Neurophysiological effects of various music genres on electroencephalographic cerebral cortex activity

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Background: Music has been associated with therapeutic properties for thousands of years across a vast number of diverse regions and cultures. This study expands upon our current understanding of music’s influence on human neurophysiology by investigating the effects of various music genres on cerebral cortex activity using electroencephalography (EEG). Methods: A randomized, controlled study design was used. EEG data were recorded from 23 healthy adults, aging 18–29 years, while listening to a music sequence consisting of five randomized songs and two controls. The five studied music genres include: Classical, Tribal Downtempo, Psychedelic Trance (Psytrance), Goa Trance, and Subject Choice. Results: Controls were most strongly associated with relative decreases in beta frequencies and increases in alpha frequencies. Psytrance was most strongly associated with relative increases in theta and delta frequencies. The lowest relative percentages of beta frequencies and highest relative percentages of alpha frequencies occurred in the occipital and parietal regions. The highest relative percentages of theta and delta frequencies occurred in the frontal and temporal regions. Subjects with prior music training exhibited relative increases in delta frequencies in the frontal region. Subject gender and music preferences did not have a significant influence on EEG activity. Conclusions: Findings from this study support those of previous music therapy studies and provide novel insights regarding music’s influence on human neurophysiology. Our findings also support the hypothesis that music may promote changes in cerebral cortex activity that has similarities to non-rapid eye movement sleep, while the listener remains awake.

Keywords: brain, clinical, EEG, medical, music, research

INTRODUCTION

Music has been associated with therapeutic properties for thousands of years across a vast number of diverse regions and cultures. The earliest documented reports of music therapy are found in historic writings from many ancient civilizations including Egypt, China, India, Greece, and Rome (University Hospitals of Cleveland, 2011). The first recorded use of music therapy in a medical setting dates back to World Wars I and II, when music was used to relieve pain and anxiety in soldiers with traumatic war injuries (University Hospitals of Cleveland, 2011). Music continues to be used today by countless individuals across the world for a wide variety of reasons. From ceremonies and celebrations, to routine listening during work, exercise, and travel, countless people continue to rely on music for its many reported therapeutic properties.

Over the past 30 years, a large number of scientific studies have generated a robust body of evidence, which suggests that music can provide significant benefits as an adjuvant treatment modality in a variety of clinical settings (Aragon, Farris, & Byers, 2002; Binek et al., 2003; Bradt & Dileo, 2009; Bradt, Dileo, Grocke, & Magill, 2011; Bringman, Giesecke, Thöne, & Bringman, 2009; Buffum et al., 2006; Chan, Chan, Mok, & Kwan Tse, 2009; Chan, Lee, Ng, & Wong, 2003; Chlan, Evans, Greenleaf, & Walker, 2000; Conrad et al., 2007; Cooke, Chaboyer, Schluter, & Hiratos, 2005; Ebnesahidi & Mohseni, 2008; Evans, 2002; Galaal, Deane, Sangal, & Lopes, 2007; Han et al., 2010; Hatem, Lira, & Mattos, 2006; Kim, Kim, & Myoung, 2011; Klassen, Liang, Tjosvold, Klassen, & Hartling, 2008; Kliempt, Ruta, Ogston, Landeck, & Martay, 1999; Korhan, Khoshid, & Uyar, 2010; Kotwal, Rinchchen, & Hartling, 2008; Kwon, Kim, & Park, 2006; Lai & Li, 2011; Lee, Chao, Yiin, Chiang, & Chao, 2011; Lee et al., 2012; Lee, Chung, Chan, & Chan, 2005; Lepage, Drolet, Girard, Chung, Chan, & Chan, 2005; Lepage, Chung, & Chan, 2005; Lepage, Demers, & Chung, 2005).• Corresponding author: Abraham Hafiz Rodriguez, MD, University of Illinois College of Medicine at Peoria, 24 Central Drive Unit A, Mill Valley, CA 94941, USA; Phone: +1 651 497 5885; Fax: +1 832 786 7488; E-mail: AbrahamHafizRodriguez@gmail.com

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Our current understanding of the neurophysiological mechanisms underlying the therapeutic effects of music suggests that the cerebral cortex, basal ganglia, and hypothalamic–pituitary–adrenal axis are involved in various degrees (Baumgartner et al., 2006; Conrad et al., 2007; Jacobs & Friedman, 2004; Kabuto et al., 1993; Lin et al., 2010; Mattei et al., 2013; Salimpoor et al., 2011; White & Richard, 2009). In addition, despite the recent expansion of scientific literature exploring outcomes-based research aimed at investigating how common, popular music genres (e.g., classical) may be beneficial for various applications related to mood, anxiety, pain, and other variables, there has been significantly less attention devoted to comparing different music genres for potential variabilities in their efficacy and potency to impact the human brain and body. Due to recent advances in computer technology and music composition software, many forms of music are currently being composed digitally, including classical symphonies, theatrical soundtracks, cultural music, etc. Digital music composition allows for an expanded range of instruments, pitches, resonances, melodies, harmonies, and other musical variables, all assembled with precise timing and flawless uniformity, without the irregularities or errors that often occur during organic music composition with manual instruments.

This study aims to investigate the neurophysiological activity associated with the therapeutic effects of music using EEG in healthy young adults, by comparing relative percentages of beta, alpha, theta, and delta frequencies in each major region of the cerebral cortex while subjects listen to randomized sequences of five unique music genres and controls. Interregion cortical comparisons will also be investigated. The potential influences of subject gender, music preferences, and prior music training will also be examined. By utilizing a randomized, controlled design and a variety of carefully selected music genres, this study aims to expand on our current understanding of how various types of music may give rise to therapeutic effects in the human brain and body. By improving our understanding of the neurophysiological effects of various music genres on different regions of the cerebral cortex, we can more effectively apply music as an adjuvant therapeutic tool in modern medical practice to benefit humankind.

METHODS

Subject details

After institutional review board (IRB) approval (IRB #267944-1), 25 healthy adults, aging 18–28 years, with normal hearing function, were recruited from the University of Illinois College of Medicine at Peoria, Bradley University and Illinois Central College campuses. Subjects were asked to avoid caffeine, tobacco, and all other psychoactive chemicals for at least 6 hr prior to their study participation. Subjects were also asked to be at adequate rest prior to study participation. Informed consent was obtained from all subjects prior to data collection.

Study design

To investigate the suspected ability of various music genres to promote changes in cerebral cortex activity that have similarities to non-rapid eye movement (NREM) sleep, this study aimed to measure relative percentages of beta, alpha, theta,
EEG response to various music genres

and delta frequencies during each segment of a subject’s randomized music sequence. Wakefulness characterized by alertness and active cognition is predominately accompanied by beta frequencies (>13 Hz), whereas wakefulness characterized by relaxation and drowsiness (e.g., meditation) is predominately accompanied by alpha frequencies (8–12 Hz; Britton et al., 2016; White & Richard, 2009). NREM sleep is generally categorized into three stages (N1–3): N1 (Stage 1) is characterized by light NREM sleep and is predominately accompanied by theta frequencies (4–7 Hz), with a lesser mixture of alpha frequencies (8–12 Hz). N2 (Stage 2) is characterized by deeper NREM sleep and is predominately accompanied by theta frequencies (4–7 Hz) interspersed with sleep spindles and K-complexes, with a lesser prevalence of delta frequencies (1–3 Hz). N3 (Stage 3) is characterized by the deepest NREM sleep and is predominately accompanied by delta frequencies (1–3 Hz; Britton et al., 2016; White & Richard, 2009). Rapid eye movement (REM) sleep is characterized by the deepest stage of sleep, and is predominately accompanied by beta frequencies (>13 Hz) coupled with REMs, dreaming, and muscle paralysis (Britton et al., 2016; White & Richard, 2009).

Data were collected at the Illinois Neurological Institute (INI) Sleep Center at OSF Saint Francis Medical Center in Peoria, Illinois, using a randomized, controlled design. Each subject participated in a single data gathering session approximately 1 hr in length, during which they completed a pre-music survey (Appendix), then listened to a randomized music sequence, and completed a post-music survey (Appendix). EEG leads were placed by a certified INI EEG technician. After completing the pre-music survey, subjects were fitted with professional, closed-ear, studio quality head-phones and a special blindfold that allowed subjects to keep their eyes open in complete darkness throughout the duration of the music sequence. This blindfold was chosen, so that subjects could keep their eyes open throughout the duration of the music sequence, since closure of the eyes often leads to states of relaxed wakefulness (predominately accompanied by alpha frequencies) and Stage 1 (N1) NREM sleep (predominately accompanied by theta and alpha frequencies; Britton et al., 2016; White & Richard, 2009).

Blindfold position was adjusted to achieve complete darkness for each subject before the music sequence began. Subjects were asked to stay awake and to keep their eyes open for the entire duration of the music sequence, and to report on the post-music survey, if they had fallen asleep or had any other concerns that arose during the music sequence. Subjects were asked not to take breaks during the music sequence. Timestamps were documented during each subject’s music sequence, so that start and end points of each song and control could be clearly identified in the EEG data. Subjects briefly rated each song immediately after hearing it without removing their blindfold or headphones using a verbal equivalent of a Visual Analog Scale (Appendix). Subjects were not informed of which music genre they had just heard when providing this rating. After the music sequence had been complete, subjects ranked the songs relative to each other as part of the post-music survey (Appendix).

Each subject’s music sequence consisted of five songs in randomized order, flanked by a control (Victoria Falls waterfall recording). Except for the subject-chosen song in each music sequence, all subjects listened to the same pre-selected music genres and controls that had been chosen in advance by the study team. One song was chosen to represent each music genre, and the study team was very careful to select a song that accurately represented each genre. Song order for each subject’s music sequence was randomized using a standard permutation. The song lengths in each subject’s music sequence were standardized to the shortest song of the sequence by removing an appropriate terminal segment from the end of longer songs and controls. Each subject’s music sequence was flanked with a control of identical length at the beginning (Control 1) and end (Control 2). Brief 2.5-min control periods were placed between songs in each music sequence for a neutral, standardized transition between genres. All music used in this study was high-quality 320 kbps digital MP3 format or better, purchased from various accredited online music vendors. The music genres selected for this study were chosen because they are widely reported as therapeutic, and for additional analytical reasons.

Classical music has been frequently used in previous music therapy studies and is recognized throughout the world. One study investigated the impact of classical music on various physiological parameters (e.g., blood pressure, heart rate, etc.) and hormones of the hypothalamic–pituitary–adrenal axis (e.g., cortisol, growth hormone, etc.) in a group of critically ill patients (Conrad et al., 2007). Compositions from world-renowned composers such as Ludwig van Beethoven, Wolfgang Amadeus Mozart, and Johann Sebastian Bach are widely recognized and are still commonly played in modern times by a variety of both public (e.g., radio and television) and private listeners. It is frequently reported to be therapeutic by listeners around the world.

Song: Ludwig van Beethoven – Symphony No. 5 in C-Minor.

Tribal Downtempo is a broad category of electronic music that features a blend of vocal chants, hand drumming, and organic instruments, which have cultural and historical relevance to human ancestral past. Some of the common instruments featured in this music genre include the djembe, dundegg, various wooden flutes, and more, which contribute to the “tribal” atmospheres present in this genre. Tribal Downtempo varies widely in tempo, but is typically much slower (<100 bpm) than more fast-paced genres of music, such as most types of electronic dance music. It is widely reported to be therapeutic by listeners around the world.

Song: Koan – When We Left Arkaim.

Psychedelic Trance (Psytrance) is a unique genre of electronic dance music that features a wide variety of melodies, harmonies, and atmospheres centered around a unique rhythm composition that is typically produced in a widely recognized 4/4 time signature, but using 16th bass notes (i.e., four bass notes per beat) instead of simple quarter notes. The typical tempo of Psytrance is around 145–155 bpm, which results in a frequency range similar to the alpha frequency band (8–12 Hz), since there are four bass notes for every beat (4 bass notes × 150 bpm = 600 bpm = ~10 Hz). Psytrance is widely reported to be both therapeutic and “trance-inducing.” Psytrance originally developed from another type of electronic dance music known as Goa Trance in the 1970s and 1980s, and has since spread throughout the world (St. John, 2010).

Song: M-Theory – L6 Echo.

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Goa Trance (Goa) is very similar in composition to Psytrance, except with a standard quarter note beat structure (i.e., no 16th bass notes), making it an excellent music genre for comparison to Psytrance. Although Goa Trance typically utilizes a standard quarter-note beat structure, it is still typically produced at a tempo very similar to Psytrance (145–155 bpm), and with similar melodies, harmonies, and atmospheres. Like Psytrance, Goa Trance is also widely reported to be both therapeutic and “trance-inducing.” Goa Trance was originally developed on the beautiful beaches of Goa, India through various collaborative organic and digital music projects in the 1970s and 1980s, and eventually spread throughout the world (St. John, 2010). Song: Goalien – Do It Now.

Subject Song is a subject-chosen song that was included in each subject’s personalized music sequence to evaluate the importance of subjective music preferences. Subjects were asked to provide their three most favorite, pleasurable songs after qualifying for the study. The study team then chose one of these songs based on its availability in a high-quality digital format (e.g., MP3), and its similarity to the other four music genres. If more than one song was available in an appropriate digital format, the principal investigator chose the song that was least similar to the other four music genres. Typical songs selected by subjects included common music genres one might hear on popular radio and television stations today, including Pop, R&B, Hip-Hop, Rock, etc.

Control (white noise) was selected to evaluate subject’s cerebral cortical activity in response to non-musical sound, for comparison to the cortical activity observed during the five music genres described above. Consideration was given to artificial types of control noise (e.g., television static, radio static, and traffic sounds), including the background noise encountered at OSF Saint Francis Medical Center where data collection took place, but this study team opted to use a natural form of white noise (i.e., waterfall recording) to increase the likelihood that subjects would complete the entire 1-hr music sequence with minimal discomfort and anxiety. Song: Victoria Falls (audio recording).

Data measurement

Subjective data were obtained using pre-music and post-music printed surveys (Appendix). EEG data were obtained using Nihon Kohden Neurofax EEG-1200A hardware and Neurofax QP 112AK v06-80 software (Appendix). Nineteen EEG electrodes were placed according to the standard international 10–20 system by a certified technician. Measurement of recorded EEG data was then performed by exporting the raw, unedited data from the Neurofax software, converting to European Data Format Plus (EDF+) format and then importing to Novatech WinEEG v2.7+ software for quantitative spectral analysis. Each subject’s EEG data were analyzed using a speed of 30 mm/s, gain of 100 μV, baseline of 0.00 μV, low cut of 0.1 s (1.6 Hz), high cut of 50 Hz, Notch of 50–70 Hz, and “monopolar average I” montage. No additional processing, “cleaning”, or modification of the EEG data was performed.

The relative percentage of beta, alpha, theta, and delta frequencies from each song and control of a subject’s music sequence were determined using the documented timestamps to identify the corresponding EEG data for a given song or control, then running the WinEEG artifact correction tool followed by the spectral analysis tool to generate a table that displayed the relative percentages of each frequency band that occurred during an individual song or control. This was performed by the principle investigator under the guidance of an attending neurologist from the INI at OSF Saint Francis Medical Center. The settings used by this study team when applying the WinEEG spectral analysis tool included: epoch length of 4 s, overlap of 50%, and Hanning time windows. The EEG data were also grouped into cortical regions by averaging the resulting percentages from individual leads corresponding to each cortical lobe (e.g., data from Fp1, Fp2, and Fz leads were averaged to generate a “frontal region” value for each song). Individual hemispheres were not studied in isolation, so this study team did not perform left versus right comparisons for each cortical region. Somatotopic cortical maps were generated from the relative percentage tables in WinEEG to visually represent the cortical regions where the greatest relative percentages of each frequency band occurred, using a brightness scale of 0%–60% (0% = no brightness, 60% = maximum brightness) to provide optimal visualization of data, since no individual frequency band showed relative percentages greater than ~60% in any cortical region.

Statistical analyses

Processed EEG data tables were exported from WinEEG and then imported into a Microsoft Excel spreadsheet for analysis using IBM SPSS software (version 21.0.0, Armonk, NY, USA). Standard descriptive statistics were calculated including mean, standard deviation, range, and correlation coefficients. Wilcoxon signed-rank tests were used to compare EEG results between pairs of music genres and controls and between pairs of individual cortical regions. Spearman’s rank-order correlation tests were used to investigate possible influences of subjective variables including subject music preferences (ranks and ratings), subject gender, and previous subject music training. A strict statistical significance threshold of $p < .01$ was used to help offset, in part, the relatively small sample size.

Ethics

This study was conducted with strict adherence to all applicable local and international laws and standards. All study authors conformed to the highest standards of ethical conduct throughout all portions of this study, including accurate data submission, acknowledging the work of others, and divulging potential conflicts of interests.

RESULTS

Twenty-three out of the 25 recruited subjects successfully participated in data collection. Two subjects dropped out of the study prior to data collection; one subject cancelled, and a second subject was outside of the required age range. Of the 23 participating study subjects, 9 were male and 14 were
female. The subjects were distributed among the following ages: 19 (2), 20 (1), 23 (3), 24 (4), 25 (3), 26 (4), 27 (1), and 28 (5), with a mean age of 24.7 years. The ethnicity of these subjects included Chinese, African, Caucasian, Hispanic, Arab, Indian, Ashkenazi Jew, and Asian/Pacific Islander. Seventeen subjects reported previous music training (e.g., playing an instrument, singing in choir, etc.). Only one subject reported briefly falling asleep during their music sequence.

**Music genre comparisons**

Mean relative percentages of beta, alpha, theta, and delta frequencies for all randomized music genres and controls within individual cortical regions are displayed in Table 1 and Figures 1–4.

Wilcoxon signed-rank analyses revealed significant differences in relative percentages of beta frequencies for paired comparisons of music genres and/or controls within individual cortical regions, which are displayed in Table 2. In the occipital region, Control 1 was associated with decreased relative percentages of beta frequencies compared to both Classical ($p = .002$) and Subject Song ($p = .008$), whereas Control 2 was associated with decreased relative percentages of beta frequencies compared to Subject Song ($p = .008$) only. In the temporal region, Tribal Downtempo, Psytrance, and Control 2 were associated with decreased relative percentages of beta frequencies compared to Control 1 ($p = .006$, $p = .008$, $p = .010$), whereas both Psytrance and Goa Trance were associated with decreased relative percentages of beta frequencies compared to Subject Song ($p = .004$, $p = .010$).

Wilcoxon signed-rank analyses revealed significant differences in relative percentages of alpha frequencies for paired comparisons of music genres and/or controls within individual cortical regions, which are displayed in Table 3. In the frontal region, Control 2 was associated with increased relative percentages of alpha frequencies compared to Classical ($p = .006$), Goa Trance ($p = .003$), and Subject Song ($p = .010$). In the parietal region, Control 2 was

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**Table 1.** Mean relative beta, alpha, theta, and delta frequency percentages for randomized music genres and controls

|       | Control 1 | Classical | Tribal | Psytrance | Goa | Subject | Control 2 | SD  |
|-------|-----------|-----------|--------|-----------|-----|---------|-----------|-----|
| **Beta** |           |           |        |           |     |         |           |     |
| Frontal | 10.17    | 10.37     | 9.57   | 9.60      | 10.52 | 10.13   | 9.27      | 0.47|
| Parietal | 8.22     | 8.18      | 7.88   | 7.85      | 8.45  | 8.56    | 7.68      | 0.33|
| Occipital | 6.78    | 7.54      | 7.08   | 6.96      | 7.16  | 7.77    | 6.76      | 0.38|
| Temporal | 9.59     | 8.89      | 8.55   | 8.08      | 8.73  | 9.78    | 8.24      | 0.64|
| **Alpha** |           |           |        |           |     |         |           |     |
| Frontal | 31.97    | 30.58     | 29.69  | 29.34     | 28.39 | 29.59   | 34.12     | 1.94|
| Parietal | 53.65    | 52.97     | 52.07  | 49.82     | 50.97 | 51.21   | 55.87     | 2.00|
| Occipital | 63.07   | 57.44     | 56.19  | 55.56     | 57.90 | 57.82   | 61.36     | 2.74|
| Temporal | 32.91    | 33.45     | 32.59  | 32.07     | 31.88 | 31.11   | 36.75     | 1.83|
| **Theta** |           |           |        |           |     |         |           |     |
| Frontal | 12.94    | 12.70     | 12.79  | 13.62     | 12.88 | 11.40   | 12.53     | 0.67|
| Parietal | 10.60    | 11.55     | 12.18  | 13.13     | 11.26 | 10.62   | 11.34     | 0.89|
| Occipital | 8.55     | 10.15     | 11.61  | 12.11     | 10.35 | 9.05    | 10.10     | 1.27|
| Temporal | 11.37    | 12.21     | 12.41  | 13.36     | 11.70 | 10.04   | 12.07     | 1.02|
| **Delta** |           |           |        |           |     |         |           |     |
| Frontal | 13.84    | 14.32     | 15.19  | 16.12     | 15.03 | 14.00   | 14.00     | 0.84|
| Parietal | 9.27     | 10.05     | 10.41  | 12.10     | 10.75 | 9.61    | 9.61      | 0.96|
| Occipital | 7.62     | 9.09      | 10.17  | 10.83     | 9.68  | 8.33    | 8.69      | 1.11|
| Temporal | 13.75    | 14.51     | 14.28  | 15.78     | 14.38 | 12.53   | 13.81     | 0.98|

Note. SD: standard deviation.
Table 2. Wilcoxon signed-rank analyses of paired music genres and control comparisons for the beta frequency band

| Genres | Frontal (p) | Parietal (p) | Occipital (p) | Temporal (p) |
|--------|-------------|--------------|---------------|--------------|
| B vs. A | .429        | .224         | .191          | .738         |
| C vs. A | .243        | .715         | .330          | .136         |
| D vs. A | .976        | .543         | .673          | .951         |
| E vs. A | .784        | .301         | .484          | .026         |
| C1 vs. A | .951        | .362         | .002*         | .039         |
| C2 vs. A | .043        | .068         | .026          | .101         |
| C vs. B | .879        | .627         | .951          | .191         |
| D vs. B | .121        | .153         | .595          | .761         |
| E vs. B | .855        | .083         | .144          | .024         |
| C1 vs. B | .784        | .605         | .236          | .006*        |
| C2 vs. B | .831        | .236         | .171          | .301         |
| D vs. C | .465        | .484         | .927          | .212         |
| E vs. C | .394        | .089         | .019          | .004*        |
| C1 vs. C | .627        | .605         | .248          | .008*        |
| C2 vs. C | .523        | .114         | .055          | .784         |
| E vs. D | .693        | .670         | .171          | .010*        |
| C1 vs. D | .627        | .784         | .110          | .033         |
| C2 vs. D | .191        | .045         | .447          | .543         |
| C1 vs. E | .976        | .114         | .008*         | .584         |
| C2 vs. E | .260        | .021         | .008*         | .019         |
| C2 vs. C1 | .089       | .191         | .903          | .010*        |

Note. A: Classical; B: Tribal Downtempo; C: Psytrance; D: Goa Trance; E: Subject Song; C1: Control 1; C2: Control 2.*Data that meet this study’s statistical significance threshold of \( p = .01 \) or less in comparison to non-significant results.

Table 3. Wilcoxon signed-rank analyses of paired music genres and control comparisons for the alpha frequency band

| Genres | Frontal (p) | Parietal (p) | Occipital (p) | Temporal (p) |
|--------|-------------|--------------|---------------|--------------|
| B vs. A | .563        | .114         | .068          | .136         |
| C vs. A | .715        | .031         | .260          | .316         |
| D vs. A | .107        | .114         | .738          | .330         |
| E vs. A | .627        | .171         | .563          | .059         |
| C1 vs. A | .316        | .927         | .010*         | .761         |
| C2 vs. A | .006*       | .236         | .201          | .023         |
| C vs. B | .726        | .224         | .465          | .951         |
| D vs. B | .301        | .394         | .563          | .429         |
| E vs. B | .784        | .429         | .879          | .212         |
| C1 vs. B | .021        | .503         | .004*         | .715         |
| C2 vs. B | .039        | .039         | .026          | .001*        |
| D vs. C | .523        | .412         | .648          | .951         |
| E vs. C | .784        | .951         | .761          | .412         |
| C1 vs. C | .346        | .064         | .010*         | .523         |
| C2 vs. C | .029        | .007*        | .052          | .004*        |
| E vs. D | .627        | .903         | .584          | .563         |
| C1 vs. D | .063        | .260         | .005*         | .316         |
| C2 vs. D | .003*       | .068         | .394          | .007*        |
| C1 vs. E | .114        | .078         | .015          | .248         |
| C2 vs. E | .010*       | .026         | .094          | .002*        |
| C2 vs. C1 | .378       | .260         | .503          | .029         |

Note. A: Classical; B: Tribal Downtempo; C: Psytrance; D: Goa Trance; E: Subject Song; C1: Control 1; C2: Control 2.*Data that meet this study’s statistical significance threshold of \( p = .01 \) or less in comparison to non-significant results.

Rodriguez et al. associated with increased relative percentages of alpha frequencies compared to Psytrance (\( p = .007 \)). In the occipital region, Control 1 was associated with increased relative percentages of alpha frequencies compared to Classical (\( p = .010 \)), Tribal Downtempo (\( p = .004 \)), Psytrance (\( p = .010 \)), and Goa Trance (\( p = .005 \)). In the temporal region, Control 2 was associated with increased relative percentages of alpha frequencies compared to Tribal Downtempo (\( p = .001 \)), Psytrance (\( p = .004 \)), Goa Trance (\( p = .007 \)), and Subject Song (\( p = .002 \)).

Wilcoxon signed-rank analyses revealed significant differences in relative percentages of alpha frequencies for paired comparisons of music genres and/or controls within individual cortical regions, which are displayed in Table 4. In the frontal region, Psytrance was associated with increased relative percentages of alpha frequencies compared to Subject Song (\( p = .002 \)). In the parietal region, Psytrance was associated with increased relative percentages of alpha frequencies compared to both Subject Song (\( p = .002 \)) and Control 1 (\( p = .009 \)). In the occipital region, Tribal Downtempo and Psytrance were associated with increased relative percentages of alpha frequencies compared to Control 1 (\( p = .005 \), \( p = .001 \)). In the temporal region, Classical, Tribal Downtempo, and Psytrance were associated with increased relative percentages of alpha frequencies compared to Subject Song (\( p = .006 \), \( p = .004 \), \( p < .001 \)).

Wilcoxon signed-rank analyses revealed significant differences in relative percentages of delta frequencies for paired comparisons of music genres and/or controls within individual cortical regions, which are displayed in Table 5. In the parietal region, Psytrance was associated with increased...
relative percentages of delta frequencies compared to Classical ($p = .008$), Control 1 ($p = .008$), and Control 2 ($p = .010$). In the occipital region, both Psytrance and Goa Trance were associated with increased relative percentages of delta frequencies compared to Control 1 ($p = .009$, $p = .010$). In the temporal region, Psytrance was associated with increased relative percentages of delta frequencies compared to Subject Song ($p = .005$).

### Cortical region comparisons

A somatotopic cortical activity map for EEG frequency band activity summarizing our EEG findings for interregion cortical comparisons across all music genres and controls is displayed in Figure 5. Statistical data analyses leading to this

![Figure 5. Somatotopic cortical activity map summarizing relative percentages of each frequency band for different cortical regions, across all music genres and controls (0% = no brightness, 60% = maximum brightness)](image)

### Table 4. Wilcoxon signed-rank analyses of paired music genres and control comparisons for the theta frequency band

| Genres   | Frontal ($p$) | Parietal ($p$) | Occipital ($p$) | Temporal ($p$) |
|----------|---------------|----------------|-----------------|----------------|
| B vs. A  | .784          | .316           | .019            | .543           |
| C vs. A  | .073          | .031           | .018            | .048           |
| D vs. A  | .976          | .693           | .287            | .648           |
| E vs. A  | .083          | .761           | .648            | .006*          |
| C1 vs. A | .693          | .976           | .301            | .394           |
| C2 vs. A | .761          | .831           | .784            | .784           |
| C vs. B  | .191          | .132           | .808            | .315           |
| D vs. B  | .738          | .412           | .346            | .248           |
| E vs. B  | .144          | .236           | .089            | .004*          |
| C1 vs. B | .831          | .128           | .003*           | .101           |
| C2 vs. B | .855          | .218           | .114            | .563           |
| D vs. C  | .447          | .061           | .412            | .015           |
| E vs. C  | .002*         | .002*          | .052            | <.001*         |

**Note.** A: Classical; B: Tribal Downtempo; C: Psytrance; D: Goa Trance; E: Subject Song; C1: Control 1; C2: Control 2.*Data that meet this study’s statistical significance threshold of $p = .01$ or less in comparison to non-significant results.

### Table 5. Wilcoxon signed-rank analyses of paired music genres and control comparisons for the delta frequency band

| Genres   | Frontal ($p$) | Parietal ($p$) | Occipital ($p$) | Temporal ($p$) |
|----------|---------------|----------------|-----------------|----------------|
| B vs. A  | .394          | .543           | .068            | .701           |
| C vs. A  | .212          | .008*          | .101            | .301           |
| D vs. A  | .447          | .176           | .394            | .465           |
| E vs. A  | .584          | .783           | .808            | .016           |
| C1 vs. A | .903          | .738           | .033            | .267           |
| C2 vs. A | .808          | .808           | .693            | .715           |
| C1 vs. B | .104          | .595           | .248            | .078           |
| C2 vs. B | .191          | .584           | .808            | .014           |
| C1 vs. C | .543          | .976           | .224            | .523           |

**Note.** A: Classical; B: Tribal Downtempo; C: Psytrance; D: Goa Trance; E: Subject Song; C1: Control 1; C2: Control 2.*Data that meet this study’s statistical significance threshold of $p = .01$ or less in comparison to non-significant results.
Table 6. Wilcoxon signed-rank analyses of paired cortical region comparisons for Classical

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .004*    | <.001*    | .036      | <.001*    |
| O vs. F   | .006*    | <.001*    | .007*     | <.001*    |
| T vs. F   | .045     | .107      | .260      | .927      |
| O vs. P   | .045     | .026      | .014      | .036      |
| T vs. P   | .171     | <.001*    | .287      | <.001*    |
| T vs. O   | .036     | <.001*    | .015      | <.001*    |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Table 7. Wilcoxon signed-rank analyses of paired cortical region comparisons for Tribal Downtempo

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .015     | <.001*    | .330      | <.001*    |
| O vs. F   | .013     | <.001*    | .144      | .002*     |
| T vs. F   | .029     | .019      | .595      | .523      |
| O vs. P   | .029     | .015      | .083      | .236      |
| T vs. P   | .128     | <.001*    | .761      | <.001*    |
| T vs. O   | .012     | <.001*    | .181      | .001*     |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Table 8. Wilcoxon signed-rank analyses of paired cortical region comparisons for Goa Trance

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .073     | <.001*    | .136      | .001*     |
| O vs. F   | .018     | <.001*    | .212      | .001*     |
| T vs. F   | .031     | .128      | .412      | .808      |
| O vs. P   | .018     | .005*     | .073      | .021      |
| T vs. P   | .927     | <.001*    | .543      | <.001*    |
| T vs. O   | .078     | <.001*    | .274      | <.001*    |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Table 9. Wilcoxon signed-rank analyses of paired cortical region comparisons for Psytrance

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .005*    | <.001*    | .036      | <.001*    |
| O vs. F   | .001*    | <.001*    | .012      | <.001*    |
| T vs. F   | .007*    | .045      | .055      | .523      |
| O vs. P   | .002*    | .002*     | .078      | .029      |
| T vs. P   | .502     | <.001*    | .447      | <.001*    |
| T vs. O   | .007*    | <.001*    | .078      | <.001*    |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Table 10. Wilcoxon signed-rank analyses of paired cortical region comparisons for Subject Song

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .064     | <.001*    | .212      | .001*     |
| O vs. F   | .033     | <.001*    | .019      | .001*     |
| T vs. F   | .648     | .236      | .068      | .094      |
| O vs. P   | .018     | <.001*    | .001*     | .015      |
| T vs. P   | .005*    | <.001*    | .465      | .002*     |
| T vs. O   | .007*    | <.001*    | .083      | .001*     |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Table 11. Wilcoxon signed-rank analyses of paired cortical region comparisons for Control 1

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .003*    | <.001*    | .001*     | <.001*    |
| O vs. F   | <.001*   | <.001*    | .001*     | <.001*    |
| T vs. F   | .484     | .523      | .023      | .523      |
| O vs. P   | <.001*   | <.001*    | .002*     | .004*     |
| T vs. P   | .004*    | <.001*    | .121      | <.001*    |
| T vs. O   | <.001*   | <.001*    | .001*     | <.001*    |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Table 12. Wilcoxon signed-rank analysis of paired cortical region comparisons for Control 2

| Regions   | Beta (p) | Alpha (p) | Theta (p) | Delta (p) |
|-----------|----------|-----------|-----------|-----------|
| P vs. F   | .073     | <.001*    | .083      | <.001*    |
| O vs. F   | .010*    | <.001*    | .014      | .001*     |
| T vs. F   | .121     | .107      | .248      | .927      |
| O vs. P   | .004*    | .001*     | .018      | .018      |
| T vs. P   | .224     | <.001*    | .162      | <.001*    |
| T vs. O   | .031     | <.001*    | .006*     | <.001*    |

Note. P: parietal; F: frontal; O: occipital; T: temporal.*Data that meet this study’s statistical significance threshold of p = .01 or less in comparison to non-significant results.

Visual somatotopic representation of our interregion cortical comparison findings can be found in Tables 6–12 and the subsequent paragraphs below.

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Classical music on relative percentages of beta, alpha, theta, and delta frequencies between different cortical regions, which are displayed in Table 6. Both the parietal and occipital regions were associated with decreased relative percentages of beta frequencies compared to the frontal region (p = .004,
pared to the parietal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions. The frontal region was associated with increased relative percentages of theta frequencies compared to the occipital region (\(p = .007\)). Both the frontal and temporal regions were associated with increased relative percentages of delta frequencies compared to the parietal (\(p < .001, p < .001\)) and occipital (\(p < .001, p < .001\)) regions.

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Tribal Downtempo on relative percentages of alpha and delta frequencies between different cortical regions, which are displayed in Table 7. Both the parietal and occipital regions were associated with increased relative percentages of alpha frequencies compared to the frontal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions. Both the frontal and temporal regions were associated with increased relative percentages of delta frequencies compared to the parietal region (\(p < .001, p < .001\)) and occipital (\(p < .001, p < .001\)) regions.

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Psytrance on relative percentages of alpha and delta frequencies between different cortical regions, which are displayed in Table 8. Both the parietal and occipital regions were associated with increased relative percentages of alpha frequencies compared to the frontal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions. Both the frontal and temporal regions were associated with increased relative percentages of delta frequencies compared to the parietal (\(p < .001, p < .001\)) and occipital (\(p = .002, p = .001\)) regions.

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Psytrance on percentage of alpha and delta frequencies between different cortical regions, which are displayed in Table 9. The parietal, occipital, and temporal regions were associated with decreased relative percentages of alpha frequencies compared to the frontal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions, whereas the occipital region was also associated with decreased relative percentages of alpha frequencies compared to the parietal region (\(p < .001\)). Both the frontal and temporal regions were associated with increased relative percentages of alpha frequencies compared to the parietal (\(p < .001, p < .001\)) and occipital (\(p < .001, p < .001\)) regions.

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Psytrance on relative percentages of alpha and delta frequencies between different cortical regions, which are displayed in Table 10. Both the parietal and occipital regions were associated with increased relative percentages of delta frequencies compared to the occipital region (\(p = .005, p = .007\)). Both the parietal and occipital regions were associated with increased relative percentages of alpha frequencies compared to the frontal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions, whereas the occipital region was also associated with increased relative percentages of alpha frequencies compared to the parietal region (\(p < .001\)). The occipital region was associated with decreased relative percentages of theta frequencies compared to the parietal region (\(p < .001\)). Both the frontal and temporal regions were associated with increased relative percentages of delta frequencies compared to the parietal (\(p = .001, p = .002\)) and occipital (\(p = .001, p = .001\)) regions.

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Control 1 on relative percentages of beta, alpha, and delta frequencies between different cortical regions, which are displayed in Table 11. Both the parietal and occipital regions were associated with decreased relative percentages of beta frequencies compared to the frontal (\(p = .003, p < .001\)) and temporal (\(p = .004, p < .001\)) regions, whereas the occipital region was also associated with decreased relative percentages of beta frequencies compared to the parietal region (\(p < .001\)). Both the parietal and occipital regions were associated with increased relative percentages of alpha frequencies compared to the frontal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions, whereas the occipital region was also associated with increased relative percentages of alpha frequencies compared to the parietal region (\(p < .001\)). The frontal, parietal, and temporal regions were all associated with increased relative percentages of theta frequencies compared to the occipital region (\(p = .001, p = .002, p = .001\)), whereas the frontal region was also associated with increased relative percentages of theta frequencies compared to the parietal region (\(p = .001\)). Both the frontal and temporal regions were associated with increased relative percentages of delta frequencies compared to the parietal (\(p < .001, p < .001\)) and occipital (\(p < .001, p > .001\)) regions, whereas the occipital region was also associated with increased relative percentages of delta frequencies compared to the parietal region (\(p = .004\)).

Wilcoxon signed-rank analyses revealed significant differences when comparing the effect of Control 2 on relative percentages of beta, alpha, and delta frequencies between different cortical regions, which are displayed in Table 12. The occipital region was associated with decreased relative percentages of beta frequencies compared to both the frontal (\(p = .010\)) and parietal (\(p = .004\)) regions. Both the parietal and occipital regions were associated with increased relative percentages of alpha frequencies compared to the frontal (\(p < .001, p < .001\)) and temporal (\(p < .001, p < .001\)) regions, whereas the occipital region was also associated with increased relative percentages of alpha frequencies compared to the parietal region (\(p = .001\)). The temporal region was associated with increased relative percentages of theta frequencies compared to the occipital region (\(p = .006\)). Both the frontal and temporal regions were associated with
increased relative percentages of delta frequencies compared to the parietal (p < .001, p < .001) and occipital (p = .001, p < .001) regions.

**Subject music preferences**

Mean subject ratings and rankings for music genres and controls are displayed in Table 13. A positive correlation \( R = .579 \) was found between subject ratings for Goa Trance and relative theta frequency percentages in the temporal region (p = .004). There were no other significant correlations noted between subject ratings and relative frequency band percentages for any other music genre or control in any other cortical region. There were no significant correlations between subject rankings and relative frequency band percentages for any music genre or control in any cortical region.

**Subject gender and music training**

Gender was not found to have a significant influence on relative beta, alpha, theta, or delta frequency percentages in any cortical region. Music training was associated with increased relative delta percentages in the frontal region (p = .002), as displayed in Figure 6.

**DISCUSSION**

Several findings from this study support those of previous music therapy studies, whereas other findings provide novel insights regarding how different music genres and pertinent variables affect neurophysiological activity in the human cerebral cortex. In particular, this study provides further supportive evidence that various genres of music may impact the central nervous system by promoting changes in cerebral cortex activity that have similarities to NREM sleep, while the listener remains awake (Baumgartner et al., 2006; Britton et al., 2016; Jacobs & Friedman, 2004; Kabuto et al., 1993; Lin et al., 2010; White & Richard, 2009).

**Music genre comparisons**

Decreased relative percentages of beta frequencies were found to be strongly associated with several music genres and controls within individual cortical regions, including Controls 1 and 2 in the occipital region, and Tribal Downtempo, Psytrance, Goa Trance, and Control 2 in the temporal region. Given that a decrease in beta frequencies is consistent with cortical activity observed during stages of NREM sleep, these findings support the findings of other music–EEG studies, which suggest that various music genres may impact the central nervous system by promoting changes in cerebral cortex activity that have similarities to NREM sleep, while the listener remains awake (Baumgartner et al., 2006; Britton et al., 2016; Jacobs & Friedman, 2004; Kabuto et al., 1993; Lin et al., 2010; White & Richard, 2009). However, given that our chosen non-musical control (Victoria Falls waterfall audio recording) was quite pleasant and was associated with a similar reduction in relative percentages of beta frequencies in comparison to several other music genres, it is difficult to draw strong conclusions from these findings. Future studies should better investigate music genres and non-musical controls by including a randomized control within each subject’s music sequence, and by selecting controls that are less pleasant (e.g., television static, radio static, traffic noise, etc.).

Increased relative percentages of alpha frequencies were found to be most strongly associated with controls within individual cortical regions. Most of these significant differences were associated with Control 2 (frontal, parietal, and temporal regions), whereas only one was associated with Control 1 (occipital region). These results may be

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**Table 13. Mean subject ratings and rankings for music genres and controls**

| Control 1 | Classical | Tribal | Psytrance | Goa | Subject | Control 2 | SD |
|-----------|-----------|--------|-----------|-----|---------|-----------|----|
| Ratings   | 3.17      | 7.80   | 6.43      | 5.94| 5.91    | 9.63      | N/A| 2.16 |
| Rankings  | N/A       | 2.70   | 3.43      | 3.74| 3.91    | 1.22      | N/A| 1.10 |

*Note.* Ratings (1 = worst, 10 = best) and rankings (1 = best, 5 = worst). SD: standard deviation.

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**Figure 6.** Impact of music training on relative percentages of delta frequencies in the frontal region
related to the pleasant nature of our chosen control (Victoria Falls waterfall audio recording), as suggested by previous music–EEG studies, which observed increased alpha frequency activity in response to pleasant music (Kabuto et al., 1993; Lin et al., 2010). The only difference between Controls 1 and 2 is that Control 2 was played at the end of each subject’s music sequence, whereas Control 1 was played at the beginning of the sequence. This suggests that subjects may have been more relaxed toward the end of their music sequence. This possibility was anticipated during planning of this study, and was controlled for by randomizing the sequence of music genres for each subject and thus the generally relaxing nature of each subject’s music sequence should not have significantly impacted the results we observed across the music genres investigated in this study. In future studies, it would be helpful to incorporate a randomized control in the music sequence in addition to the flanking controls, to better assess cortical responses for a control that does not always occur at the same points in a subject’s music sequence. It would also be helpful to select a less-relaxing control, such as television static or radio static, or perhaps an audio-recording representative of typical non-musical noise encountered during one’s routine day, such as traffic noise.

Increased relative percentages of theta frequencies were found to be most strongly associated with Psytrance within individual cortical regions. Tribal Downtempo and Classical also exhibited significant but weaker associations. The superior association observed between Psytrance and increased relative percentages of theta frequencies may be attributed to its unique 16th note rhythmic beat structure, as that is the primary difference between Psytrance and the other music genres investigated in this study, including Goa Trance. Goa Trance lacks the unique 16th note rhythmic beat structure that is found in Psytrance, but is otherwise very similar. Further investigation is warranted to better clarify the reasons why Psytrance exhibited a superior association with increased relative percentages of theta frequencies compared to the other studied music genres. Given that increased theta frequency activity is associated with stages of NREM sleep, these findings support those of previous music therapy studies, which suggest that certain types of music may impact the central nervous system by promoting changes in cerebral cortex activity that have similarities to NREM sleep, while the listener remains awake (Baumgartner et al., 2006; Jacobs & Friedman, 2004; Kabuto et al., 1993; Lin et al., 2010).

Overall, we observed several findings consistent with previous music therapy studies, namely the finding that various types of music influence the central nervous system by promoting changes in cerebral cortex activity that have similarities to NREM sleep, while the listener remains awake (Baumgartner et al., 2006; Jacobs & Friedman, 2004; Kabuto et al., 1993; Lin et al., 2010). Furthermore, by comparing a variety of carefully selected music genres and controls, we observed potentially novel insights regarding how some music genres may have a more robust association with these changes in cerebral cortex activity, such as the observed findings regarding Psytrance and increased relative percentages of theta and delta frequencies.

Cortical region comparisons

Decreased relative percentages of beta frequencies and increased relative percentages of alpha frequencies were found to be most strongly associated with the parietal and occipital regions in comparison with other cortical regions, with the most robust association being observed in the occipital region. These findings were rather consistent across all music genres and controls. The observed association between decreased relative percentages of beta frequencies in both the parietal and occipital regions appears to be closely correlated with the association we observed between increased relative percentages of alpha frequencies in both the parietal and occipital regions. Both the frontal and temporal regions showed significantly increased relative percentages of theta and delta frequencies when compared to other cortical regions. In contrast, the lowest relative percentages of theta frequencies were observed in the parietal and occipital regions. These findings suggest that individual cortical regions have unique, region-specific responses to music that remain somewhat consistent across a variety of musical (i.e., music genres) and non-musical (i.e., controls) auditory input.

Given that the unique responses of each individual cortical region were observed to be rather consistent across all music genres and controls, these findings suggest that although individual cortical regions exhibit different frequency band responses in comparison to each other when subjected to one particular music genre, individual cortical regions still
respond rather consistently across a wide variety of musical (i.e., music genres) and non-musical (i.e., controls) auditory input. These findings are similar to those observed in other music–EEG studies, including those that reported increased alpha frequency activity in the occipital region in response to Classical music and other “pleasant” types of music (Kabuto et al., 1993; Lin et al., 2010).

**Subject music preferences**

The observed correlation between subject music genre ratings and the association of Goa Trance with increased relative percentages of theta frequencies in the temporal region suggests that subject music preferences may possibly influence the amount of theta activity in the temporal region when listening to music, but this finding is likely spurious since no other relationship was found between subject ratings or rankings for any music genre or control in any other cortical region. This finding, although statistically significant, is rather inconclusive, and further investigation is both warranted and encouraged. Given that no other significant correlations were observed between subject music preferences and relative percentages of beta, alpha, theta, or delta frequencies, these findings suggest overall that subject music preferences do not play a significant role in determining the relative percentages of each frequency band that are generated within a given cortical region when listening to various music genres. Overall, our findings do not suggest a significant impact of subjective music preferences on relative frequency band percentages in any cortical region.

The observed paucity of significant correlations between subject music preferences and relative frequency band percentages in all cortical regions is supported by other findings from this study that have been discussed in previous sections, such as the finding that the music genres most effective at significantly modifying relative percentages of beta, alpha, theta, or delta frequencies were not rated or ranked very favorably by most subjects (e.g., Controls, Psytrance, etc.). However, it is important to note that these findings do not address the likely possibility that personal music preferences may still play a very important role in the subjective sensations (e.g., relaxation, pleasure, happiness, etc.) that are experienced while listening to various music genres.

**Subject gender and music training**

The lack of significant findings observed when examining the effect of gender on relative percentages of beta, alpha, theta, and delta frequencies in the cerebral cortex suggests that music has a similar impact on EEG activity in males and females within individual frequency bands and cortical regions. However, this study did not compare individual EEG leads, individual cerebral hemispheres, or other related variables that could still potentially be influenced by gender. Although this study did not find any gender-related differences when comparing individual frequency bands and cortical regions, a previous music–EEG study observed gender-related differences in music processing when comparing individual cerebral hemispheres (Koelsch et al., 2003). Given this finding, future studies should examine both interregional and interhemispheric cortical comparisons to further clarify the current understanding of gender-related differences in cortical music processing.

The finding that subjects with previous music training had increased relative percentages of delta frequencies in the frontal region suggests that music training may enable subjects to have stronger neurophysiological responses to music in the frontal cortex, at least in regard to delta activity. This finding may possibly be related to the association of the frontal lobe with executive function, judgment, cognition, and abstract thought. This possibility is supported by other music therapy studies, which have described multiple cognitive processes, including some with contribution from the frontal lobe, that have been associated with music perception and processing (Maeyama et al., 2009; Shabanloei et al., 2010). Given that music training did not have a significant influence on relative percentages of beta, alpha, theta, or delta frequencies in any other area of the cerebral cortex, the potential influence of music training on music perception and processing may be limited to the frontal lobe.

**Study limitations and future research**

This study has a number of limitations that could be improved during future research. A larger sample size would be beneficial and would allow for stronger conclusions to be drawn. Subjects could be asked to abstain from routinely encountered psychoactive chemicals for a longer period of time (e.g., >12 hr), since many medications and chemicals continue having psychoactive effects beyond the 6-hr abstinent period required by this study. Subjects also could be screened to rule out recent consumption of long-acting psychoactive chemicals, such as methamphetamine, lysergic acid diethylamide, etc. Future studies may be improved by utilizing different subject groups based on certain variables (e.g., age, music training, etc.), allowing for intergroup comparisons and a deeper understanding of the resulting EEG data.

Future studies may be improved by focusing on a smaller number of variables during the investigation. Because the study attempted to investigate a large number of different variables, there were many pieces of data we collected from subjects that we were unable to include in our analysis due to limitations in time, personnel, and length of this manuscript. For example, we assessed the ethnicity of each subject using our pre-music questionnaire, as well as the familiarity of each subject with the music genres included in this study, but were unable to thoroughly investigate these data and variables. Although we investigated the potential influence of subject music preferences in this study, we did not investigate other closely related variables using other subjective information that we gathered in our pre-music questionnaire, such as subject ethnicity or familiarity with each music genre.

Future studies may be improved using a non-musical control that more accurately represents commonly encountered non-musical noise (e.g., television static, radio static, traffic noise, construction sounds, footsteps, etc.). The soft, monotonous waterfall recording used as the sole control in
Potential bias in the study could be prevented by blinding the individuals who measured the EEG data from the order of the songs in each music sequence. Potential bias could also be prevented using multiple representative songs for each music genre, and by having multiple individuals select the songs used to represent each music genre, given that different individuals may disagree as to whether or not an individual song is an appropriate representation of a broad music genre. This study used only one song to represent each music genre, and only one individual selected each song (other than Subject Song). This study was also biased by the age of the subjects, as all were young adults, and by their occupations, as most were undergraduate or graduate students.

CONCLUSIONS

Controls were most strongly associated with decreased relative percentages of beta frequencies, while Psytrance, Goa Trance, and Tribal Downtempo also had significant but weaker associations. Controls were most strongly associated with increased relative percentages of alpha frequencies. Psytrance was most strongly associated with increased relative percentages of theta frequencies, while Tribal Downtempo and Classical also had significant but weaker associations. Psytrance was most strongly associated with increased relative percentages of delta frequencies, while Goa Trance also had a significant but weaker association. The lowest relative percentages of beta frequencies and the highest relative percentages of alpha frequencies across all music genres and controls occurred in the occipital and parietal regions. The greatest relative percentages of theta and delta frequencies across all music genres and controls occurred in the frontal and temporal regions. Subjects with previous music training exhibited greater relative percentages of delta frequencies in the frontal region. Subject gender and music preference did not have a significant influence on relative frequency band percentages in any cortical region.

Findings from this study support those of previous music therapy studies and provide novel insights regarding music’s influence on human neurophysiology. Our findings also support the hypothesis that music may promote changes in cerebral cortex activity that have similarities to NREM sleep, while the listener remains awake. In addition, findings from this study suggest that certain music genres may have a more robust association with these changes in cerebral cortex activity than other music genres.

This study expands upon our current understanding of music’s influence on the human brain and body by providing evidence that further elucidates the neurophysiological activity that arises in the cerebral cortex when listening to various music genres. Future studies are required to better investigate and clarify these findings. The authors of this study encourage the scientific and medical communities to further investigate music’s therapeutic properties and its ability to influence human physiology. By improving our understanding of the physiological effects of music, we can more effectively apply music as an adjuvant therapeutic modality to benefit humankind.

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APPENDIX

NEUROFAX EEG-1200A ELECTROENCEPHALOGRAPH

- Neurofax EEG-1200 PC-based EEG and polygraph system enables registration, evaluation, and analysis of EEG and polygraph data. This technical high-end solution includes amplifiers for recording 38, 44, 64, 128, or 192 channels at sampling frequencies of up to 10,000 Hz. Sixteen additional DC channels including eight external triggers are available optional. Up to 250 EEG channels can be traced at the same time in real time. The Neurofax EEG-1200 system includes a highly functional and intuitive software package for data recording, playback, and quantitative analysis.
- Product URL: [http://www.nihonkohden.de/products/neurology/eeg/research/eeg-1200.html?L=1](http://www.nihonkohden.de/products/neurology/eeg/research/eeg-1200.html?L=1)

WINEEG ANALYSIS SOFTWARE

- User manual: [http://bio-medical.com/media/support/wineeg.pdf](http://bio-medical.com/media/support/wineeg.pdf)
- Website: [http://www.novatecheeg.com/wineeg.html](http://www.novatecheeg.com/wineeg.html)

PRE-MUSIC QUESTIONNAIRE

- What is your name? What is your age? What is your gender? What is your ethnicity?
- Have you ever had any type of musical training, e.g., have you ever composed or produced music, played a musical instrument, or had singing lessons?
  1. If so, what music training do you have and how much?
- What are your three most favorite genres of music (any)?
- What are your three least favorite genres of music (any)?
- Have you heard songs from any of this study’s music genres before?
  1. If so, how many times have you heard a song from each genre?
  2. If so, how do you feel about the genres (i.e., like, dislike, and neutral)?
- How much sleep did you get last night?
- How tired do you feel on a scale of 1–10 (1 = very alert, 10 = extremely tired)?

VISUAL ANALOG SCALE USED FOR SUBJECT RATING OF EACH MUSIC GENRE

1 - Strongly Dislike
5 - Neutral (Neither Like or Dislike)
10 - Strongly Like

Please rate the song you just heard by drawing a vertical mark on the linear graph above to indicate how much you liked or disliked the last song.

POST-MUSIC QUESTIONNAIRE

- Now that you have heard all five music genres, will you please rank the songs you heard in order of how much you liked them?
  1. List the songs in order of how much you liked them, starting with the song you liked most in the #1 position at the top, and finishing with the song you liked least in the #5 position at the bottom.
- Did you fall asleep at all during the music therapy session?
- Do you have any questions or concerns?

STUDY IMAGES

- [Illinois Neurological Institute](https://www.osfmc.org/)

EEG response to various music genres
EEG response to various music genres
