Electrocortical (EEG) correlates of music and states of consciousness

Lazar Skaric [1] **- Milorad Tomasevic** [2] **- Dejan Rakovic** [1, 3]
Emil Jovanov [6, 4] **- Vlada Radivojevic** [5] **- Predrag Sukovic** [1]
Marko Car [5] **- Dejan Radenovic** [1]

[1] *Faculty of Electrical Engineering, Belgrade, Yugoslavia*
[2] *Vinca Institute of Nuclear Sciences, Belgrade, Yugoslavia*
[3] *ECPD of the United Nations University for Peace, Belgrade, Yugoslavia*
[4] *Electrical and Computer Engineering Dept. The University of Alabama in Huntsville*
[5] *Institute for Mental Health, Department of Clinical Neurophysiology, Belgrade, Yugoslavia*
[6] *Institute for Biological Research, Center for Multidisciplinary Studies, Belgrade, Yugoslavia*

jovanov@ieee.org

Abstract

The study of the perception of music is a paramount example of multidisciplinary research. In spite of a lot of theoretical and experimental efforts to understand musical processing, attempts to localize musical abilities in particular brain regions were largely unsuccessful, save for the difference between musicians and non musicians, especially in hemispheric specialization and in EEG correlational dimensions. Having in mind that human emotional response to music and to art in general is limbic dependent, this motivated us to address our question to a similar possible neurobiological origin of musicogenic altered states of consciousness and its possible EEG correlates, "resonantly" induced by deep spiritual music. For example, as in sound-induced altered states of consciousness cultivated in some Eastern yogic practices. The musicogenic states of consciousness are evaluated within a group of 6 adults, upon the influence of 4 types of spiritual music. The most prominent changes in theta or alpha frequency bands were induced in two subjects, upon the influence of Indian spiritual music, Bhajan.

Keywords: Music Perception; States of Consciousness; EEG

Why do we like music? We all are reluctant, in music and art, to examine our sources of pleasure and strength. In part we fear success itself – that Understanding might spoil Enjoyment. And rightly so; Art often loses power when its psychological roots are exposed. No matter: when this happens we will go on, as always to seek more robust illusions! (Marvin Minsky)

1. Introduction

The study of the perception of music is a paramount example of multidisciplinary research, in which musicians, psychologists, neurobiologists, physicists, and engineers must communicate and work together. This study comprises three broad problem areas (Roederer, 1982): (a) perception of musical tones; (b) interpretation of acoustical information relevant to music; and (c) emotional response to musical messages. In the past two decades, a considerable mutual integration of these three problem areas has taken place, due to the progress in the understanding of general human brain functions, and the recognition that in the conscious state even the simplest perceptual events are bound to trigger operations that involve the brain as a whole.

The human brain does not appear to contain many new or drastically different processing centers when compared with the brains of any of our primate ancestors – save for cerebral hemisphere specialization, which is the basic evolutionary novelty of the human brain. This specialization is related to two quite different operational modes. One mode involves sequential analysis of single-channel information (such as required in language, speech, and thought processing, characteristic of the "dominant" hemisphere; the left hemisphere in about 97% of the subjects – the right-handed ones). The other involves a synthesis of many different parallel channels to accomplish the holistic determination of input stimuli (characteristic of the "minor" hemisphere).

Along these lines, it has been proposed that music is a language-like form by which humans express themselves and communicate with each other (Pribram, 1982). This analogy would then suggest that processing of musical indicants (such as melody and harmony) are predominantly "minor" hemisphere related, and that processing of musical symbols (such as hierarchically arranged phase structures) predominantly involves the "dominant" hemisphere. Semantic processing of both musical indicants and symbols should be related to the posterior cortical convexity. However, pragmatic processing of a user's musical experience and expression should be related to the frontolimbic cortical formations. And finally, syntactic processing of the arrangement of indicants and symbols should be related to the motor system of the brain, to which both posterior and frontal cortical formations project. However, it should be pointed out that the syntactic structure of music might be more dependent on semantic processing.

In spite of a lot of theoretical and experimental efforts to relate music and language processing (Pribram, 1982; Bernstein, 1976; Jackendoff & Lerdahl, 1982; Chomsky, 1980), attempts to localize musical abilities in particular brain regions were largely unsuccessful – both by electroencephalography (Petsche, Lindner, Rappelsberger & Gruber, 1988) and positron emission tomography (Sergent, 1993) – save for the difference between musicians (or musically talented subjects) and non-musicians:

(a) The processing of single musical notes and melodic line is represented in the "minor" hemisphere when presented to musically less sophisticated subjects, while it is equally well represented in both hemispheres of more sophisticated subjects.

(b) Less sophisticated subjects responded with a prop in brainwave complexity to rhythmical weakly chaotic music, while more sophisticated subjects showed higher EEG correlational dimensions (Birbaumer, Lutzenberger, Tau, Mayer-Kress & Braun, in press). It should also be added that neuroendocrinological measurements revealed a specific pattern of sexual hormones (increased testosterone in females; decreased in males) in composers and highly talented adolescents (Hassler & Birbaumer, 1988).

It should be also pointed out that one of the most profound consequences of the evolution of human brain functions (and human consciousness itself) has been the emergence of systematic postponing of behavioral goals and rearrangement of behavioral priorities. This led to conflicts between cortical functions and those of the limbic system. While the limbic system in animals is mostly activated by environmental and somatic input, in humans it can also respond to internally evoked images displayed on the cortex during the process of thinking. As motivation and emotion are integral manifestations of limbic function (assuring that all cortical processes are carried out so as to be of maximum benefit to the organism, through the extended reticular-thalamic activating system: Baars, 1988), in humans they can be triggered with no relationship to the current state of the environment. It is along this line that we should seek leads toward understanding the human emotional response to music and to art in general, when the messages therein seem to be of no obvious survival value (Roederer, 1982).

This motivated us to address our question to a similar possible neurobiological origin of musicogenic altered states of consciousness, induced by deep spiritual music of different cultures (Rouget, 1980), and its possible EEG correlates.

The analogous, more frequently used physical mechanism for sound-induced altered states of consciousness is an introspective repeating of a certain type of sound or “mantr”, which is chosen so as to “resonate” with the structure of an individual’s nervous system (Nader, 1995). The sound resonances within the human lobe would be then achieved through a formation of standing sound waves, with a principal harmonic (of ~ 1000 Hz) having its maximal amplitude in the centre of the lobe cavity, i.e. around the region of limbic system. This activity therefore induces the local stimulation of thalamic formation through some mechano-chemical receptors (to be still specified therein).

2. Method

2.1. Subjects

The study was carried out on 6 healthy adult volunteers. There was one male and five females, whose ages ranged from 18 to 29 years with a mean age of 25 years. All subjects were free of any medication. Prior to the experiment, the subjects were informed verbally about all aspects of the experimental procedure.

2.2. Music

Four types of spiritual music were provided to the subjects during the experiments: (1) Indian Bhajan in Sanskrit, (2) Byzantine Pasha Liturgy in Greek, (3) Maronite Song in Arabian, and (4) Mozart’s Requiem in Latin.

2.3. Apparatus

Electroencephalographs were recorded in an electromagnetically shielded room by a MEDELEC 1A97 EEG machine, with lower and upper band-pass filter limits set at 0.5 Hz and 30 Hz, respectively. Ag/AgCl electrodes with impedance less than 5 kΩ were placed at 16 locations (F7, F8, T3, T4, T5, T6, Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2) according to the International 10-20 system with average reference. The EEG outputs were digitized with 12-bit precision at a sampling rate of 128 Hz per channel using A/D converter Data Translation 2801.

2.4. Procedure

The experiment was conducted in a sound-proof room, with only one music piece a day. Each recording session was divided into three sequential periods:

- relaxing 5 min with eyes closed;
- listening of the music 10 min;
- after listening, 5 min.

During those periods three samples, one minute each, were recorded for every subject. The EEG record was stored on a hard-disk.

2.5. Data analysis

The length of each EEG-trace was 60 s (7680-points). Time-varying EEG spectra (spectrograms) with 0.5 Hz resolution were calculated by the MATLAB program using a 256-point FFT algorithm performed on 2 s Hamming-windowed, half-overlapped epochs. An array of EEG partial power spectra for each subject and each derivation was computed by integration by the trapezoidal rule of the spectrogram over the three frequency bands: θ (from 4 to 8 Hz), α (from 8 to 13 Hz), and β_1 (13 to 18 Hz). The Wilcoxon matched pairs test and Mann-Whitney U-test were used to determine significant differences between the spectral arrays of the relaxing period and the spectral arrays of the meditation period. The coherence of spectral arrays was estimated using Welch's averaged periodogram method at 512-point (4 s) epochs of EEG data divided into 256-point (2 s) detrended Hamming-windowed subsets with 240-point overlap. Total coherence for the each frequency band was calculated using the same methods as those described by Levine et al. (Levine, Hebert, Haynes & Strobel 1977).

3. Results

In Table 1 the results of the Wilcoxon matched pairs test for medians of EEG power of all 16 channels, prior and during the listening of music are shown.

In most cases, during the listening of music, the EEG power decrease is observed in various frequency bands. In three cases (out of 20), a significant power increase in theta and alpha bands is registered, in accordance with an intense aesthetic experience in these cases; the two most prominent spectrograms and corresponding diagrams of the temporal changes of spectral power are shown in Figs. 1 and 2.

Table 1. The EEG power changes during the listening of music

music	SUBJECT 1 band θ α β_1	SUBJECT 2 band θ α β_1	SUBJECT 3 band θ α β_1	SUBJECT 4 band θ α β_1	SUBJECT 5 band θ α β_1	SUBJECT 6 band θ α β_1
1	- - 0	- - 0	- + 0	+ - 0	- - -	0 - -
2	0 - -	- - -	- - -	0 0 0	- - -	x x x
3	x x x	+ + -	- - -	0 - 0	0 - -	- - -
4	0 - -	0 - -	- - -	x x x	0 - 0	x x x

+ sign. increase; - sign. decrease; 0 sign. no changes; x sign. not recorded.

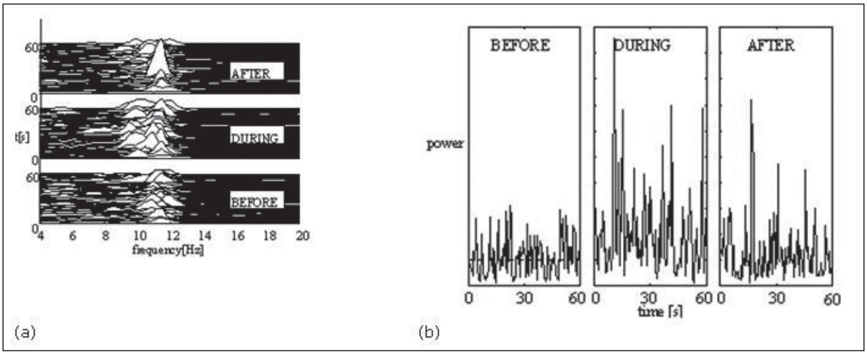

Figure 1. (a) The spectrogram with the observed EEG power increase in the alpha band and the appearance of slower alpha frequencies during the listening of music 1 in channel P3 of subject 3; (b) The corresponding temporal power changes in the alpha band

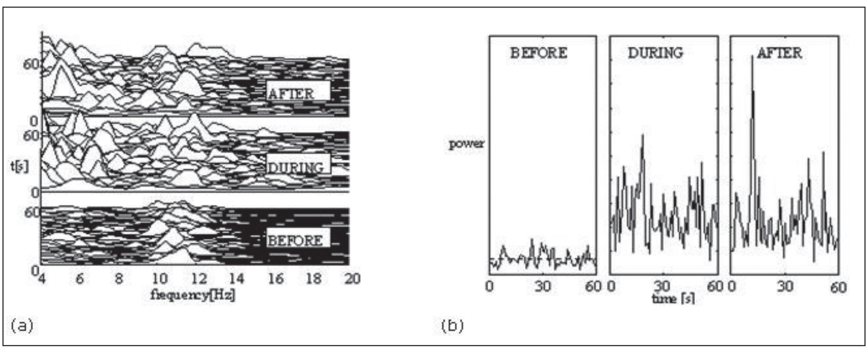

Figure 2. (a) The spectrogram with the observed high EEG power increas in the theta band during the listening of music 1 in channel T6 of subject 4; (b) The corresponding temporal power changes in the theta band

In Table 2 the results of the Mann-Whitney U-test for temporal arrays of the mean coherences of corresponding pairs of EEG channels are presented.

Table 2. The EEG coherence changes during the listening of music

music	cannels	SUBJECT 1 band $\theta\ \alpha\ \beta_1$	SUBJECT 2 band $\theta\ \alpha\ \beta_1$	SUBJECT 3 band $\theta\ \alpha\ \beta_1$	SUBJECT 4 band $\theta\ \alpha\ \beta_1$	SUBJECT 5 band $\theta\ \alpha\ \beta_1$	SUBJECT 6 band $\theta\ \alpha\ \beta_1$
1	F3-C3	0 0 -	0 0 0	0 0 0	+ - 0	0 0 0	0 - 0
	F4-C4	0 - 0	0 0 0	0 0 0	- - -	- - +	0 + 0
	F3-F4	0 0 0	0 0 0	0 0 0	0 - 0	- - +	0 - 0
	01-02	0 0 0	0 0 0	0 0 -	0 - 0	0 0 0	+ + 0
2	F3-C3	0 0 0	- 0 0	0 + 0	0 - 0	0 0 0	x x x
	F4-C4	0 0 0	0 0 0	0 + 0	0 0 0	0 0 0	x x x
	F3-F4	0 0 0	+ 0 0	0 + 0	0 0 +	0 0 0	x x x
	01-02	0 0 0	0 0 0	0 + 0	- 0 0	0 0 0	x x x
3	F3-C3	x x x	0 0 -	0 0 -	0 0 0	0 0 0	0 0 0
	F4-C4	x x x	0 0 -	0 0 0	0 - 0	0 0 +	0 + 0
	F3-F4	x x x	0 0 0	0 0 0	0 0 0	- 0 0	0 + 0
	01-02	x x x	0 0 0	0 + 0	0 0 0	+ 0 0	0 0 0
4	F3-C3	0 0 0	0 0 -	0 + 0	x x x	- - 0	x x x
	F4-C4	0 0 0	0 - 0	0 + 0	x x x	0 0 0	x x x
	F3-F4	0 0 0	0 0 0	0 0 0	x x x	- 0 +	x x x
	01-02	0 + 0	0 0 0	0 + 0	x x x	+ 0 0	x x x

+ sign. increase; - sign. decrease; 0 sign. no changes; x sign. not recorded.

It seems that changes in coherence during the listening of music are not correlated with aesthetic experiences. This might be a consequence of the observed increase in the mean ratio of EEG power of the right and the left hemispheres, the corresponding medians for all channels, and all subjects being R/L = 1.015 prior the music, and R/L = 1.082 during the listening of music. This fact is indicative, although the Wilcoxon matched pairs test did not give significant changes ($p = 0.09$).

4. Conclusion

According to our pilot study with six subjects and four types of spiritual music, it might be concluded that EEG power changes during their listening are quite individual. In the three cases where significant raise of power (i.e. relaxation) in theta and alpha bands is observed, the subjects have described their musical experiences as very pleasant – in contrast to the cases with drop in EEG power and unpleasant musical experiences. The most prominent changes were observed in subjects 3 and 4 upon the influence of the music 1 (Bhajan, Indian spiritual music, sung in Sanskrit); and somewhat less in subject 2 upon the influence of the music 3 (the Maronite spiritual music, sung in Arabian). Concerning the coherence increase, it seems not to be correlated with the aesthetic experience as, for instance, all subjects described their experience of music 2 as "slightly unpleasant", while their coherence was even increased.

In spite of the observed particular EEG changes upon some types of spiritual music, it might be that more conclusive results could be achieved only in the case of more careful choice of subjects, regarding their musical affinities and/or education.

References

Baars, B.J. (1988). *A Cognitive Theory of Consciousness*. Cambridge: Cambridge University Press.

Bernstein, L. (1976). *The Unanswered Question: Six Talks at Harvard*. Cambridge, MA: Harvard University Press.

Birbaumer, N., Lutzenberger, W., Tau, H., Mayer-Kress, G., & Braun, C. (1996). Perception of music and dimensional complexity of Brain activity. *International Journal of Bifurcation and Chaos*, 6, 267-278.

Chomsky, N. (1980). *Rules and Representations.* New York: Columbia University Press.

Hassler, M., & Birbaumer, N. (1988). Handedness, music abilities, and dichaptic and dicjotic performance in adolescents: A longitudinal study. *Development Neuropsychology*, 4, 129-145.

Jackendoff, R., & Lerdahl, F. (1982). Grammatical parallel between music and language. In: Clynes, M. (ed.), *Music, Mind, and Brain: The Neuropsychology of Music*. New York: Plenum.

Levine, H., Hebert, J.R., Haynes, C.T., & Strobel, U. (1977). EEG coherence during the Transcendental Meditation technique. In: Orme-Johnson, D.W., & Farrow, J.T. (eds.), *Scientific Research of the Transcendental Meditation Program - Collected Papers*, vol. 1. Seelisberg: MERU Press, pp. 187-207.

Nader, T. (1995). *Human Physiology: Expression of Veda and the Vedic Literature*. Vlodrop: Maharishi.

Petsche, H., Lindner, K., Rappelsberger, P., & Gruber, G. (1988). The EEG: An adequate method to concretice brain process elicited by music. *Music Perception*, 6, 133-160.

Pribram, K.H. (1982). Brain mechanism in music: Prolegomena for a theory of the meaning of meaning. In: Clynes, M. (ed.), *Music, Mind, and Brain: The Neuropsychology of Music*. New York: Plenum.

Roederer, J.G. (1982). Physical and neuropsychological foundations of music: The basic questions. In: Clynes, M. (ed.), *Music, Mind, and Brain: The Neuropsychology of Music*. New York: Plenum.

Rouget, G. (1980). *La Musique et la Transe*. Paris: Gallimard.

Sergent, S. (1993). Mapping the musician brain. *Human Brain Mapping*, 1, 20-39.