Electroencephalographical characteristics of mental representation of music in practical application to musical composition.

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Abstract: We assume that perception of music is based on identification and detachment of music structure. Music structure is determined by a range of characteristics: pitch and phonic characteristics, mode, timbre, tempo and dynamics, rhythm, meter, and general texture (means of music composition, which form the technical structure of music). Identification of music structures is conditioned by experience, on one hand, which includes all the cultural luggage of an individual – cultural environment, education, everyday experience, and by physiological mechanisms of auditory perception, processing, working memory and emotional regulation of the nervous system, on the other hand. Different physiological aspects of music perception have been studied in details. But there is still a big gap between physiological studies concerning particular mechanisms of auditory perception and music theory. How to compose music so that it would always hit the target, be remembered and understood? This is still a question for modern composers.

Key words: perception of music, music patterns, EEG, EEG coherence, mental representation task, music composition.

1 Introduction

When discussing mechanisms of music perception, we have to appeal to studies in different fields – music acoustics, behavioral sciences, neurophysiology, computing science etc. Perception of music engages a wide range of physiological processes. The pathways of acoustic signal processing and analysis have been studied in neurophysiology with methods of functional magnetic resonance imaging (fMRI), electroencephalography (EEG), magnetoencephalography (MEG), and genetic analysis, which contribute to better understanding of perception and processing of music, and overlap with processing of emotional speech and vocal communication in animals.

In fMRI research by Koelsh, Gunter et al. [29] chord sequences with unexpected musical events were presented to the participants. These events caused increase of cerebral hemodynamic response in the areas of Broca and Wernicke, the superior temporal sulcus, Heschl's gyrus, planum polare and planum temporale, and anterior superior insular cortices. These structures are involved both in music and language processing: areas of Broca and Wernicke are described as speech motion and linguistic information decoding centers [15], and superior temporal sulcus (with dominance of the right hemisphere) is associated with speech emotional intonation processing [1, 2, 50]. In experiments using fMRI by Angulo-Perkins and co-aughtors [6], the anterior portion of the superior temporal gyrus (planum polare) showed preferential activity in response to musical stimuli in musicians and non-musicians (regardless of musical training, and invariant across different musical instruments), as compared to speech and non-linguistic vocalizations. Activation of Broca and Wernicke areas in music processing is reported by different researchers. For example, it is shown that involvement of Broca`s area is important in interpreting whether a note is on or off key [36]. Activation of inferior frontal gyrus (inferior Brodmann's area (BA) 44 – Broca area, BA 45, and BA 46) in music-syntactic analysis was demonstrated in fMRI studies by Koelsh et al. [36], Margulis et al. [39]. At the same time, the speech sensitive auditory cortex is not activated by pure tones, environmental sounds, or attention directed toward elementary components of a sound such as intensity, pitch, or duration, which means that language and music processing have more complicated interactions [48].

Envolvement of the “*emotional brain*” into music perception was revealed in fMRI studies based on comparison of effects of “pleasant” and “unpleasant” music. An fMRI experiment conducted by Koelsh and co-aughtors [30] showed that exposition to “unpleasant” (permanently dissonant) music contrasted with “pleasant” (consonant) music is correlated with activations of amygdala, hippocampus, parahippocampal gyrus, and temporal poles. These structures are acknowledged as parts of emotion regulation system [2, 46, 50]. Activations of Rolandic opercular areas during perception of the pleasant (consonant) music was also reported by Koelsh et al. [30]. Comparative analysis of EEG and fMRI data obtained during “pleasant” in comparison with “unpleasant” music presentation exposed activation of the left primary auditory area, posterior temporal, inferior parietal and prefrontal regions. (music by Bach and Mahler was subjectively classified by participants as “pleasant”, selection from Prodromidès was recognized as “unpleasant”) “Unpleasant” music stimulation was correlated with activation of the right frontopolar and paralimbic areas [17]. Functional brain asymmetry in positive and negative emotional processing has been frequently reported in neurophysiological studies of emotions [2, 50] and in studies of music-specific emotions [6, 13, 18, 37]. Nevertheless musical perception is based on fundamental brain mechanisms in both hemispheres [7].

Apart from methodology of fMRI studies, there are evidences of “emotional brain” participation in music processing from behavioral, neurophysiological and genetic studies on animals, concerning emotional vocalizations, singing and communication learning. The “language of emotions” is considered to be one of the basic communication instruments across cultures and in evolution of species [5, 34, 42, 58]. In review by Petkov and Jarvis [42] motor system is discussed as a link between birds and humans in evolution of vocal production and perception. Another point of view is that the brain pathways that control the learning and production of song and speech were derived from adjacent motor brain pathways.

Studies of acoustic communication patterns of crickets introduce to the neural mechanisms underlying signal generation and auditory pattern recognition [20, 53]. Male cricket singing is driven by a “pattern generator”. Destruction of particular segments of male cricket nervous system (ganglion) leads to additional syllables and reset of the ongoing chirp rhythm. Certain nervous mechanisms are responsible for recognition of singing patterns in female crickets as well. “Local auditory brain neurons are tuned to the structure of the calling song, based on fast integration of inhibitory and excitatory synaptic activity.” [20] Studies of singing pattern generation and recognition in birds bring into research of the mechanisms of *neural plasticity* [34]. Hearing song, but not the act of singing, induces gene expression in parts of the auditory forebrain of the canaries [23]. Production of song is accompained by distinct pattern of gene expression. The research by Pfenning et al. [43] explores brain region gene expression specific to song patterns similar across species of vocal-learning birds and humans. It was found that activation of striatal region necessary for vocal learning in birds is most similar to a part of the human striatum activated during speech production.

It is important that *premotor representation* of the stimulus is envolved in recognition of this stimulus concerning music. It is justified also in case of emotion recognition. For example, recognition of disgust involves activation of the insular cortex, which is involved into the process of feeling disgust [1]. The same is with judging other`s pain and experience of pain [30, 40]. Premotor representation for vocal sound production during perception of pleasant auditory information is localized in rolandic operculum, anterior superior insula, and ventral striatum. Research by Margulis et al. [39] using fMRI showed, that activation of auditory association cortex is correlated to timbre, and activation of precentral gyrus - to sound-motor interactions while listening to music in group of experts – musicians with the same instrument specialization, as the stimulus presented. The Mozart effect is widely studied in psychology and implies that listening to music by Mozart improves motor skills, which indirectly implies activation of motor areas during exposition to music [22, 45]. Direct evidence of involuntary motor activity evoked by music perception is presented by Haueisen [19], this study was conducted with professional musicians – pianists**.**

Peculiar data concerning the influence of long-term music training (education) on processing of music were obtained in magnetoencephalography research by Herholz, Lappe et al. [21]. Musicians and non-musicians performed a music imaginary task, they listened to the beginning of a melody and had to continue it in mind. The melody was followed by a tone which was either a correct or an incorrect continuation of the melody. In group of musicians an early preattentive brain response to unexpected incorrect stimulus was registered (mismatch negativity peaked approximately 175 ms after tone onset and right-lateralized). The subject of imagination of music is also discussed in study by Kumara and co-aughtors concerning musical hallucinations [35]. Consistent significant coherence changes with respect to the averaged EEG at rest were revealed in the task of mentally playing an instrument in research by Petsche and colleagues [41]. Magnetoencephalography revealed left-lateralised power increases, associated with stronger hallucinations in the gamma band in left anterior superior temporal gyrus, and in the beta band in motor cortex and posteromedial cortex. Thus, *mental representation* of music is a convenient methodological construct for music research.

2 Problem Formulation

Briefly, perception of music is a complex process involving speech centers and emotion regulation system, motor and premotor representation areas, involving mechanisms of neural plasticity and based on regularities of auditory perception. Different physiologyical aspects of music perception have been studied in details: perception of pitch [4, 52], consonance and dissonance [52, 55,56], influence of music on emotional states [30, 31, 37, 38, 47, 54], and other higher nervous processes [22, 45], etc. Computer programmes for composing music have been elaborated [3, 14, 16, 33]. But the general question how to compose music so that it could touch every listener is still topical. We suggest that if a listener is able to detach the structure of music, he is able to perceive sound as music and to remember it. The objective criteria of detachment of music structure is the ability to remember the melody.

3 Problem Solution

An original classification of music structures was elaborated by I.Urupin on the following criteria: duration of melodic patterns, quantity and quality of the subsequent variations (structural, pitch, tembre, tempo, dynamics, etc.). According to this classification, in modern popular music we observe the most simple patterns of variations (for example: 1 pitch variation in 1 regularly repeated pattern), and avant-gardist music of the 20th century has the highest rate of variations per music pattern. The ability to perceive music patterns is considered to be conditioned by the physiological regularities of nervous system (general activation, sensitization, working memory processes), and to some extent modified by the long term memory processes: musical education and general context of the musical culture.

3.1 Materials and Methods

Several music melodies presenting different music structures were selected: 3 pieces of classical music (Rakhmaninov, Vagner, Bach), 3 pieces of modern avant-gardist music (Berio, Pusser and Vebern) and 3 popular melodies(Aha; Metallica; 50 cent) (Table 1). Duration of the stimuli varied from 1 min 45 sec to 3 min 10 sec. Melodies were presented in random order from loudspeakers. Music was processed with professional programme Steinberg(c) Nuendo 3.0 in order to equalize sound and pitch differences.

Subjects participating in the experiment were professional musicians (composers, vocalists, and performers) – 10 persons, and average people without musical education (“non-musicians”) – 10 persons, all participants aged 18-35.

The task for the participants was to listen to the music melodies and to play them in mind after a short signal, which followed every melody. Duration of the session of mental representation of the melodies after every music piece was 30 seconds. Participants had also to evaluate the length of the melodies and to note, if they liked music or not. EEG was registered while listening to music and remembering melodies. Baseline EEG (4 minutes) was also recordered in the beginning of the experiment. 21-channel biopotentials amplifier by “Statokin” (Moscow) and professional programmes for processing EEG and statystical calculations by Statokin were used for EEG analysis. Monopolar EEG electrodes were placed according to 10-20% scheme with combined ear electrodes. EEG recordings were made from 16 leads: Fp1, Fp2, F3, F4, F7, F8, C3, C4, P3, P4, O1, O2, T3, T4, T5 and T6.

The processing of data included calculation of power spectrum in 0.5-45 Hz frequencies, in 6 frequency bands: 0,5-4 Hz (delta), 4-8 Hz (theta), 8-13 Hz (alpha), 13-20 Hz (betha-1), 20-30 Hz (betha-2) and 30-45 Hz (gamma) bands with averaging of values for every participant and then for groups of participants. The EEG analysis epoch was 4 seconds and the sampling frequency was 250 Hz. Differences in normalized coherence values were calculated with t-criterium by Student. The differences were taken as significant on condition that $0.001<p<0.05$, data less significant than $p<0.05$ are not presented here. In order to reduce hindrances in EEG recordings all the data were reviewed in order to correct the artifacts [25, 51].

3.2 Results

Comparison of EEG in 2 groups of participants – musicians and non-musicians – revealed statistically significant ($p<0.05$) differences of coherence during mental representation of music as compared to the baseline EEG, and inter-group differences during mental representation of different types of music.

Statistically significant differences were obtained during mental representation of popular music as compared with baseline EEG both in “musicians” and “non-musicians” groups. Significant differences were obtained in delta- and gamma-bands in temporal and central areas of both hemispheres. During remembering melodies from classical music in comparison with baseline EEG significant differences were not discovered until frequencies were divided to 1 Hz step bands.

Statistically significant differences in logarithm of the power autospectres (normalized power evaluation) in betha-1, betha-2 and gamma bands were obtained in comparison of mental representation of the popular melodies in 2 groups – musicians and nonmusicians – localized in the frontal regions of both hemispheres ($p<0.05$). In betha-2 band the significant differences are localized also in the central areas in both hemispheres and right hemispheric posterious temporal region (Fig.1). For classical music significant differences were localized only in the right FP-electrode spot in betha-1 band, when compairing all classical melodies in one group of EEG-files (Fig.2). When analysing every melody, significant differences are found for music by Wagner. For modern avant-gard music significant differences between groups were found in frontal regions and anterior temporal regions of the right hemisphere and in central regions of both hemispheres in betha-2 frequency band ($p<0.05$) (Fig.3).

Summing up, the most peculiar differences in logarithm of the power autospectres in 2 groups of listeners – musicians and non-musicians – were obtained in betha and gamma-bands in central and frontal regions of the right or both hemispheres.

The measures of coherence (Table 2) were significantly higher for popular and classical music as compared to the baseline EEG in group of musicians in delta-band (1-2 Hz, 3-4 Hz). For non-musicians the coherences were significantly higher for all music melodies in 4-5 Hz theta-band. In betha-2 band (23-24, 27-28 Hz) the coherences were significantly higher for popular and avant-gard music in comparison to the baseline EEG in group of musicians, and in 26-27 Hz band in group of non-musicians. In gamma-band (30-45 Hz) statistically significant differences in coherence during mental representation in comparison with the baseline were obtained for classical (31-32, 34-35, 39-40 Hz) and modern avant-gard music (30-31, 33-34, 40-41 Hz) in non-musicians, and for popular (31-32, 35-36, and 39-40 Hz) and classical music (34-35, 39-40, 41-42 Hz) in musicians.

At the same time, in group of musicians the coherences were significantly lower in delta-band (1-2 Hz), and in theta-band (5-6 Hz) for modern avant-gard music in comparison to the baseline. Coherences were significantly lower in theta-band (7-8 Hz) also for classical music in group of musicians. In general the coherences were significantly lower in alpha-band in both groups for all types of music (see table 2), with exception of 8-9 Hz frequency band in group of non-musicians for classical music in comparison to the baseline. There are many 1Hz-step- values of coherence, which were significantly lower in music representation EEG as compared to the baseline, in betha-1 and betha-2 bands. And, which is most interesting, the same picture is in gamma-band with exception of classical and modern avant-gard music for non-musicians and popular and classical music for musicians, where some frequencies showed significantly higher coherences. As displayed in table 2, in the group of non-musicians during representation of popular music in comparison with the baseline coherences were significantly lower in 31-32, 34-35, 37-38, 39-40, 40-41, 41-42, 44-45 Hz bands, and in the group of musicians – in 30-31, 31-32, 32-33, 33-34, 34-36, 37-39, 42-43 Hz bands. But there are higher coherences in non-musicians in 31-32, 35-36, 39-40 Hz bands. The classical and modern-avantgard music have different patterns of changes in coherences in musicians and non-musicians. In group of musicians the coherences are significantly lower for classical (30-31, 31-32, 34-36, 38-39, 40-41, 41-42, 44-45 Hz) and modern avantgard-music (31-32, 33-34, 35-36, 36-37, 37-38, 40-41, 42-43, 44-45 Hz), whereas in non-musicians there are more higher coherences for classical (31-32, 34-35, 39-40) and modern avant-gard music (30-31, 33-34, 40-41).

Thus, there are different tendencies in gamma-band frequencies in comparison of music remembering task to the baseline: coherences are significantly higher in non-musicians for classical and avant-gard music, and significantly lower in the same situation in group of musicians.

Briefly, comparison of coherence during mental representation of modern avant-gardist music with the baseline EEG revealed higher coherences in gamma-, betha2- and alpha-bands in temporal and occipital areas . However in some electrode pairs in central and occipital areas in alpha- and betha-1 frequency bands the coherences were significantly higher in baseline EEG as compared to remembering avant-gard music in group of professional musicians. Significant differences of EEG coherences during mental representation of modern avant-gard music were revealed only in group of professional musicians. During mental representation of music by Wagner statistically significant growth of coherence was revealed in comparison with the baseline in a number of electrode pairs in group of “musicians”.

3.3 Discussion

EEG analysis in standard frequency bands revealed peculiarities of mental music processing in musicians as compared to average participants (without musical education): in betha-1, betha-2 and gamma bands in comparison of mental representation of the melodies to the baseline EEG. The measures of coherence were significantly higher for popular and classical music as compared to the baseline EEG in group of musicians in gamma-band. In betha-2 band the coherences were significantly higher for popular and avant-gard music in comparison to the baseline EEG in group of musicians. The classical and modern-avantgard music have different patterns of changes in coherences in musicians and non-musicians. In group of non-musicians the coherences were significantly higher in gamma-band (30-45 Hz) for classical and modern avant-gard music. At the same time, there are lower coherences in some pairs of electrodes during mental representation task as compared to the baseline both in musicians and non-musicians.

The presence of phase synchronization in mental music representation task proves that participants were consistent and honest in their performance, because coherences are observed during music perception and are connected to music appraisal [10, 11]. Statistically significant changes in coherences in gamma- and betha-bands in music mental representation task are consistent with data in music imaginary research by Petsche and colleagues [41], and music hallucinations study by Kumara and co-aughtors [35]. Changes of coherence in upper alpha and gamma-band are frequently associated with verbal and non-verbal performance during analysis of emotional prosody and logical meaning of speech [24, 26, 57]. Increase of coherences and power in alpha and theta-band are also related to cognitive and memory performance [12, 27, 49]. Synchronization in alpha-band is also supposed to be an index of lower anxiety [8, 28]. So when talking about increase of coherences in gamma-band during mental representation of popular and classic music in musicians, we may propose, that remembering these melodies are not stressful for participants (as we see a lower level of anxiety), and not so demanding, as remembering modern avant-gard music (as we see a higher level of cognitive effort in avant-gard music representation task). In contrary, we observe higher level of coherences in non-musicians in modern avant-gard music representation task. According to the subjective reports, non-musicians did not remember these melodies, they seemed to be unstructured and annoying, so we may suppose, that there was lower level of general arousal in non-musicians during modern avant-gard music representation task. This may be explained as the difficulty of modern avant-gard music processing even in the group of musicians, as it demands much cognitive effort. Higher level of coherences in theta-band (4-5 Hz) during mental representation of music in average participants also indicates lower level of general arousal, as compared with non-musicians [32, 44].

Music mental representation was accompained by increase of synchronization in delta-band (3-4 Hz) in musicians as compared with the baseline EEG. This is consistent with the study by Bhattacharya [11], where musicians showed increase in phase synchrony during perception of music [see also 9]. This shows that perception and mental representation of music have much in common as concerning the brain organization of the processing. The same analogous processing is discussed in mental representation of situations [59] in Theory of Mind models. Higher levels of EEG power spectrum in betha-2 and gamma-bands in modern avant-gard music representation task in musicians as compared to non-musicians is revealed in frontal (Fp leads) and central (C leads) areas. The same is in popular music representation, even more pronounced widespread. There is significant growth of power in betha-2 and gamma-bands in popular music representation task in musicians as compared to non-musicians. This may be connected to activation of premotor cortices during music presentation, which supposedly accompanies music processing [19, 29-31]. This can be also explained by subjective appraisal of popular music – it was often judged as pleasant [37]. Process of listening to classical music corresponds to the increase of the EEG spectral power in the alpha-range in the parietal and occipital areas of both hemispheres [54]. Pleasant emotions evoked by music increase upper alpha activity in left anterior and posterior regions [18]. In our research, such changes were revealed only in betha-2 and gamma frequency bands, but the localization of the changes is equal.

4 Conclusions

1. The mental representation of music involves specific patterns of EEG phase-synchronization and activation of frontal areas, which may be a subject for analysis as well as the processes of music perception in central nervous system.

2. During the mental representation, patterns of EEG in alpha and theta bands correlated with an increase of anxiety are observed, when the music is complicated, in conformity with subjective reports of the listeners and the applied analysis of music structures, and we suppose that music is not processed and remembered correctly.

3. Processing of the complicated music structures in modern avant-gard music demand much cognitive effort both in groups of professional musicians and average listeners, which follows from the patterns of EEG synchronization in gamma-band (correlated

with cognitive effort), during music mental representation task.

4. Music mental representation task may be applied as an appropriate analysis instrument in psychophysiological research of music perception and for composition.

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Tables.

Table 1. Choice of musical melodies.

Order of melodies presentation	I. Popular music	II. Classical music	III. Modern avant-gardist music
I, II, III	Metallica “Enter Sandman” [1:55]	S. Rakhmaninov – symphonical dances, part 1 [3:05]	Berio – Labyrinth, the beginning [1:45]
II, III, I	Aha “Summer Moved on” [2:35]	R. Vagner – Valcyrie, 2 act, forespiel [2:00]	Vebern – Oktet [2:35]
III, I, II	50 Cent “Candy Shop (NY mix)” [2:00]	I-S Bach – fugue for organ E minor key [3:00]	Pusser – Intersection of colours [3:10]

Table 2. Comparison of EEG coherences with 1 Hz step in mental representation of melodies to baseline EEG.

Red – coherences are higher in mental representation task as compared with baseline EEG.
Black – coherences are lower in mental representation task as compared with baseline EEG.

	non-musicians			musicians		
Frequencies, Hz	Popular music	Classical music	Modern avant-gard	Popular music	Classical music	Modern avant-gard
delta (0.5-4.0)	-	-	-	1-2, 3-4	0-1, 3-4	1-2 3-4
theta (4.0-8.0)	4-5	4-5	4-5	-	7-8	5-6
alpha (8.0-13.0)	6-7, 9-10, 10-11, 12-13	12-13 8-9	6-7, 7-8, 12-13	5-6	-	11-12
betha-1 (13.0-20.0)	16-17, 17-18, 19-20	17-18	13-14, 17-18 15-16	14-15, 15-16, 18-19 13-14	13-14	13-14, 15-16
betha-2 (20.0-30.0)	20-21, 21-22, 23-25, 26-27, 29-30	20-21, 28-29 26-27	20-21, 21-22	20-21, 21-22, 22-23, 26-27, 28-29 20-21, 23-24, 27-28	21-22, 25-26, 27-28	20-21, 21-22, 22-23, 27-28 23-24, 26-27

gamma (30.0-45.0)	31-32, 34-35, 37-38, 39-40, 40-41, 41-42, 44-45	42-43 31-32, 34-35, 39-40	31-32 30-31, 33-34, 40-41	30-31, 31-32, 32-33, 33-34, 34-36, 37-39, 42-43 31-32, 35-36, 39-40	30-31, 31-32, 34-36, 38-39, 40-41, 41-42, 44-45 34-35, 39-40, 41-42	31-32, 33-34, 35-36, 36-37, 37-38, 40-41, 42-43, 44-45

Figures

Figure 1. Differences in logarithm of the power autospectres (normalized power evaluation) in comparison of mental representation of the popular melodies in 2 groups: musicians (N1) and non-musicians (N2).

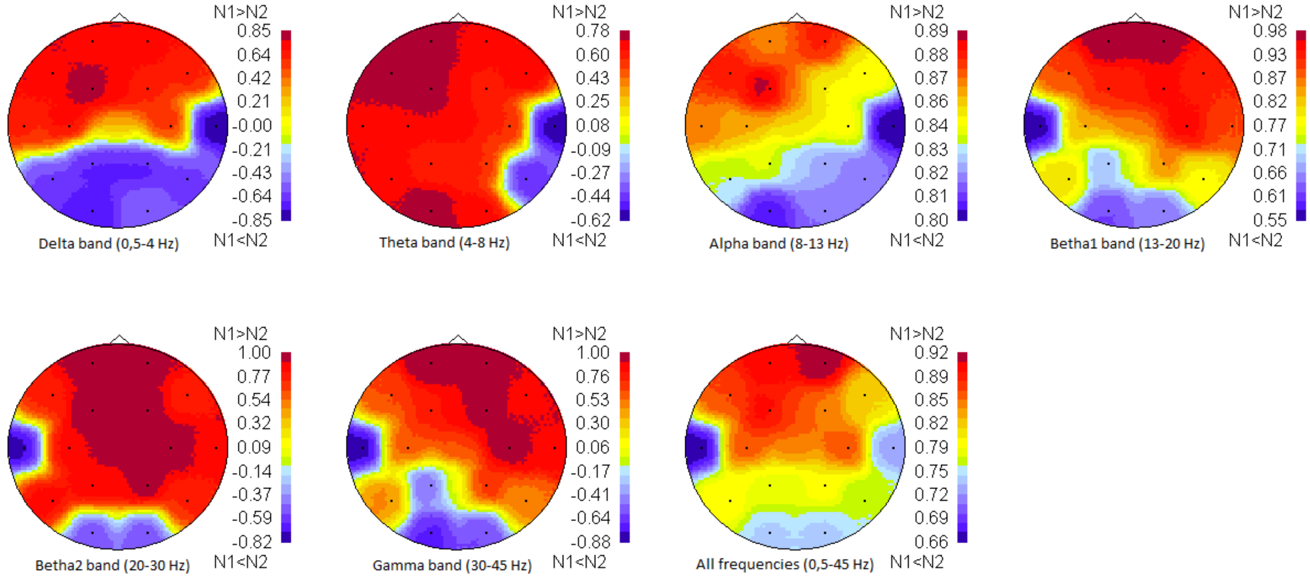

Figure 2. Differences in logarithm of the power autospectres (normalized power evaluation) in comparison of mental representation of the classical melodies in 2 groups: musicians (N1) and non-musicians (N2).

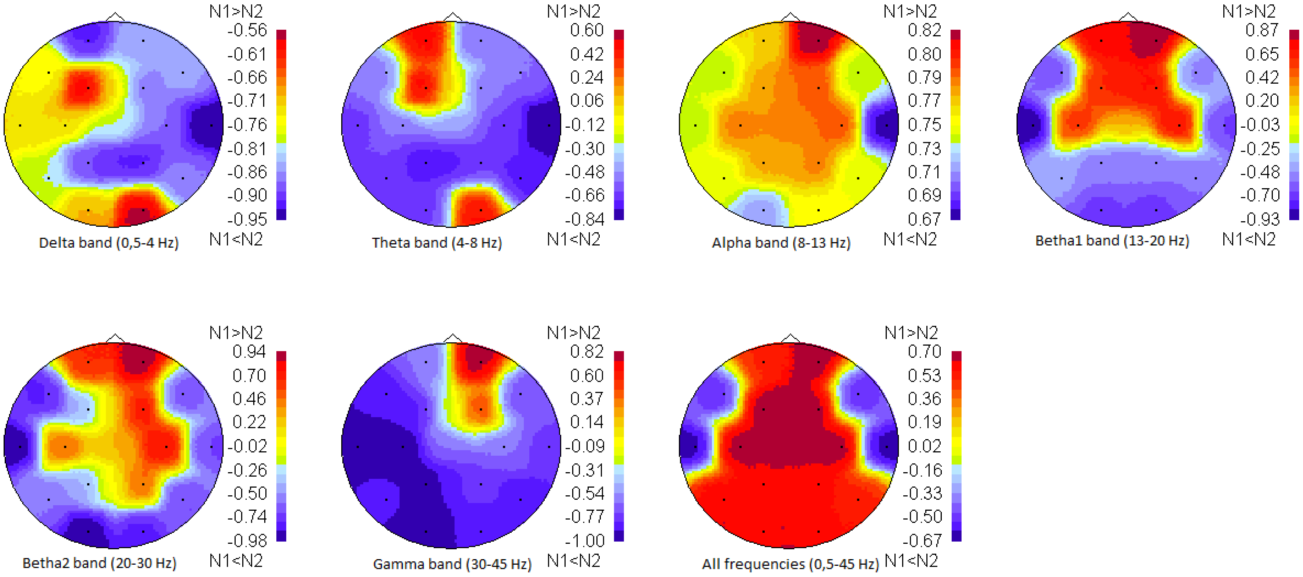

Figure 3. Differences in logarithm of the power autospectres (normalized power evaluation) in comparison of mental representation of the avant-gard melodies in 2 groups: musicians (N1) and non-musicians (N2).