in frontal and midline regions involving theta, alpha and beta1 bands, while between-group differences existed (in alpha power) even during BI. Between-condition analysis using frontal electrodes exhibited increased alpha and beta1 power in group B, and increased theta and beta1 power in group C, across the intervention. Also, between short segments of each condition (temporal analysis), Group B showed significant drop in frontal alpha and beta1 power DI, while Group A and C showed drop in beta2 power AI. In contrast, the between-group analysis using baseline-normalized power showed that Group A differed most from Group D, with significant decrease in frontal delta and beta2 AI. Further frontal asymmetry was analyzed to measure the activation of the avoidance-withdrawal system associated with negative emotions [42]. In that group A differed significantly in frontal alpha asymmetry (more alpha on left) from group B, DI.

Therefore, two results based on two different analysis approaches were obtained. When the conditions were treated separately, group B (listening to *raga Kaunsi Kanada*) and group C (listening to *raga Bhimpalas*) showed a significant increase in frontal theta, alpha and beta1 power across music intervention, and drop in the same band powers within the conditions. But, when put into a general linear model and contrasted against BI, Group A (listening to *raga Ahir Bhairav*) showed decrease in frontal delta and beta2 power relative to Group D. This could be because of the inherent differences in the approaches or due to probable complex relation between the oscillatory state BI (baseline) as well as DI and AI periods. A plausible explanation that incorporates both these findings is provided here forth.

As midline frontal power in several low-frequency bands could represent the activity of default mode network (DMN) (an indicator of mind-wandering); the wide variations in frequency bands with different melodic scales would point to modulation to this brain network. The rise in frontal midline theta seen especially in Group D could either indicate an increase in focused attention[43] due to increased drowsiness accompanied by increased long-range theta connectivity or listening to non-music natural sounds[44]. Whereas a similar increase in theta seen in Group C (listening to *raga Bhimpalas*) was accompanied by increase in beta1 power (instead of decrease), which is unlikely to be due to drowsiness. The rise in frontal alpha and beta1 in Group B & C, listening to *raga Kaunsi Kanada* and *raga Bhimpalas* respectively, may suggest disengagement from external information processing after music listening. This could mean relaxation, involving mind wandering[11]. An increase in both frontal alpha (or lower beta) and theta has been attributed to disengagement of prefrontal brain networks in maintaining efficient internal attention and top-down inhibition of irrelevant sensory processing or interfering with information retrieval, as seen during meditation states[46]. Frontal alpha has been linked to creative ideations and music imagery[47] and is reviewed in[48].

In contrast, the significant drop of frontal delta and beta2 power in Group A (listening to *Ahir Bhairav*), based on baseline-relative power analysis, indicate a lower DMN activity. It should be noted that DMN activity can be modulated by the type of music (happy or sad), so that participants perceiving intense negative emotions tend to withdraw their attention inwards and engage in self-referential cognitive processes[49]. Furthermore, significant frontal alpha asymmetry towards the left was seen in Group A, which is usually associated with negative mentation/mood[50,51]. A recent study observed a similar drop in delta power during listening to in rapid eye movement brain-wave music versus slow wave sleep brain-wave music (indicating higher cortical activation)[52]. Taken together, Group B and C (unlike Group A) may indeed be showing increased mind-wandering like state which is probably not part of negative cogitation and could reflect a more relaxed state.

Since previous studies[53] have shown that the effects of music could vary across listening duration (like the first few minutes of listening or at stopping of music), we further split the 10 minutes of EEG data into 2-minute segments within each condition (before, during and after the music), studying the temporal dynamics of frontal power in all bands. Interestingly, most groups either did not show any significant change or showed a gradual decline in specific band power over time. Despite an increase in alpha power during music listening we observed a uniform reduction in alpha on temporal analysis within the during music condition in Group B. Group B showed a drop in alpha and beta1 power during music, while group C showed drop in beta2 power after music. This shows that the condition effects could differ between groups between earlier epochs and later epochs. Studies have shown that a general decline in the power of alpha after closing the eyes is related to sleepiness or low alertness[54]. Whereas an increase in alpha power, from a background of lower power, is found to be associated with divergent thinking and memory recall[55]. A similar observation was made in a previous similar study, among 14 healthy volunteers (18-45 years) in the state of rest and during listening to music (popular classical symphonic pieces). Though they observed increased EEG alpha power in the bilateral parietal and occipital areas of both hemispheres, repeated exposure to the same musical fragment tended to reduce this band power. Further, the peak frequency of the alpha-band reduced significantly during listening. The authors concluded that these findings could suggest a reduction in the level of CNS activation on continued listening to music[12]. Similarly, in another EEG study conducted during three conditions: a) Resting-state with eyes closed (3 minutes) b) Listening to white noise (20 seconds) c) listening to part #1 of BWV 1041 - J.S. Bach Violin Concerto in A minor (20 seconds), the researchers observed a uniform reduction of alpha power and increase in the high gamma power localized in the electrodes around the auditory-cortex brain regions (e.g. FT7, TP7, FC3, FT8, T4), during music listening[56]. Therefore, in the current study, a general drop in frontal alpha and beta1 may be a sign of relaxation/sleepiness induced by silence or certain melodic scales; while some *ragas* (*Kaunsi Kanada*) may allow greater divergent thoughts in this state. The effect of music listening should thus be explored in the future, after considering this temporal change within state as well as across states.

Recent neuroscience research suggests that at least 18 areas are activated in the brain during the performance of specific tasks of making or hearing music[57]. Both hemispheres of the brain are needed for a complete music experience, while the frontal cortex has a significant role in rhythm and melody perception. The centers for perceiving pitch, melody, harmony, and rhythm are identified in the right hemisphere. The left hemisphere is important for processing rapid changes in frequency and intensity of tune[58]. Therefore, the frontal asymmetry seen in this study between Group A and Group B could have also been due to such differences in musical preception, inherent to those melodic scales.

In the present study, we also observed a significant rise in beta1 power in groups B and C, across music listening. Increased beta power, during unconstrained music listening, is difficult to explain, as tonic beta band power increase is generally reported during increased tonic alertness[59]. A rise in beta in the perisylvian regions was said to be associated with semantic processing during music listening[53]. In similar lines a previous study on passive listening to Indonesian Gamelan music by 8 healthy volunteers showed that beta power significantly rose during music condition, while no significant effect of condition was found on alpha power. Listening to music increased cerebral blood flow freshly in the posterior portions of the precuneus bilaterally that positively correlated with beta power[60]. This, probably explains the association between music and mental events, like in music-evoked memory recall or visual imagery[61] or enhanced cognitive function[47]. Enhanced spatial performance after exposure to music has also been shown to be associated with lower alpha2 (10.5-11.97 Hz) and higher beta1 (12.02-17.97 Hz)[48].

Increase in frontal theta power was observed in Group C (*raga Bhimpalas*). Many prior music intervention studies have also observed similar changes in theta power. As study on depressive patients on long-term music therapy observed a significant increase in the left frontotemporal alpha power and an increase in left frontocentral and the right temporoparietal theta power[62]. A music therapy study (monochord sounds) among cancer patients showed increased posterior theta power and a decrease in mid-frontal beta and posterior alpha bands, along with a reduction in the degree of anxiety[63]. Listening to the musical piece of Mozart, Sonata K448 improved spatial performance along with reduced theta power in the left temporal area; increased beta in the left temporal, the left frontal, and the right temporal regions; increased alpha1 power on the left temporal region[48]. Passive listening to low to moderate intensity classical music increased the power of alpha_2, beta_1, beta_2, and gamma bands generalized over the brain cortex. But moderate and high-intensity rock music increased the power of θ and α_1 frequency bands[64]. Listening to highly pleasant music was associated with higher theta activity over the frontocentral (FC) area and alpha over the parietooccipital area, and a gradual increase in the oscillatory power over time. The theta power over the frontocentral area is said to thus correlate with pleasantness while listening to music[65]. In another study, on the impact of the valence of musical sounds (e.g., consonant and dissonant chords) using intracranial electrodes, it was found that low-frequency power increased in the auditory cortex with a gradual rise in theta and alpha power in the amygdala and orbitofrontal cortex (probable higher analysis of music) with time. Three participants showed an increase in the alpha, theta, and beta1 waves in the orbitofrontal cortex while listening to consonant sounds[66]. Positively valenced pieces of music elicit a greater theta power in mid-frontal electrodes than do negatively valenced pieces. Furthermore, this effect increases towards the end of a piece of music. According to the authors, this type of gradual rise in theta activity is connected not only to attentional but also to emotional functions[67]. A similar gradual rise in theta was observed in group C (*raga Bhimpalas*) in the current study.

The exact cause for the above effects may be difficult to be pointed out. This is because the music used was not just tones of the melodic scale, but an elaboration of the scale, note by note, with its prominent phrases appearing, some repeated notes, and so forth. The music unfolds itself to produce a particular effect on the listener. However, among the scales we used and based on previous literature[68], it may be said that emotions depend on the tonal structure of the scale. In that, major intervals (*Shuddh Swaras*) cause happy emotions, while minor intervals (*Komal Swaras*) cause sad emotions. In the present study, *Raga Ahir Bhairav* had a minor second as one of its notes, which is inversely correlated with happy, calm, or romantic emotion[21,68]. But, *Kaunsi Kanada* in spite of having three minor tones, did not have a similar effect, which is in line with the previous observation that minor second had the maximal negative affect. Though tonal-affect relationship conclusions are difficult to draw in current study a better understanding of cause-effect would be possible, probably on the extraction of the musical components of the clips used and correlating the findings with the same. One of the study limitations was that subjective emotions induced by the scales were not recorded. Nevertheless, the results are in line with the findings of lower state anxiety in with group B and C after music intervention compared to group A [69]. Similar to previous literature, intervention with natural sounds and silence did cause a relaxation effect as well.

To the best of our knowledge, for the first time, three different Indian melodic scales have been studied in detail concerning their electroencephalographic effect during the passive listening task, among young healthy individuals. Indian music was used as a model due to its predefined structured aspects during improvisation. The sample size was adequate for statistical comparisons and conclusions to be drawn. The music used was standardized, concerning the instrument, musical components, or absence of percussion.

It may thus be concluded that each melodic scale has a specific effect on the brain as analyzed using scalp EEG, with an overall relaxation effect observed on passive listening. Of the three clips that were used in the current study, *raga Kaunsi Kanada* and *raga Bhimpalas* could have caused an increase in the activity of the default mode network (DMN) (mind-wandering effect on passive listening to music), while *raga Ahir Bhairav* caused the opposite. Frontal alpha and theta increase seen with the former two melodic scales pointed towards prefrontal brain activity, causing top-down inhibition of irrelevant sensory processing and higher internal attention. This may also be due to creative ideations and music imagery.

Though we did not begin with the objective of understanding the emotions generated by a *raga,* we may remark that *raga Kaunsi Kanada* produced happy/pleasant emotions among the participants, especially at the end of the intervention.

The different melodic scales of Indian music show differential effect on the frontal brain oscillation dynamics associated with mind wandering and visual imagery/recall, which is in turn dependent on the baseline brain oscillatory state of each individual before music listening. Future studies should consider the temporal dynamics of EEG data to study the temporal effects of music as it unfolds in time. Though scale-specific effects have been observed using Indian music among young healthy Indians in this study, which could be attributed to the tones/ notes in the scale and its arrangements or familiarity with the type of music, future studies should explore cross-cultural effects as well.

References

1. M. L. Chanda and D. J. Levitin, The neurochemistry of music, *Trends Cogn. Sci.*, vol. 17, no. 4, pp. 179–193, Apr. 2013, doi: 10.1016/j.tics.2013.02.007.
2. K. C. Barrett, R. Ashley, D. L. Strait, N. Kraus, Art and science: how musical training shapes the brain, *Front. Psychol.*, vol. 4, 2013, doi: 10.3389/fpsyg.2013.00713.
3. American Music Therapy Association | American Music Therapy Association (AMTA). https://www.musictherapy.org/ (accessed May 13, 2020).

4. C. Dileo, Effects of music and music therapy on medical patients: a meta-analysis of the research and implications for the future, *J. Soc. Integr. Oncol.*, vol. 4, no. 2, pp. 67–70, 2006.
5. T. Särkämö *et al.*, Music listening enhances cognitive recovery and mood after middle cerebral artery stroke, *Brain J. Neurol.*, vol. 131, no. Pt 3, pp. 866–876, Mar. 2008, doi: 10.1093/brain/awn013.
6. M. Geretsegger, K. A. Mössler, Ł. Bieleninik, X.-J. Chen, T. O. Heldal, and C. Gold, Music therapy for people with schizophrenia and schizophrenia-like disorders, *Cochrane Database Syst. Rev.*, no. 5, 2017, doi: 10.1002/14651858.CD004025.pub4.
7. M. Sharda *et al.*, Music improves social communication and auditory–motor connectivity in children with autism, *Transl. Psychiatry*, vol. 8, Oct. 2018, doi: 10.1038/s41398-018-0287-3.
8. A. Alves-Pinto, V. Turova, T. Blumenstein, and R. Lampe, The Case for Musical Instrument Training in Cerebral Palsy for Neurorehabilitation, *Neural Plast.*, vol. 2016, 2016, doi: 10.1155/2016/1072301.
9. V. N. Salimpoor, M. Benovoy, K. Larcher, A. Dagher, and R. J. Zatorre, Anatomically distinct dopamine release during anticipation and experience of peak emotion to music, *Nat. Neurosci.*, vol. 14, no. 2, pp. 257–262, Feb. 2011, doi: 10.1038/nn.2726.
10. V. N. Salimpoor, M. Benovoy, G. Longo, J. R. Cooperstock, and R. J. Zatorre, The Rewarding Aspects of Music Listening Are Related to Degree of Emotional Arousal, *PLoS ONE*, vol. 4, no. 10, Oct. 2009, doi: 10.1371/journal.pone.0007487.
11. A. Markovic, J. Kühnis, and L. Jäncke, Task Context Influences Brain Activation during Music Listening, *Front. Hum. Neurosci.*, vol. 11, Jun. 2017, doi: 10.3389/fnhum.2017.00342.
12. A. V. Sulimov, I. V. Liubimova, R. A. Pavlygina, and V. I. Davydov, Spectral analysis of the human EEG while listening to music, *Zh. Vyssh. Nerv. Deiat. Im. I. P. Pavlova*, vol. 50, no. 1, pp. 62–67, Feb. 2000.
13. J. Madsen, E. H. Margulis, R. Simchy-Gross, and L. C. Parra, Music synchronizes brainwaves across listeners with strong effects of repetition, familiarity and training, *Sci. Rep.*, vol. 9, no. 1, Dec. 2019, doi: 10.1038/s41598-019-40254-w.
14. D. L. Bowling, J. Sundararajan, S. Han, and D. Purves, Expression of Emotion in Eastern and Western Music Mirrors Vocalization, *PLoS ONE*, vol. 7, no. 3, Mar. 2012, doi: 10.1371/journal.pone.0031942.
15. A. A. Bardekar and A. A. Gurjar, Empirical Study of Indian Classical Ragas Structure and its Emotional Influence on Human Body For Music Therapy, no. 4, p. 7, 2016.
16. N. A. Jairazbhoy, *The Rāgs of North Indian Music: Their Structure and Evolution*. Popular Prakashan, 1995.
17. Maharishi Ayurveda | The Health Benefits of Different Ragas. https://www.maharishi.co.uk/the-health-benefits-of-different-ragas (accessed Jun. 13, 2018).
18. RAGAS FOR HEALTH, *NAADOPASANA*. http://sruthilaya.weebly.com/ragas-for-health.html (accessed Jun. 13, 2018).
19. A. McNeil, Ragas, Recipes, and Rasas, *Oxford Handbooks Online*, Apr. 07, 2015. https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199935321.001.0001/oxfordhb-9780199935321-e-43 (accessed Apr. 29, 2020).
20. J. Sarkar and U. Biswas, An effect of Raga Therapy on our human body, *Int. J. Humanit. Soc. Sci. Res.*, vol. 1, no. 1, pp. 40–43, Nov. 2015.
21. [A. Mathur, S. H. Vijayakumar, B. Chakrabarti, and N. C. Singh, Emotional responses to Hindustani raga music: the role of musical structure, *Front. Psychol.*, vol. 6, p. 513, 2015, doi: 10.3389/fpsyg.2015.00513.
22. K. U. Kunikullaya *et al.*, Music versus lifestyle on the autonomic nervous system of prehypertensives and hypertensives--a randomized control trial, *Complement. Ther. Med.*, vol. 23, no. 5, pp. 733–740, Oct. 2015, doi: 10.1016/j.ctim.2015.08.003.
23. K. U. Kunikullaya *et al.*, Combination of music with lifestyle modification versus lifestyle modification alone on blood pressure reduction - A randomized controlled trial, *Complement. Ther. Clin. Pract.*, vol. 23, pp. 102–109, May 2016, doi: 10.1016/j.ctcp.2015.05.004.
24. Indian Ragas on Health - a Electrophysiological Study (RAGA-1) - Full Text View - ClinicalTrials.gov. https://clinicaltrials.gov/ct2/show/NCT02691585 (accessed Jul. 01, 2019).
25. Select Indian Ragas on Electrophysiological Parameters - Full Text View - ClinicalTrials.gov. https://clinicaltrials.gov/ct2/show/NCT03790462 (accessed Jul. 01, 2019).
26. K. Okada *et al.*, Effects of music therapy on autonomic nervous system activity, incidence of heart failure events, and plasma cytokine and catecholamine levels in elderly patients with cerebrovascular disease and dementia, *Int. Heart. J.*, vol. 50, no. 1, pp. 95–110, Jan. 2009.
27. Acute effects of passive listening to Indian musical scale on blood pressure and heart rate variability among healthy young individuals – a randomized controlled trial | bioRxiv. https://www.biorxiv.org/content/10.1101/2020.05.03.073916v1 (accessed May 13, 2020).
28. A. Molarius, K. Kuulasmaa, and S. Sans, Quality Assessment of Weight and Height Measurements in the WHO MONICA Project, Nov. 05, 1999. https://www.thl.fi/publications/monica/bmi/bmiqa20.htm (accessed May 02, 2020).
29. M. J. Aminoff, Electroencephalography: General Principles and Clinical Applications, in *Aminoff's electrodiagnosis in clinical neurology*, 6. ed., Philadelphia: Elsevier Saunders, 2012.
30. The Ten Twenty Electrode System: International Federation of Societies for Electroencephalography and Clinical Neurophysiology, *Am. J. EEG Technol.*, vol. 1, no. 1, pp. 13–19, Mar. 1961, doi: 10.1080/00029238.1961.11080571.
31. [E. H. Idrobo-Ávila, H. Loaiza-Correa, L. van Noorden, F. G. Muñoz-Bolaños, and R. Vargas-Cañas, Different Types of Sounds and Their Relationship With the Electrocardiographic Signals and the Cardiovascular System - Review, *Front. Physiol.*, vol. 9, p. 525, 2018, doi: 10.3389/fphys.2018.00525.
32. Maharishi Ayurveda | The Health Benefits of Different Ragas. https://www.maharishi.co.uk/the-health-benefits-of-different-ragas (accessed Aug. 23, 2018).
33. NPXLab Suite. http://www.brainterface.com/joomla2/npxlab-suite (accessed May 15, 2020).
34. GNU Octave. https://www.gnu.org/software/octave/ (accessed May 15, 2020).
35. EEGLAB. https://sccn.ucsd.edu/eeglab/index.php (accessed Jan. 05, 2020).
36. N. Bigdely-Shamlo, T. Mullen, C. Kothe, K.-M. Su, and K. A. Robbins, The PREP pipeline: standardized preprocessing for large-scale EEG analysis, *Front. Neuroinformatics*, vol. 9, Jun. 2015, doi: 10.3389/fninf.2015.00016.
37. [LIMO EEG: a toolbox for hierarchical LInear MOdeling of ElectroEncephaloGraphic data - PubMed. https://pubmed.ncbi.nlm.nih.gov/21403915/ (accessed Dec. 08, 2021).
38. S. Sharma *et al.*, Indian classical music with incremental variation in tempo and octave promotes better anxiety reduction and controlled mind wandering—A randomised controlled EEG

study, *EXPLORE*, vol. 17, no. 2, pp. 115–121, Mar. 2021, doi: 10.1016/j.explore.2020.02.013.

39. S. M. Smith and T. E. Nichols, Threshold-free cluster enhancement: addressing problems of smoothing, threshold dependence and localisation in cluster inference, *NeuroImage*, vol. 44, no. 1, pp. 83–98, Jan. 2009, doi: 10.1016/j.neuroimage.2008.03.061.
40. P. Mair and R. Wilcox, Robust statistical methods in R using the WRS2 package, *Behav. Res. Methods*, vol. 52, no. 2, pp. 464–488, 2020, doi: 10.3758/s13428-019-01246-w.
41. S. Holm, A Simple Sequentially Rejective Multiple Test Procedure, *Scand. J. Stat.*, vol. 6, no. 2, pp. 65–70, 1979.
42. G. Wiedemann, P. Pauli, W. Dengler, W. Lutzenberger, N. Birbaumer, and G. Buchkremer, Frontal brain asymmetry as a biological substrate of emotions in patients with panic disorders, *Arch. Gen. Psychiatry*, vol. 56, no. 1, pp. 78–84, Jan. 1999, doi: 10.1001/archpsyc.56.1.78.
43. M. Gärtner, S. Grimm, and M. Bajbouj, Frontal midline theta oscillations during mental arithmetic: effects of stress, *Front. Behav. Neurosci.*, vol. 9, Apr. 2015, doi: 10.3389/fnbeh.2015.00096.
44. A. Canales-Johnson *et al.*, Decreased Alertness Reconfigures Cognitive Control Networks, *J. Neurosci.*, vol. 40, no. 37, pp. 7142–7154, Sep. 2020, doi: 10.1523/JNEUROSCI.0343-20.2020.
45. C. Braboszcz and A. Delorme, Lost in thoughts: neural markers of low alertness during mind wandering, *NeuroImage*, vol. 54, no. 4, pp. 3040–3047, Feb. 2011, doi: 10.1016/j.neuroimage.2010.10.008.
46. J. Lagopoulos *et al.*, Increased theta and alpha EEG activity during nondirective meditation," *J. Altern. Complement. Med. N. Y. N*, vol. 15, no. 11, pp. 1187–1192, Nov. 2009, doi: 10.1089/acm.2009.0113.
47. J. W. Kozelka and T. A. Pedley, Beta and mu rhythms, *J. Clin. Neurophysiol. Off. Publ. Am. Electroencephalogr. Soc.*, vol. 7, no. 2, pp. 191–207, Apr. 1990.
48. B. E. Rideout and C. M. Laubach, EEG correlates of enhanced spatial performance following exposure to music, *Percept. Mot. Skills*, vol. 82, no. 2, pp. 427–432, Apr. 1996, doi: 10.2466/pms.1996.82.2.427.
49. L. Taruffi, C. Pehrs, S. Skouras, and S. Koelsch, Effects of Sad and Happy Music on Mind-Wandering and the Default Mode Network, *Sci. Rep.*, vol. 7, no. 1, Art. no. 1, Oct. 2017, doi: 10.1038/s41598-017-14849-0.
50. A. J. Tomarken, R. J. Davidson, and J. B. Henriques, Resting frontal brain asymmetry predicts affective responses to films, *J. Pers. Soc. Psychol.*, vol. 59, no. 4, pp. 791–801, Oct. 1990, doi: 10.1037//0022-3514.59.4.791.
51. M. Palmiero and L. Piccardi, Frontal EEG Asymmetry of Mood: A Mini-Review, *Front. Behav. Neurosci.*, vol. 11, Nov. 2017, doi: 10.3389/fnbeh.2017.00224.
52. D. Gao *et al.*, SWS Brain-Wave Music May Improve the Quality of Sleep: An EEG Study, *Front. Neurosci.*, vol. 14, p. 67, Feb. 2020, doi: 10.3389/fnins.2020.00067.
53. L. Jäncke, J. Kühnis, L. Rogenmoser, and S. Elmer, Time course of EEG oscillations during repeated listening of a well-known aria, *Front. Hum. Neurosci.*, vol. 9, p. 401, 2015, doi: 10.3389/fnhum.2015.00401.
54. A. A. Putilov and O. G. Donskaya, Alpha attenuation soon after closing the eyes as an objective indicator of sleepiness, *Clin. Exp. Pharmacol. Physiol.*, vol. 41, no. 12, pp. 956–964, Dec. 2014, doi: 10.1111/1440-1681.12311.
55. D. Schwab, M. Benedek, I. Papousek, E. M. Weiss, and A. Fink, The time-course of EEG alpha power changes in creative ideation, *Front. Hum. Neurosci.*, vol. 8, 2014, doi: 10.3389/fnhum.2014.00310.
56. D. A. Adamos, N. A. Laskaris, and S. Micheloyannis, Harnessing functional segregation across brain rhythms as a means to detect EEG oscillatory multiplexing during music listening, *J. Neural Eng.*, vol. 15, no. 3, p. 036012, Jun. 2018, doi: 10.1088/1741-2552/aaac36.
57. [Roots of musicality: On neuro-musical thresholds and new evidence for bridges between musical expression and 'inner growth': Music Education Research: Vol 6, No 3. https://www.tandfonline.com/doi/abs/10.1080/1461380042000281767 (accessed Apr. 23, 2019).
58. V. Demarin, M. Roje Bedeković, M. Bosnar Puretić, and M. Pašić, Arts, Brain and Cognition, *Psychiatr. Danub.*, vol. 28, pp. 343–348, Dec. 2016.
59. J. Kamiński, A. Brzezicka, M. Gola, and A. Wróbel, β band oscillations engagement in human alertness process, *Int. J. Psychophysiol. Off. J. Int. Organ. Psychophysiol.*, vol. 85, no. 1, pp. 125–128, Jul. 2012, doi: 10.1016/j.ijpsycho.2011.11.006.
60. S. Nakamura, N. Sadato, T. Oohashi, E. Nishina, Y. Fuwamoto, and Y. Yonekura, Analysis of music-brain interaction with simultaneous measurement of regional cerebral blood flow and electroencephalogram beta rhythm in human subjects, *Neurosci. Lett.*, vol. 275, no. 3, pp. 222–226, Nov. 1999.
61. P. C. Fletcher, C. D. Frith, S. C. Baker, T. Shallice, R. S. Frackowiak, and R. J. Dolan, The mind's eye--precuneus activation in memory-related imagery, *NeuroImage*, vol. 2, no. 3, pp. 195–200, Sep. 1995, doi: 10.1006/nimg.1995.1025.
62. M. Kwon, M. Gang, and K. Oh, Effect of the Group Music Therapy on Brain Wave, Behavior, and Cognitive Function among Patients with Chronic Schizophrenia, *Asian Nurs. Res.*, vol. 7, no. 4, pp. 168–174, Dec. 2013, doi: 10.1016/j.anr.2013.09.005.
63. E.-J. Lee, J. Bhattacharya, C. Sohn, and R. Verres, Monochord sounds and progressive muscle relaxation reduce anxiety and improve relaxation during chemotherapy: a pilot EEG study, *Complement. Ther. Med.*, vol. 20, no. 6, pp. 409–416, Dec. 2012, doi: 10.1016/j.ctim.2012.07.002.
64. R. A. Pavlygina, D. S. Sakharov, and V. I. Davydov, Spectral Analysis of the Human EEG during Listening to Musical Compositions, *Hum. Physiol.*, vol. 30, no. 1, pp. 54–60, Jan. 2004, doi: 10.1023/B:HUMP.0000013765.64276.e6.
65. S. Nemati, H. Akrami, S. Salehi, H. Esteky, and S. Moghimi, Lost in music: Neural signature of pleasure and its role in modulating attentional resources, *Brain Res.*, pp. 7–15, May 2019, doi: 10.1016/j.brainres.2019.01.011.
66. R. S. Schaefer, R. J. Vlek, and P. Desain, Music perception and imagery in EEG: alpha band effects of task and stimulus, *Int. J. Psychophysiol. Off. J. Int. Organ. Psychophysiol.*, vol. 82, no. 3, pp. 254–259, Dec. 2011, doi: 10.1016/j.ijpsycho.2011.09.007.
67. D. Sammler, M. Grigutsch, T. Fritz, and S. Koelsch, Music and emotion: Electrophysiological correlates of the processing of pleasant and unpleasant music, *Psychophysiology*, vol. 44, no. 2, pp. 293–304, Mar. 2007, doi: 10.1111/j.1469-8986.2007.00497.x.
68. L.-L. Balkwill and W. F. Thompson, A Cross-Cultural Investigation of the Perception of Emotion in Music: Psychophysical and Cultural Cues, *Music Percept. Interdiscip. J.*, vol. 17, no. 1, pp. 43–64, Oct. 1999, doi: 10.2307/40285811.
69. Kunikullaya Ubrangala, K., Kunnavil, R., Goturu, J., M, V., Prakash, V. S., & Murthy, N. S. (2021). Effect of specific melodic scales of Indian music in reducing state and trait anxiety: A randomized clinical trial. Psychology of Music. https://doi.org/10.1177/03057356211055509)

Biographical Statements

Kirthana Kunikullaya U is currently a post-doc in Thierry D Charlier's lab at the University of Rennes 1. She is studying the effect of neurosteroids and environmental toxins on behavior using zebrafish models and molecular biology approaches. Trained as a medical doctor, with interest in medical research, she pursued higher education in Physiology. is also a trained Carnatic classical vocalist, teacher of music, and a founding trustee of Kalamshu, Bangalore (www.kalamshu.org).

Arun Sasidharan did MBBS (Medical College, Kottayam) and then PhD in Neurophysiology (NIMHANS, Bangalore). Currently, he is a Scientist at Center for Consciousness Studies (CCS), Dept of Neurophysiology, NIMHANS. It is a multi-disciplinary work in consciousness research and technology development.

Rakshith Srinivasa completed MBBS (undergraduate medical graduation) from Sri Devaraj urs medical college masters in general surgery (M S) from Ramaiah medical college and is currently is working as a senior consultant in the Department of Neurosurgery at M S Ramaiah Memorial Hospital. His research interests include non-invasive and minimalistic modes of treatment approaches.

Jaisri Gotur pursued her further studies on Neuro anatomy (Study of mammalian neuroanatomy and histology), and Electrophysiology (Study of recording of electrical potentials in nerves and unit recordings) from Purdue University, Indiana, U.S.A. and is presently working as the Head of department, Department of Physiology, International medical school, MSRIT Post, MSR Nagar, Bangalore - 560054. She was Ex Head of department, Department of Physiology, M S Ramaiah Medical College, MSRIT Post, MSR Nagar, Bangalore e 560054. Her Research specialization include role of Lifestyle change in Diseases, Alternative Methods of Stress Management, Pranic healing.

Nandagudi Srinivasa Murthy, a well-known Bio- Statistician, did his Ph.D. (Epidemiology), School of Public Health, University of Tampere, Finland. Research Director, Division of Research & Patents, Gokula Education Foundation (Medical), Professor and Research Coordinator, Department of Community Medicine, M.S. Ramaiah Medical College,Bangalore. He is emeritus scientist of ICMR (Cancer research division). His main area of interest included teaching of Bio- statistics, Research methodology, designing, execution and analysis of data of epidemiological research studies in the field of bio-medical sciences, public health, dental health and cancer epidemiological studies.

Supplementary File

Table S1: *Baseline demographic and clinical characteristics for each group*

	A (n=36)	B (n=33)	C (n=36)	D (n=33)	P
Age	20.94±2.85	20.39±2.18	20.33±2.55	21.28±3	0.406
Gender M(F)	17 (19)	16 (17)	18 (18)	10 (22)	0.393
BMI	23.33±5.26	23.65±4.33	23.5±4.74	22.58±4.16	0.8
Physical activity Y(N)	17 (19)	20 (13)	13 (23)	20 (12)	0.098
Mind body relaxation technique Y(N)	15 (21)	23 (10)	16 (10)	20 (12)	0.067
Training in music Y(N)	13 (23)	16 (17)	10 (26)	11 (20)	0.353

Note: Values are shown as mean±SD and as Yes/No (Y/N) frequency of yes and no.

Description of music intervention

*Ahir Bhairav (*A mixture of *Bhairav raga* and *raga Ahiri or Abhiri)*, an ancient *raga*, the intervention A of this study, is now a rare *raga. Arohana: S r G M P D n S^, Avarohana: S^ n D P M G r S* (C B♭ A G F E D♭ C, on western scale). It is thus a scale that has 7 notes in the ascent and descent (*sampoorna raga*). *S, G, M, P, D are all shuddha (natural)* whereas *r and n are komal* (flat). There are no sharp notes. *Chakravakam*, the 16th *melakarta raga* of Carnatic music, closely resembles. The notes Ma and Sa are the *vadi-samvadi* notes (the most important, the second most important). *Ahir Bhairav.* This *raga* is typical *uttarang raga*, it is best suited for the first *prahar* of the morning, around 6 am - 9 am. ("Ahir Bhairav," 2020). While the first half of the ascend is pensive, the start of the second half seems full of positivity and hope, with a feeling of dispassionate and unconditional love ("Delving Deeper Into Ahir Bhairav," n.d.). *Raga Kaunsi Kanada*, is *Malkauns* on its way up and *Darbari* on its way down. *Arohana:* S g M d n S^, *Avarohana:* S^ n d P M g R S. On western scale the notes are C, B♭, A♭, G, F, E♭ and D (Descent). Time for best effects is between 12 am - 3 am during 3rd *prahar* of the night. *Kaunsi Kanada* highlights the exceptional sophistication of the *Hindustani Raga* system of "colouring our minds". However, it takes discerning taste to understand what this is all about ("Raga Kaunsi Kanada – a midnight conversation," 2016). *Kaunsi Kanada* was the *Raga* B in this study. *Bhimpalas raga,* (raga C of this study) belongs to the *Kapi thaat,* is a soft, poignant and passionate *raga* that evokes a feeling of love and yearning. It is generally classified as a 'late-afternoon' *raga.* In Carnatic music (South Indian classical music) the *raga* '*Abheri*' is the closest counterpart of this Hindustani *raga* ("Hindi film songs based on raga Bhimpalasi | My Views On Bollywood," n.d.). The scale of this *raga* is as follows: *Arohaṇa:* S G_2 M_1 P N_2 S. *Avarohaṇa:* S N_2 D_2 P M_1 G_2 R_2 S (*shadja, shuddha Rishabh, komal Gandhar, suddha Madhyam, pancham, shuddha Dhaivath, komal Nishadh*). Equivalent notes on western scale are B♭ C E♭ F G B♭ C as ascent and C B♭ A G F E♭ D C as descent on western scale ("Bhimpalasi," 2020). Thus the scale is made up of two flat keys and no sharps.

Just intonation and 12 - equal temperament:

Just intonation or pure intonation is the tuning of musical intervals as whole number ratios (such as 3:2 or 4:3) of frequencies. Any interval tuned in this way is called a just interval. Just intervals (and chords created by combining them) consist of members of a single harmonic series of a (lower) implied fundamental. For example, in the diagram at right, the notes G and middle C (labeled 3 and 4), are both members of the harmonic series of the lowest C and their frequencies will be 3 and 4 times, respectively, the fundamental frequency; thus, their interval ratio will be 4:3. If the frequency of the fundamental is 64 Hertz, the frequencies of the two notes in question would be 192 and 256. Instruments are not always tuned using these intervals.

In the Western world, instruments of fixed pitch, such as pianos, are typically tuned using equal temperament, in which intervals other than octaves consist of irrational-number frequency ratios. An equal temperament is a musical temperament or tuning system, which approximates just intervals by dividing an octave (or other interval) into equal steps. This means the ratio of the frequencies of any adjacent pair of notes is the same, which gives an equal perceived step size as pitch is perceived roughly as the logarithm of frequency. In classical music and Western music in general, the most common tuning system since the 18th century has been twelve-tone equal temperament (also known as 12 equal temperament, 12-TET or 12-ET; informally abbreviated to twelve equal), which divides the octave into 12 parts, all of which are equal on a logarithmic scale, with a ratio equal to the 12th root of 2 (12√2 ≈ 1.05946). That resulting smallest interval, 1⁄12 the width of an octave, is called a semitone or half step. In Western countries the term equal temperament, without qualification, generally means 12-TET. In modern times, 12-TET is usually tuned relative to a standard pitch of 440 Hz, called A440, meaning one note, A, is tuned to 440 hertz and all other notes are defined as some multiple of semitones apart from it, either higher or lower in frequency. The standard pitch has not always been 440 Hz. It has varied and generally risen over the past few hundred years.("Equal temperament," 2020; "Just intonation," 2020)

Table S2: *Names & equivalents of the 12 basic notes of Indian music*

Carnatic					**Western**			**Hindustani**		
Full Name		***Short forms***		***Alt***[1]	***Interval***	***Cents***[2]	***Note***[3]	***Full Name***	***Short forms***	
1	Shadjam	Sa	S		P1	0	C	Shadj	S	S
2	Suddha Rishabham	Ri1	R1		m2	100	D♭	Komal Rishab	kR	R1
3	Chatusruthi Rishabham	Ri2	R2		M2	200	D	Suddh Rishab	R	R2
	Suddha Gantharam[4]	Ga1	G1	G0			E♭♭			
4	Shatsruthi Rishabham[4]	Ri3	R3		m3	300	D#	Komal Gandhar	kG	G1
	Saadarana Gantharam	Ga2	G2	G1			E♭			
5	Antara Gantharam	Ga3	G3	G2	M3	400	E	Suddh Gandhar	G	G2
6	Suddha Madhyamam	Ma1	M1		P4	500	F	Suddh Madhyam	M	M1
7	Prati Madhyamam	Ma2	M2		4	600	F#	Tivra Madhyam	tM	M2
8	Panchamam	Pa	P		P5	700	G	Pancham	P	P
9	Suddha Dhaivatham	Da1	D1		m6	800	A♭	Komal Dhaivat	kD	D1
10	Chatusruthi Dhaivatham	Da2	D2		M6	900	A	Suddh Dhaivat	D	D2
	Suddha Nishadham[4]	Ni1	N1	N0			B♭♭			
11	Shatsruthi Dhaivatham[4]	Da3	D3		m7	1000	A#	Komal Nishad	kN	N1
	Kaisiki Nishadham	Ni2	N2	N1			B♭			
12	Kaakali Nishadham	Ni3	N3	N2	M7	1100	B	Suddh Nishad	N	N2

[1] Instead of labeling the 3 Ga-s and the 3 Ni-s using {1,2,3}, some authors have used {0,1,2} instead. This alternate numbering scheme also makes comparison to the Western and Hindustani notes easier. Both conventions are present in the literature, sometimes causing unnecessary confusion to novices! Note also that in this alternate scheme, all "vivadhi notes" are labeled by 0 or 3, and all notes labeled with a 0 or 3 are vivadhi.

[2] Western Equal Temperament tuning.

[3] Note names if and only if "C" is chosen as the tonic. If another note, say F#, is chosen as the tonic, then this column would have to be modified. The point is that the Indian notes correspond to the intervals - P1, m2, M2 , ..., M7 - rather than to absolute pitches/frequencies. The artist can choose Sa/the tonic to be any frequency he or she desires at the beginning of a performance.

[4] Vivadhi notes. These are are not new intervals/swarasthanams, but are enharmonic to 4 other "normal" notes. Ie, out of the sixteen Carnatic notes listed, there are only twelve unique intervals.

Table S3*: Svara and their names in North Indian system of raga and its equivalent western scale notes ("Svara," 2020)*

Svara in North Indian system of *raga*							
Svara (Long)	Ṣaḍja	Ṛiṣabha	Gāndhāra	Madhyama	Pañcama	Dhaivata	Niṣāda
Svara (Short)	Sa	Re	Ga	Ma	Pa	Dha	Ni
12 Varieties (names)	C (shadja)	D♭ (komal re) D (shuddha re)	E♭ (komal ga) E (shuddha ga)	F (shuddha ma) F♯ (teevra ma)	G (panchama)	A♭ (komal dha) A (shuddha dha)	B♭ (komal ni) B (shuddha ni)

Scalp distribution of Alpha and Beta1 power changes between conditions within groups showing differential effects in early and later segments

This analysis examines if the early and later segments show differential effects of music listening across scalp locations. The increase in Alpha and Beta1 seen in the previous sections (for Group B & C) are significant only in the later segments [Figure S1-S8].

Figure S1: *Between Condition effect showing differential effects in early and later segments for Group A in Alpha band (ALP: 8 – 12 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

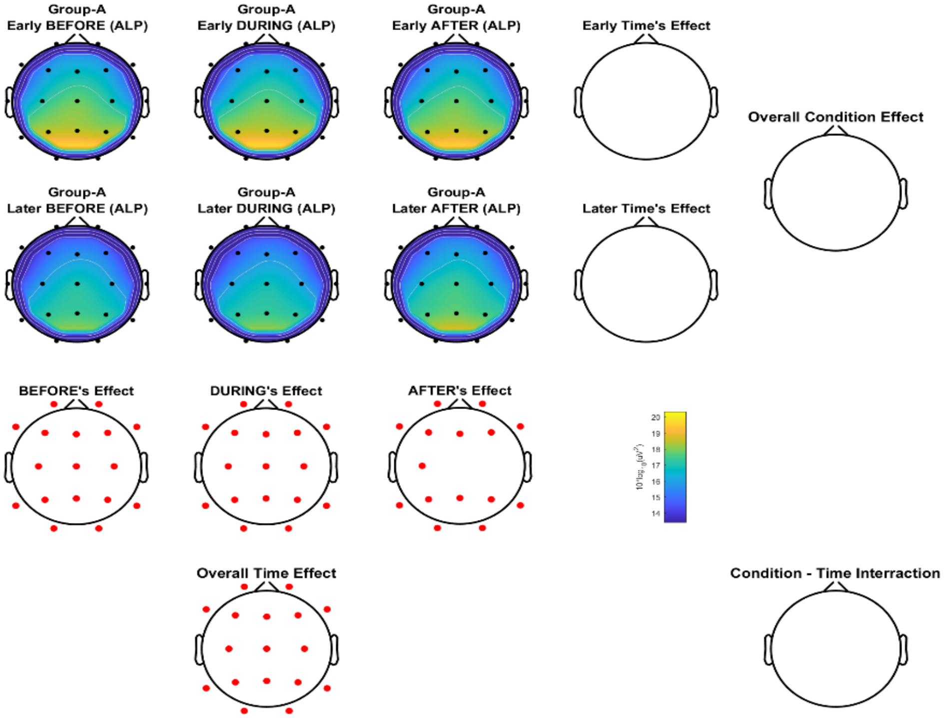


Figure S2: *Between Condition effect showing differential effects in early and later segments for Group B in Alpha band (ALP: 8 – 12 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

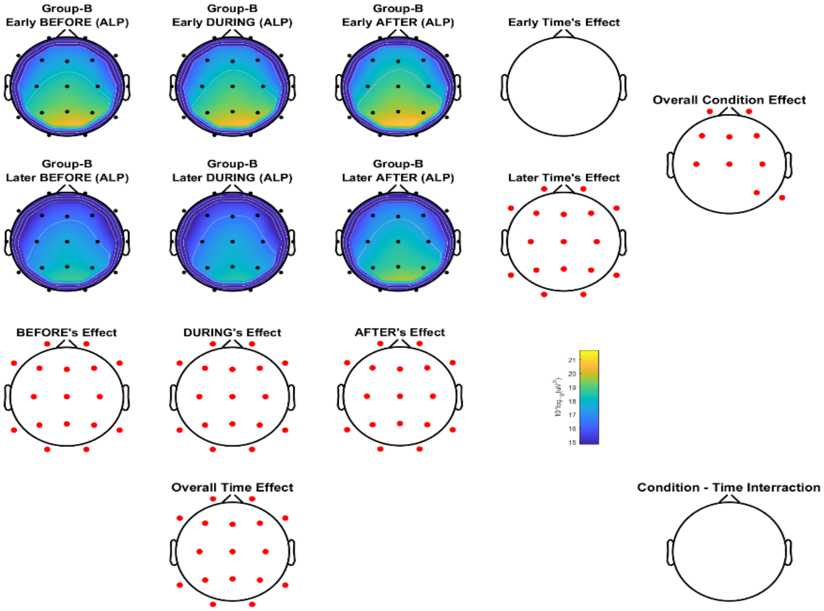


Figure S3: *Between Condition effect showing differential effects in early and later segments for Group C in Alpha band (ALP: 8 – 12 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

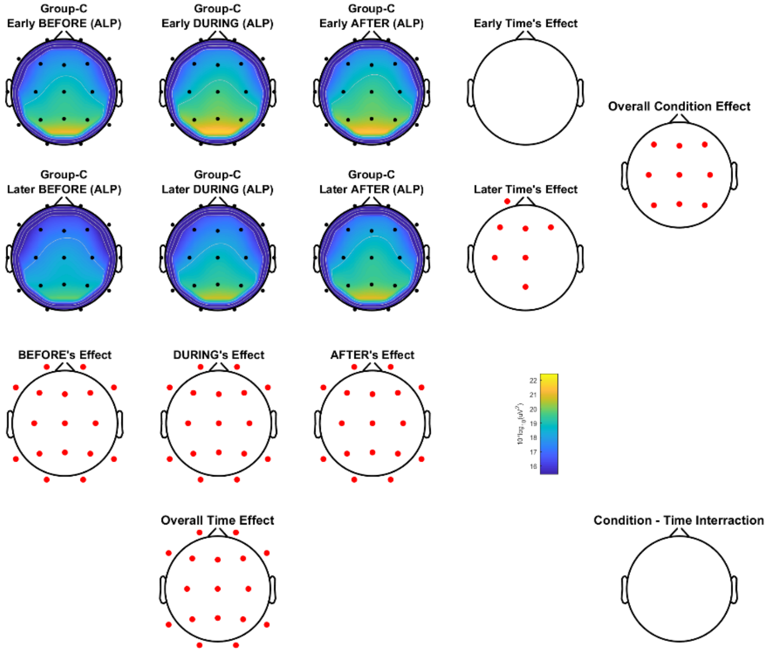


Figure S4: *Between Condition effect showing differential effects in early and later segments for Group D in Alpha band (ALP: 8 – 12 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

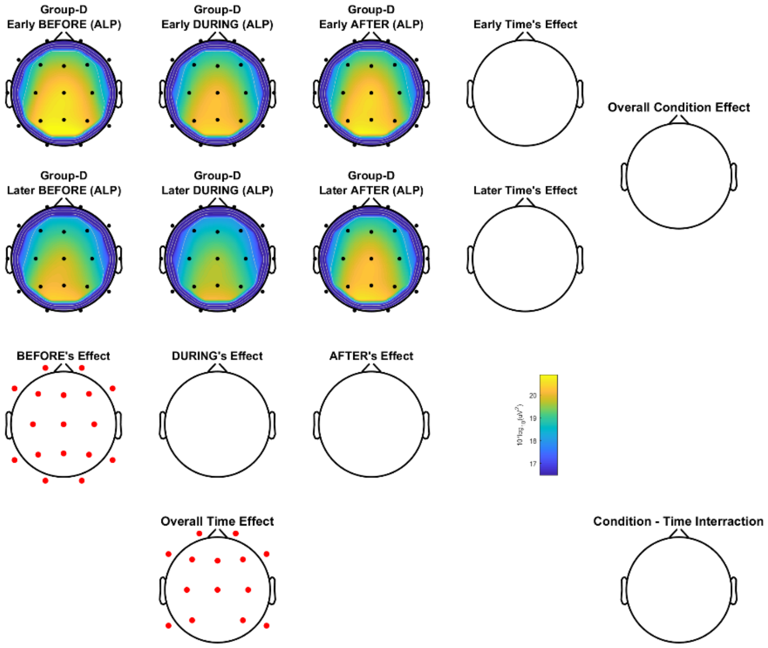


Figure S5: *Between Condition effect showing differential effects in early and later segments for Group A in Beta band (BET1: 13 – 20 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

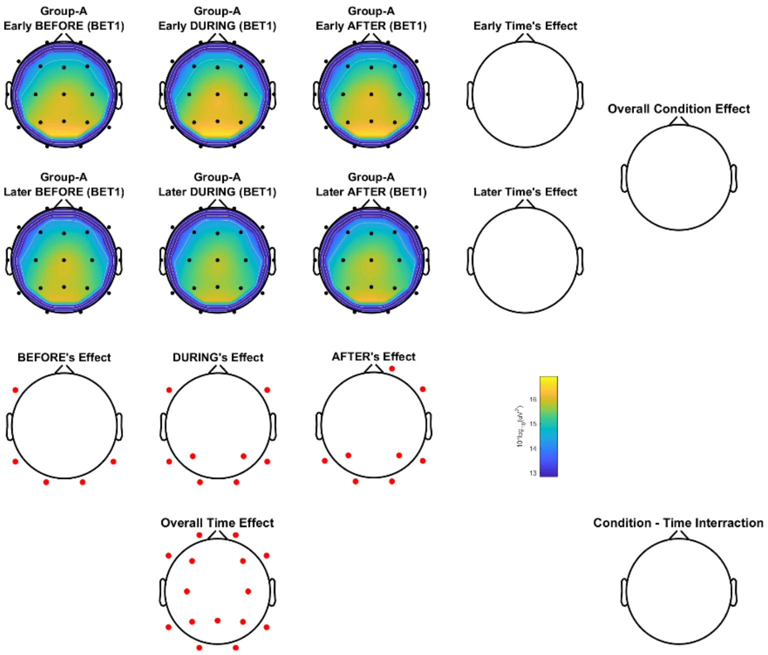


Figure S6: *Between Condition effect showing differential effects in early and later segments for Group B in Beta band (BET1: 13 – 20 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

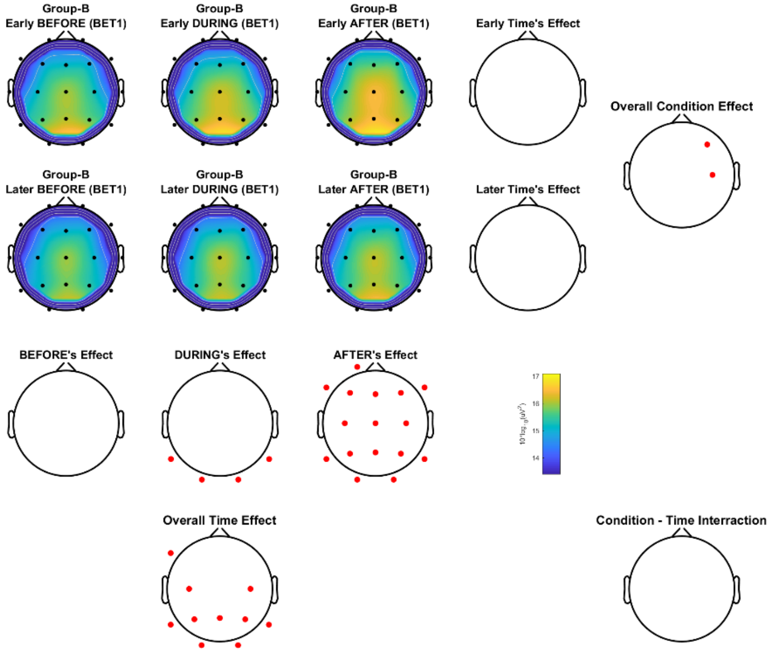


Figure S7: *Between Condition effect showing differential effects in early and later segments for Group C in Beta band (BET1: 13 – 20 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*

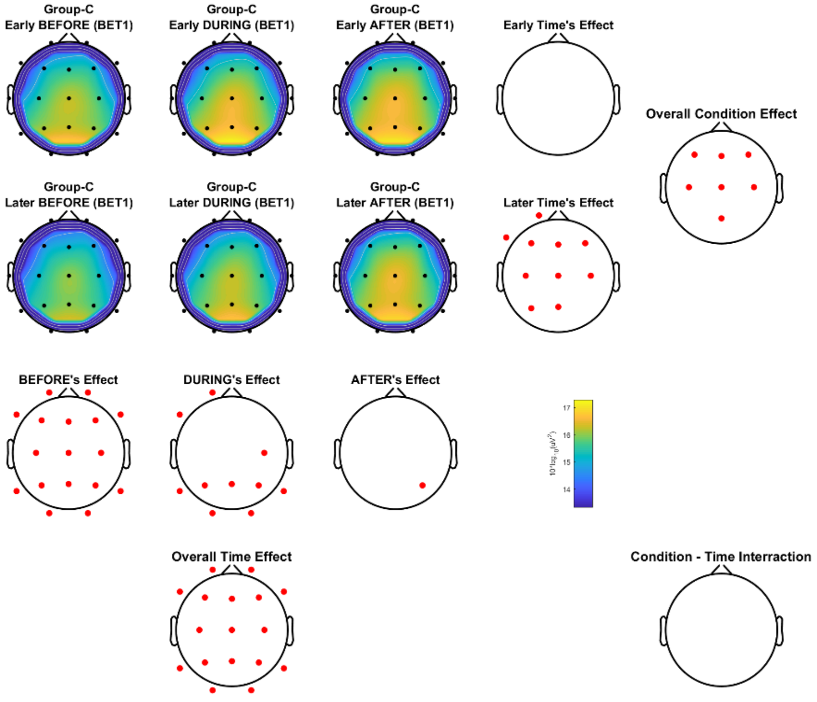


Figure S8: *Between Condition effect showing differential effects in early and later segments for Group D in Beta band (BET1: 13 – 20 Hz). The head maps show mean power at each electrode site (warmer color indicates higher power), for each condition and time segment. The outer unfilled head maps show the statistical results (red dots represent electrodes with significant p-values), with the outermost layer showing overall effects of two-way ANOVA (condition, time and interaction) and the inner layer showing one-way ANOVA effects. The p-values are FDR-corrected for multiple comparisons.*