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Research Paper

The Influence of a Low-Frequency Musical Fragment on the Neural Oscillations

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Study of musical-acoustic influences, which are used to improve the functional state of a person, as well as her/his neurophysiological or psychological rehabilitation, is very relevant nowadays. It is related with a large number of conflict situations, significant psychological and informational overloads of modern human, permanent stress due to the pandemic, economic crisis, natural and man-made disasters. This work examines the effect of listening to low-frequency music on the percentage of alpha, beta, delta, and theta waves in the total spectral power of the electroencephalogram in the frequency band 0.5–30 Hz. To obtain rhythms of the brain the spectral analysis of filtered native electroencephalogram was used. For statistical analysis of neural oscillations the Student's t-test and the sign test were implemented with usage of the Lilliefors normality criterion and the Shapiro-Wilk test. Statistically significant differences were identified in alpha, theta and delta oscillations. For the beta rhythm presented music did not play any significant role. An increase in the activity of the alpha rhythm in the temporal (for 2.20 percentage point), central (for 1.51 percentage point), parietal (for 2.70 percentage point), occipital (for 2.22 percentage point) leads of the right hemisphere and the parietal (for 1.74 percentage point) and occipital (for 2.46 percentage point) leads of the left hemisphere and also of the theta rhythm in the temporal leads of the left hemisphere (for 1.13 percentage point) were observed. The downfall of delta rhythm in the frontal lead of the left hemisphere (for 1.51 percentage point) and occipital in both hemispheres (for 1.64 and 1.33 percentage points respectively in the left and right hemispheres) was detected. These may indicate that listening to low-frequency compositions helps to restore the brain in physiological conditions at different functional overload levels, decrease the level of emotional tone, and promote relaxation.

Keywords: electroencephalogram; brain rhythms; music therapy; acoustic influences; bioelectrical activity; spectral analysis.

1. Introduction

Many scientific works are devoted to study the neurophysiological aspects of musical-acoustic influences perception (Jantzen *et al.*, 2014; Miendlarzewska, Trost, 2014; Taylor, Dewhurst, 2017; Rodriguez *et al.*, 2019; Zhou *et al.*, 2021). These works differ in methodological approaches and practical recommendations.

Pythagoras was one of the first ones who explained the healing effect of music (Crocker, 1963). He argued that music obeys a higher law (mathematics) and restores harmony in the human body. Later, scientists concluded that music can relieve fatigue and charge a person with energy, positively affecting the circulatory and respiratory systems. In the late XIX – early XX centuries, new data appeared indicating beneficial effects of music on the central nervous system, respiration, blood circulation, and gas exchange.

Among modern scientists' works, two main directions can be distinguished. First direction – study of the influence of various styles musical works or musical elements (sound, rhythm) on the human physical, emotional, intellectual, social, aesthetic and spiritual state and/or brain state, development and implementation of music therapy (Fancourt *et al.*, 2014; Semiletova, 2017). According to World Federation of Music Therapy (WFMT) conception, listening to music helps to achieve various therapeutic goals: activation of cognitive processes, motor skills, emotional development, acquisition and development of communication skills and hence the improvement of the quality of life. This type of noninvasive therapy is also used to improve physiological variables including heart rate, blood pressure (Smolen *et al.*, 2002; Joice *et al.*, 2016; Rodriguez *et al.*, 2019), normalize internal organs functions, systems, and so on (Riganello *et al.*, 2015). Indeed, the sessions of listening to certain musical compositions affect memory (Lehmann, Seufert, 2017), verbal and nonverbal intelligence (Ferreri, Verga, 2016), increase the productivity of the work performed by a person (Nazarova, 2013), and enhance regeneration and restoration of brain structures (Fukui, Toyoshima, 2008).

If we talk about the musical material selection, authors usually use different styles of music, indicating only the author and style, for example, classical, ethnic, spiritual, pop-music, hard-rock, and so on. Effects of music on humans are usually researched with trial and error method. In this case, only qualitative changes in human's or their subjective sensations are taken into account, without trying to understand the psychophysiological mechanisms of music perception (Kunavin, Sokolova, 2014). With this approach, various, often contradictory, conclusions are drawn regarding the influence of the same type of musical-acoustic stimulus. As an example we can take the study of the "Mozart effect", conducted by various authors (Jenkins, 2001; Hughes *et al.*, 1998; Jausovec *et al.*, 2008). The discrepancies in the results can be explained by the lack of the component-structural composition and spectral characteristics of the selected musical-acoustic signals analysis, duration of musical compositions data analysis, as well as the lack of the objectively proven patterns regarding the connection between the various characteristics of musical compositions with features of semantic and aesthetic information perception (Liashko, Naida, 2019).

Second direction is the development of adaptive biocontrol theory with electroencephalogram (EEG) feedback or development of "brain music" (Fedotchev *et al.*, 2013; 2016; 2018). In adaptive biocontrol procedures, music is used as a feedback signal. During the study, it turns on when the amplitude of the current value of a certain EEG rhythm exceeds a predetermined threshold, and turns off when the amplitude is less than predetermined threshold. The patient is asked to find a condition, when melody will sound continuously. Carrying out such procedures leads to the normalization of the EEG and the psychological state of adolescents with deviant behaviour (Fedotchev *et al.*, 2013).

"Brain music" – music or music-like signals created on the basis of the conversion of the current values of human bioelectric processes using specialized software. Fedotchev *et al.* (2013) reported that the acoustic signals obtained in the way mentioned above, in case of listening before bedtime, help to reduce the fall asleep time, improve sleep performance, increase sleep duration, improve self-feeling after waking up, reduce depression and anxiety, increase attention, and also contribute to correction of central nervous system (CNS) functional impairment. Computer conversion of EEG into musical-acoustic signals is also used in the so-called method of EEG-acoustic correction, which allows hearing the brain work – "brain music" in real time. The peculiarity of this method is in unnecessity of EEG restructuring. The patient just listens to how his own brain works (Fedotchev *et al.*, 2013). Using this method enables us to adjust the human functional state, as well as modulate auditory and visual systems' activity.

The undoubted advantage of these methods is the simplicity of solving the problem of the correct choice of musical works for listening. Improving the effectiveness of musical therapeutic procedures can be achieved by matching the parameters of audio stimulus and the internal characteristics of the bioelectric activity of the patient's brain. The disadvantages of this method are the difficulty of brain activity control, the difficulty of the adequate use of feedback signals from the brain biopotentials, which, by their nature, are not intended for conscious control.

To study the effect of music on the bioelectric activity of the brain, an electroencephalogram is recorded and its analysis is carried out. Since EEG reflects the difference in electrical potentials of postsynaptic neural membranes, changes in its frequency components (rhythms) may be the basis of such analysis. The main rhythms of the brain are alpha (frequency from 8 to 13 Hz, amplitude 15–100 μV), beta (frequency from 13 to 30 Hz, amplitude 3–10 μV), delta (frequency from 0.5 to 4 Hz, amplitude 20-30 μV), theta (frequency from 4 to 8 Hz, amplitude up to 40 μV), and gamma rhythm (frequency >30 Hz, amplitude usually up to 10 μV) (Buzsáki, 2006). The alpha waves are associated with the ability of a person to relax, to overcome stress. Normally, there is a decrease in the alpha rhythm of the EEG during opening the eyes, anxiety, with active mental activity, as well as during sleeping. The beta rhythm is enhanced during drowsiness, when falling asleep and sometimes when waking up. During the deep sleep, the amplitude and severity of the beta rhythm significantly decreases. The theta rhythms in a state of vivacity are fixed in children. They can be registered on the EEG of a healthy and conscious adult during emotional activation. However, there are many pathological states or altered states of consciousness (sleep, meditation), accompanied by the development of extended and short-term theta activity. The delta rhythm is recorded during the deep sleep, hyperventilation or in a state of anesthesia. The dominance of delta activity in adolescents and adults in a state of wakefulness is a sign of pathology. It is manifested in patients with the presence of encephalopathy, accompanied by changes in the level of consciousness (coma), and is also a sign of a severe structural cerebral disorder (tumor, stroke, trauma and abscess). Moreover, specific neural oscillations can be identified with particular cognitive processes: the theta and gamma rhythms with memory encoding and retrieval, the alpha and gamma rhythms with attention suppression and focusing, and global synchronization at the gamma frequency with consciousness (Ward, 2003).

Since there is no single scientifically justified and experimentally confirmed system or methodology of acoustic (including musical) material application in music therapy, establishing a connection between the objective characteristics of signals used for audio stimulation with the dynamic of neural rhythms may be one of the possible solutions of this problem. The frequency composition of the musical signal was chosen as such characteristic. This work is the first part of the project dedicated to the study of different frequency ranges audio stimuli effects on brain oscillations and aims to establish the effect of listening to a low-frequency music on the percentage of alpha, beta, delta and theta rhythms in the total spectral power of the EEG in the frequency band 0.5–30 Hz.

2. Research methodology

2.1. Study participants

In total, 24 experiments were conducted – 12 in a male group, 12 in a female group. Selected respondents, aged 18–22 years, had no special musical education, were right-handed, at the time of the research were physically healthy, and had no history of traumatic brain injury (TBI), severe hearing problems, or central nervous system (CNS) diseases. Before the experiment, all respondents provided informed consent to participate in the study.

2.2. Self-reports and questionnaires

Before the start of the research, in the women's group, six cases of complaints on health problems were registered (headache, sleep disturbance, general weakness). In the men's group – three cases (sense of anxiety, irritability, and headache). Also, in four cases, in the men's group, the quality of sleep was assessed as unsatisfactory; in the women's group – in eight cases (difficulty falling asleep, shallow or insufficiently prolonged sleep, lack of vigor after waking up).

The anxiety rate was determined using the standardized Hospital Anxiety and Depression Scale (HADS): 0–7 points (norma) – 6 cases (men); 11 cases (women); 8–10 points (subclinically expressed anxiety) – 5 cases (men); 1 case (woman); 11 and more points (clinically expressed anxiety) – 1 case (man). The depression rate was determined using the standardized Hospital Anxiety and Depression Scale (HADS): 0–7 points (norma) – 10 cases (men); 12 cases (women); 8–10 points (subclinically expressed depression) – 2 cases (men); 11 and more points (clinically expressed depression) – 0 cases.

2.3. Conditions and procedure of the experiment

Registration of the EEG was conducted in 16 monopolar leads with the application of electrodes at the same distance from each other over the main parts of the brain – frontal lobe, central lobe, parietal lobe, occipital lobe, temporal lobe, according to International 10–20 system (Fig. 1).

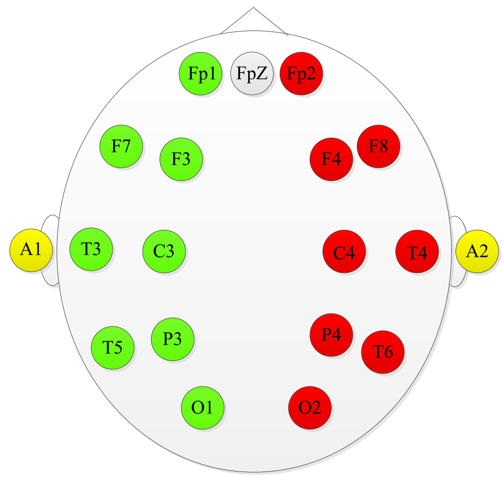

Fig. 1. EEG montage.

The electrodes were fixed on the respondent's head with a soft rubber helmet. The potentials of the active electrodes were measured to zero reference electrodes placed on the earlobes. For research we used the BRAINTEST-16 electroencephalographic computer complex (LLC RPE "DX-Systems", Ukraine, Kharkiv) (Fig. 2a).

a) b)

Fig. 2. Equipment and venue for the experiment: a) electroencephalograph BRAINTEST-16; b) soundproof room at Department of Acoustic and Multimedia Electronic Systems.

Researches were conducted in an acoustic anechoic chamber (Fig. 2b) at comfortable temperature conditions, in a sitting position. During the whole experiment the respondents' eyes were closed. At the first stage, background EEG was recorded during 1 minute in the absence of acoustic stimulus.

At the next stage, the EEG was recorded while the respondent was listening to the music fragment lasting 1 minute (binaurally, in headphones XOKO XB-450). The sound level gradually increased from zero to 50–60 dB. After acoustic stimulation ending, an EEG was recorded to research the effect of acoustic exposure conservation (1 minute). The recording of the EEG occurred under the following settings of the filters system: a low-pass filter – 100 Hz, a high-pass filter – 0.16 Hz, a band-stop filter – 50 Hz.

2.4. Selection of musical material

This paper presents the results of changes in the brain rhythms conditioned by a low frequency audio stimulation by a fragment of the composition "On Demon Wings" by Bohren & der Club of Gore. This musical material was selected based on the results of spectral analysis carried out using fast Fourier transform. The MATLAB application software package with a sampling rate of 44.1 kHz and smoothing window of Hamming were used. Using the method mentioned above, we concluded that the maximum amplitudes of the spectral components are observed in about 80 Hz range. A fragment containing these components, one-minute duration, was used as a musical acoustic impact. A graphical representation of selected work fragment is shown in a spectrogram form (Fig. 3).

2.5. Signal processing

Obtained data preprocessing was made using the BrainTest software product of the BRAINTEST-16 electroencephalographic computer complex and Microsoft Excel 2010 application. The methods of digital filtering and spectral analysis (Cherninskyi *et al.*, 2011; Kulaychev, 2018) were applied. The EEG signal was filtered in the band 0.5–30 Hz, artifacts that remained after that were visually identified and manually rejected. For analysis, EEG data were averaged for certain groups of leads (Fp1-F3-F7; Fp2-F4-F8; T3-T5; T4-T6), for the leads in the right and left hemisphere, data for the single leads (C3, C4, P3, P4, O1, O2) were also used. The groups of leads were formed to reflect the state of certain regions of the brain (frontal or temporal lobes) for the different hemispheres. The analysis was carried out in the generally accepted frequency ranges – alpha, beta, delta, and theta.

For the statistical analysis p-value of 0.05 was selected. For the direct analysis were implemented:

- the Student's t-test

$$t_c = \frac{|M_d|}{\sigma_d/\sqrt{N}}, \tag{1}$$

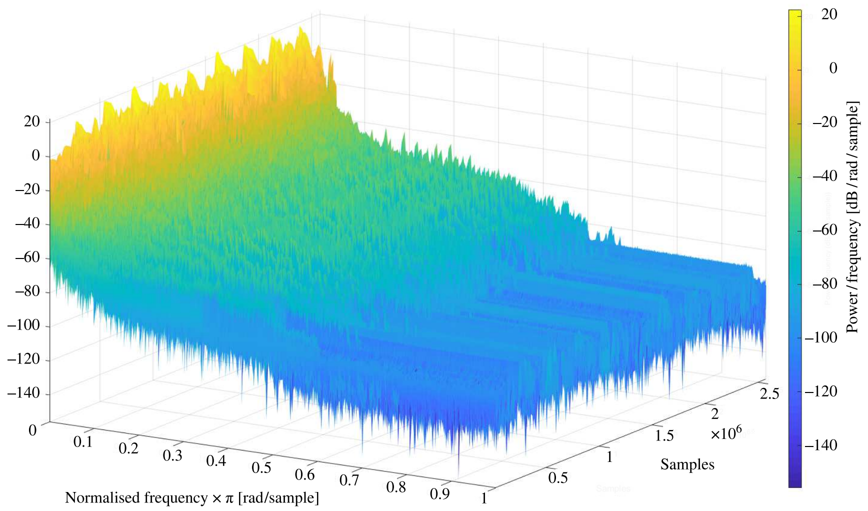

Fig. 3. Spectrogram of "On Demon Wings" by Bohren & der Club of Gore musical composition fragment.

where M_d is the average difference of values, σ_d is the standard deviation of values, N is the number of values in the sample group,

- the sign test (Montelpare *et al.*, 2021)

$$P_x = \frac{n!}{x!(n-x)!} p^x q^{n-x}, \tag{2}$$

where P_x shows the probability of x events appearing in the n trials, p^x is the expected probability of the x associated event, q^{n-x} is the probability of an event on any given trial, n shows the complete number of events, x is the number of a given outcome being evaluated.

The first one was used to determine the presence or absence of a statistically significant difference between subgroups if distribution of results in the group followed a normal law, otherwise the second type of test was applied.

In the case where the results in the compared samples had the normal distribution, the specified criterion which had variations for related or unrelated samples, depending on their internal relations was used. The opportunity of such size samples usage was described by Pareniuk (2021). The sign test determined the presence or absence of a statistically significant difference between subgroups in case of non-normal distribution of the data in a sample group. The normality of the distribution was estimated via usage of the Lilliefors normality criterion, the Shapiro-Wilk test, and a graphical comparison with the graph of the normal distribution.

Lilliefors criterion was estimated as (Mohd Razali, Yap, 2011):

$$D_n = \max |F^*(x) - S_n(x)|, \tag{3}$$

where $S_n(x)$ is the sample cumulative distribution function, $F^*(x)$ is the cumulative normal distribution function.

The Shapiro-Wilk test was calculated as (Mohd Razali, Yap, 2011):

$$W = \frac{\left(\sum\limits_{i=1}^{n} a_i y_i\right)^2}{\sum\limits_{i=1}^{n} (y_1 - \overline{y})^2}, \tag{4}$$

where y_i is the i-th order statistic; $\overline{y}$ is the sample mean,

$$a_i = (a_i, ..., a_n) = \frac{\mathbf{m}^\mathrm{T}\mathbf{V}^{-1}}{\left(\mathbf{m}^\mathrm{T}\mathbf{V}^{-1}\mathbf{V}^{-1}\mathbf{m}\right)^{1/2}}, \tag{5}$$

$\mathbf{m} = (m_1, ..., m_n)^\mathrm{T}$ are the expected values of the order statistics of independent and identically distributed random variables sampled from the standard normal distribution, $\mathbf{V}$ is the covariance matrix of those order statistics.

3. Obtained results analysis

Experimental data obtained during the study are given in Tables 1–4. The data in the tables are the

Table 1. The dynamics of the α-rhythm during the experiment.

	Left cerebral hemisphere			
α-rhythm [%]	Frontal lobe, Fp1-F3-F7		Temporal lobe, T3-T5	
	Before	After	Before	After
	22.4	23.7	24.4	25.8
	Central furrow section, C3		Parietal lobe, P3	
	Before	After	Before	After
	25.4	27.1	29.6	31.2
	Occipital lobe, O1		Average data, left cerebral hemisphere	
	Before	After	Before	After
	32.6	34.9	25.5	27
	Right cerebral hemisphere			
	Frontal lobe, Fp2-F4-F8		Temporal lobe, T4-T6	
	Before	After	Before	After
	22.6	23.3	22.9	24.9
	Central furrow section, C4		Parietal lobe, P4	
	Before	After	Before	After
	24.6	26	28.9	31.3
	Occipital lobe, O2		Average data, right cerebral hemisphere	
	Before	After	Before	After
	34.8	37	25.2	26.8

Table 2. The dynamics of the β-rhythm during the experiment.

	Left cerebral hemisphere			
	Frontal lobe, Fp1-F3-F7		Temporal lobe, T3-T5	
	Before	After	Before	After
	35.8	35.7	39.7	37.8
	Central furrow section, C3		Parietal lobe, P3	
	Before	After	Before	After
	34.2	34.3	34.2	33.4
	Occipital lobe, O1		Average data, left cerebral hemisphere	
β-rhythm [%]	Before	After	Before	After
	35.1	34.1	36	35.5
	Right cerebral hemisphere			
	Frontal lobe, Fp2-F4-F8		Temporal lobe, T4-T6	
	Before	After	Before	After
	35.8	35.8	39.9	38.8
	Central furrow section, C4		Parietal lobe, P4	
	Before	After	Before	After
	33.4	33.4	32.9	32
	Occipital lobe, O2		Average data, right cerebral hemisphere	
	Before	After	Before	After
	34.2	33.5	36	35.5

Table 3. The dynamics of the δ-rhythm during the experiment.

	Left cerebral hemisphere			
	Frontal lobe, Fp1-F3-F7		Temporal lobe, T3-T5	
	Before	After	Before	After
	22.6	21	19.6	18.9
	Central furrow section, C3		Parietal lobe, P3	
	Before	After	Before	After
	21.1	18.9	19.3	18
	Occipital lobe, O1		Average data, left cerebral hemisphere	
δ-rhythm [%]	Before	After	Before	After
	14.7	14.2	20.4	19
	Right cerebral hemisphere			
	Frontal lobe, Fp2-F4-F8		Temporal lobe, T4-T6	
	Before	After	Before	After
	22.5	21.5	19.7	18.9
	Central furrow section, C4		Parietal lobe, P4	
	Before	After	Before	After
	21.6	20.5	20	17.9
	Occipital lobe, O2		Average data, right cerebral hemisphere	
	Before	After	Before	After
	15.7	14.4	20.5	19.4

result of spectral analysis of the registered EEG, obtained using the BrainTest software, which were submitted as a percentage of each biorhythm in the total power of EEG and averaged across all participants.

For the observed groups the statistically significant differences were obtained for the following leads for the delta rhythm (Fig. 4) – Fp1-F3-F7 (delta wave power fell by 1.51 percentage point), O1 (delta wave

Table 4. The dynamics of the θ-rhythm during the experiment.

θ-rhythm [%]	Left cerebral hemisphere			
	Frontal lobe, Fp1-F3-F7		Temporal lobe, T3-T5	
	Before	After	Before	After
	18.9	19.3	15.9	17.1
	Central furrow section, C3		Parietal lobe, P3	
	Before	After	Before	After
	18.9	19	16.6	16.9
	Occipital lobe, O1		Average data, left cerebral hemisphere	
	Before	After	Before	After
	16.5	16.1	17.6	18
	Right cerebral hemisphere			
	Frontal lobe, Fp2-F4-F8		Temporal lobe, T4-T6	
	Before	After	Before	After
	18.6	18.9	17.2	16.9
	Central furrow section, C4		Parietal lobe, P4	
	Before	After	Before	After
	20.1	19.8	17.6	17.9
	Occipital lobe, O2		Average data, right cerebral hemisphere	
	Before	After	Before	After
	14.6	14.2	17.8	17.8

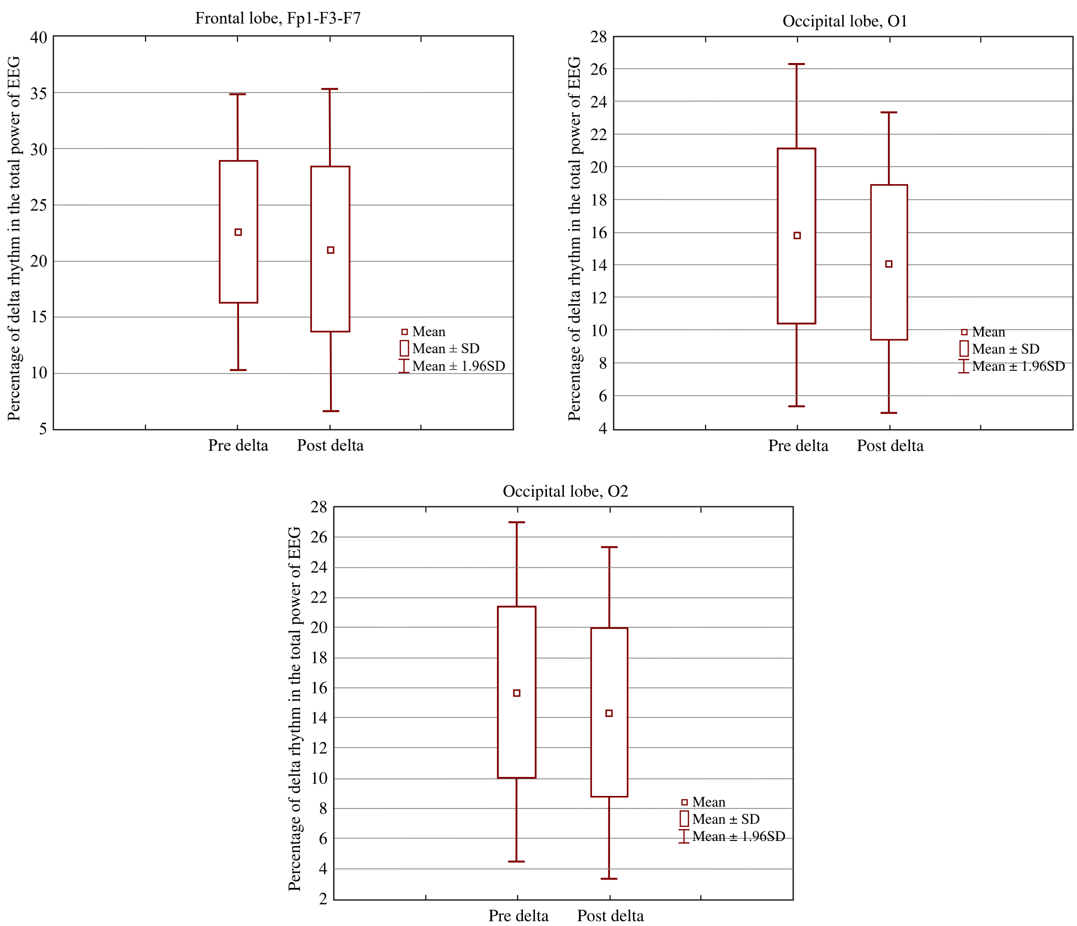

Fig. 4. The box plot representation of delta rhythm for leads and lead groups with the statistically significant difference.

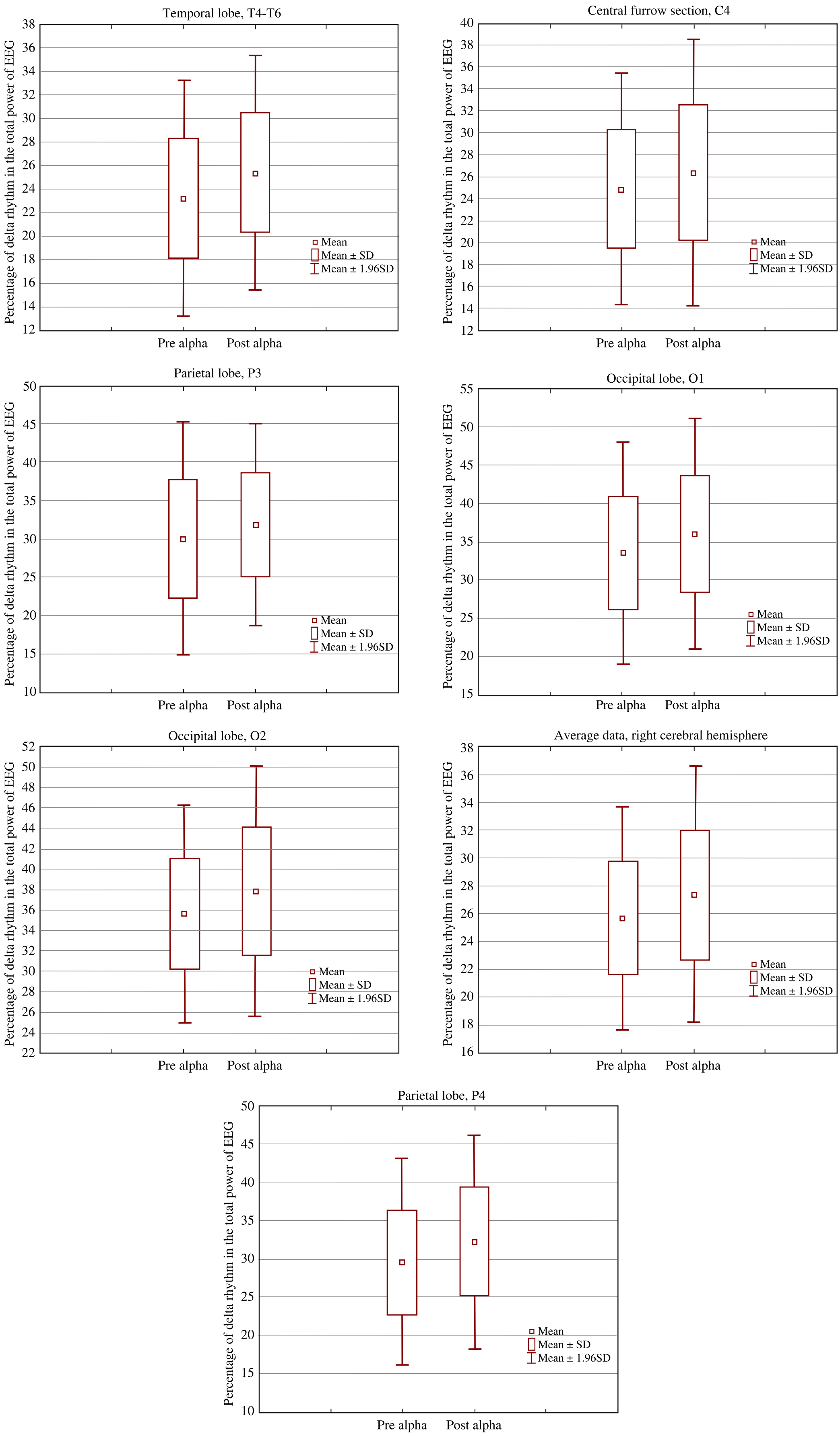

Fig. 5. The box plot representation of alpha rhythm for leads and lead groups with the statistically significant difference.

power fell by 1.64 percentage point) and O2 (delta wave power fell by 1.33 percentage point).

Statistically significant differences in the alpha rhythms (Fig. 5) were observed for the following leads and lead groups:
T4, T6 (alpha wave power rose by 2.2 percentage point),
C4 (alpha wave power rose by 1.51 percentage point),
P3 (alpha wave power rose by 1.74 percentage point),
P4 (alpha wave power rose by 2.7 percentage point),
O1 (alpha wave power rose by 2.46 percentage point),
O2 (alpha wave power rose by 2.22 percentage point),
average data, right cerebral hemisphere (alpha wave power rose by 1.66 percentage point).

In T3, T5 group past exposure theta wave rose by 1.13 percentage point (Fig. 6).

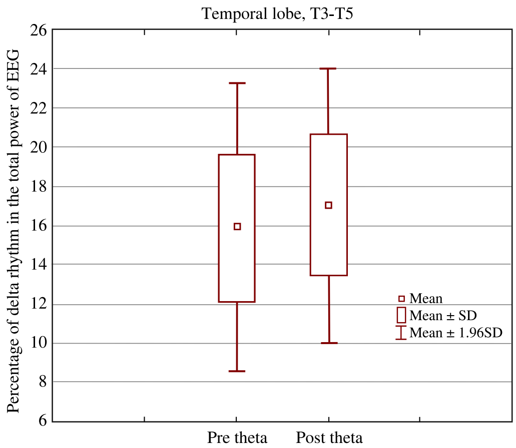

Fig. 6. The box plot representation of theta rhythm for leads and lead groups with the statistically significant difference.

It should be noted that no statistically significant difference in the beta rhythm was found. All observed cases with calculated statistically meaningful differences are presented in Table 5 via shoving the difference between starting and finishing data. This table shows downfall of δ-rhythm on three leads, growth of the theta rhythm level for T3, T5 group and grows of levels of alpha rhythm in groups T4, T6 and average data, right cerebral hemisphere and leads C4, P3, P4, O1, and O2. The lowest estimated change for downfall is 1.33 percentage points, highest – 1.64; for grows – lowest is 1.51, highest – 2.7 percentage points.

Table 5. Statistically meaningful differences in delta, theta, and alpha rhythms ($p \leq 0.05$).

	Delta δ	Theta θ	Alpha α
Fp1, F3, F7	–1.51		
T3, T5		1.13	
T4, T6			2.20
C4			1.51
P3			1.74
P4			2.70
O1	–1.64		2.46
O2	–1.33		2.22
Average data, right cerebral hemisphere			1.66

Subjective assessments of participants of the study after the session were as follows. In the men's group – 10 cases of relaxation, improvement of self-feeling, a decrease of anxiety, irritability (in case of complaints before the session), in 2 cases – no significant changes. Among women: in 8 cases – relaxation, better health, less headache (in case of complaints before the session), 4 cases – without significant changes.

4. Discussion

This article presents the study of alpha, beta, theta and delta rhythms percentage changes in the spectral power of EEG in response to listening to the low-frequency music fragment. Analysis of brain activity rhythms showed that before the beginning of listening to low-frequency music on the background EEG in all areas except the occipital right hemisphere, the dominant frequency of beta rhythm was observed. This can be interpreted as a sign of initial emotional experience and psychological excitation (Shpenkov *et al.*, 2014). To estimate the changes in the spectral power, a comparison of EEG rhythms obtained before and after listening to music was conducted. Analysis of the results shows that statistically significant differences are observed in the alpha, delta, and theta waves. For the beta rhythm suggested music did not play any significant role. There was an increase in the activity of the alpha rhythm in the temporal, central, parietal, occipital leads of the right hemisphere and the parietal and occipital leads of the left hemisphere. Similar dynamics of the alpha waves was observed as a reaction to listening to pleasant music in works (Rodriguez *et al.*, 2019; Kabuto *et al*, 1993). Activation of the theta rhythm in the temporal leads of the left hemisphere may indicate a decrease in the level of emotional tone, relaxation with positive emotional color (Trochidis, Bigand, 2012), the creation of conditions for better assimilation of the received information (Rodriguez *et al.*, 2019). Since this type of waves is associated with sleep, it can be concluded that the low-frequency music fragment affects the central nervous system, causing changes in the activity of the cerebral cortex, similar to those observed during sleep, although the listener remains awake. The data obtained is consistent with the data of studies in music therapy (Jacobs, Friedman, 2004; Kabuto *et al.*, 1993; Lin *et al.*, 2010). The downfall of δ-rhythm in the frontal lead of the left hemisphere and occipital in both hemispheres was detected. If we talk about the registration of δ-rhythm in a state of wakefulness, in general, there are several different, sometimes inconsistent concepts about the meaning and mechanisms of this rhythm. Harmony (2013) notes that δ-fluctuations are recorded during cognitive processes associated with attention and the detection of motivationally noticeable stimuli in the environment. During the performance of mental tasks, the role of δ-waves is associated with the inhibition of sensual stimuli that interfere with internal concentration. An alternative explanation for delta and cognition was proposed by Sachdev *et al.* (2015). They associate local delta rhythms with inattentiveness, fainting, or even sleep in this part of the brain. In general, it can be assumed that listening to the low-frequency composition helps to restore the brain in physiological conditions at different functional overload levels.

5. Conclusions

After listening to the low-frequency music, the most significant changes occurred mainly in high-frequency and low-frequency brain oscillations, which are associated with emotional and cognitive processes. It should also be noted that a possible reason for obtaining of minor changes in severity index of brain rhythms is the insufficient exposure time, which will be taken into account in subsequent studies. It is also planned to use simultaneous recording of EEG and ECG to monitor, for example, indices of relaxation.

References

1. Amaral J.A., Guida H.L., Abreu L.C., Barnabé V., Vanderlei F.M., Valenti V.E. (2016), Effects of auditory stimulation with music of different intensities on heart period, *Journal of Traditional and Complementary Medicine*, **6**(1): 23–28, doi: 10.1016/j.jtcme.2014.11.032.
2. Buzsáki G. (2006), *Rhythms of the Brain*, Oxford University Press: New York, doi: 10.1093/acprof:oso/9780195301069.001.0001.
3. Cherninskyi A.O., Kryzhanovskyi S.A., Zyma I.H. (2011), *Elektrofiziolohiia golovnoho mozku ludyny: metodychni rekomendatsii do praktykumu* [in Ukrainian], pp. 49, Vydavets V. S. Martyniuk, Kyiv.
4. Crocker R. (1963), Pythagorean Mathematics and Music, *The Journal of Aesthetics and Art Criticism*, **22**(2): 189–198, doi: 10.2307/427754.
5. Fancourt D., Ockelford A., Belai A. (2014), The psychoneuroimmunological effects of music: a systematic review and a new model, *Brain, Behavior and Immunity*, **36**: 15–26, doi: 10.1016/j.bbi.2013.10.014.
6. Fedotchev A.I., Bondar A.T., Bakhchina A.V., Parin S.B., Polevaya S.A., Radchenko G.S. (2016), Music-acoustic signals controlled by subject's brain potentials in the correction of unfavorable functional states [in Russian], *Advances in Physiological Sciences*, **47**(1): 69–79.
7. Fedotchev A.I., Radchenko G.S. (2013), Music therapy and "brain music": state of the art, problems and perspectives [in Russian], *Advances in Physiological Sciences*, **44**(4): 35–50.
8. Fedotchev A., Radchenko G., Zemlianaia A. (2018), Music of the brain approach to health protection, *Journal of Integrative Neuroscience*, **17**(3): 291–293, doi: 10.31083/JIN-170053.
9. Ferreri L., Verga L. (2016), Benefits of music on verbal learning and memory: how and when does it work?, *Music Perception: An Interdisciplinary Journal*, **34**(2): 167–182, https://www.jstor.org/stable/26417442.
10. Fukui H., Toyoshima K. (2008), Music facilitates the neurogenesis, regeneration and repair of neurons, *Medical Hypotheses*, **71**(5): 765–769, doi: 10.1016/j.mehy.2008.06.019.
11. Harmony T. (2013), The functional significance of delta oscillations in cognitive processing, *Frontiers in Integrative Neuroscience*, **7**: article 83, doi: 10.3389/fnint.2013.00083.
12. Hughes J.R., Daaboul Y., Fino J.J., Shaw G.L. (1998), The "Mozart effect" on epileptiform activity, *Clinical Neurophysiology*, **29**(3): 109–119, doi: 10.1177/155005949802900301.
13. Jacobs G.D., Friedman R. (2004), EEG spectral analysis of relaxation techniques, *Applied Psychophysiology and Biofeedback*, **29**(4): 245–254, doi: 10.1007/s10484-004-0385-2.
14. Jantzen M.G., Howe B.M., Jantzen K.J. (2014), Neurophysiological evidence that musical training influences the recruitment of right hemispheric homologues for speech perception, *Frontiers in Psychology*, **5**: article 171, doi: 10.3389/fpsyg.2014.00171.
15. Jaušovec N., Jaušovec K., Gerlič I. (2006), The influence of Mozart's music on brain activity in the process of learning, *Clinical Neurophysiology*, **117**(12): 2703–2714, doi: 10.1016/j.clinph.2006.08.010.
16. Jenkins J.S. (2001), The Mozart Effect, *Journal of the Royal Society of Medicine*, **94**(4): 170–172, doi: 10.1177/014107680109400404.
17. Kabuto M., Kageyama T., Nitta H. (1993), EEG power spectrum changes due to listening to pleasant music and their relation to relaxation effects, *Nihon Eiseigaku Zasshi*, **48**(4): 807–818, doi: 10.1265/jjh.48.807.
18. Kulaychev A.P. (2018), *Kompiuternaia elektrofiziolohiya i funktsionalnaya diahnostika* [in Russian], p. 469, Izdatelskyi Dom "Infra-M", Moskva.
19. Kunavin M.A., Sokolova L.V. (2014), Spectral characteristics of bioelectrical brain activity of students in listening to audio-stimuli of different component-structural composition [in Russian], *Human Ecology*, **3**: 34–42, doi: 10.33396/1728-0869-2014-3-34-42.
20. Lehmann J., Seufert T. (2017), The influence of background music on learning in the light of different theoretical perspectives and the role of working memory capacity, *Frontiers in Psychology*, **8**: article 1902, doi: 10.3389/fpsyg.2017.01902.

21. Liashko D.A., Naida S.A. (2019), Research spectra of complex audio signals and methods of music therapy [in Ukrainian], *Electronic and Acoustic Engineering*, **2**(2): 58–62, doi: 10.20535/2617-0965.2019.2.2.
22. Lin Y.P., Duann J.R., Chen J.H., Jung T.P. (2010), Electroencephalographic dynamics of musical emotion perception revealed by independent spectral components, *Neuroreport*, **21**(6): 410–415, doi: 10.1097/WNR.0b013e32833774de.
23. Miendlarzewska E.A., Trost W.J. (2014), How musical training affects cognitive development: rhythm, reward and other modulating variables, *Frontiers in Psychology*, **7**: article 279, doi: 10.3389/fnins.2013.00279.
24. Mohd Razali N., Yap B. (2011), Power Comparisons of Shapiro-Wilk, Kolmogorov-Smirnov, Lilliefors and Anderson-Darling Tests, *Journal of Statistical Modeling and Analytics*, **2**(1): 21–33.
25. Montelpare W.J., Read E.A., McComber T., Mahar A., Ritchie K. (2021), *Applied Statistics in Healthcare Research*, https://pressbooks.library.upei.ca/montelpare/.
26. Nazarova K.A. (2013), Impact assessment subjective perception of music the functional state of human, *Akmeologiya*, **46**(2): 69–72.
27. Pareniuk D. (2021), Method of evaluation of the minimal sample size for acoustical signal therapy monitored via electroencephalographic activity of human brain, *ScienceRise*, **2**: 75–82, doi: 10.21303/2313-8416.2021.001736.
28. Riganello F., Cortese M., Arcuri F., Quintieri M., Dolce G. (2015), How can music influence the autonomic nervous system response in patients with severe disorder of consciousness?, *Frontiers in Neuroscience*, **9**: article 461, doi: 10.3389/fnins.2015.00461.
29. Rodriguez A.H., Nath Zallek S., Xu M., Aldag J., Russel-Chapin L., Mattei T.A., Litofsky N.S. (2019), Neurophysiological effects of various music genres on electroencephalographic cerebral cortex activity, *Journal of Psychedelic Studies JPS*, **5**(2): 128–148, doi: 10.1556/2054.2019.027.
30. Sachdev R.N.S., Gaspard N., Gerrard J.L., Hirsch L.J., Spencer D.D., Zaveri H.P. (2015), Delta rhythm in wakefulness: evidence from intracranial recordings in human beings, *Journal of Neurophysiology*, **114**(2): 1248–1254, doi: 10.1152/jn.00249.2015.
31. Semiletova V.A. (2017), Influence of music of different musical directions on psychophysiological state of human depend on the background eeg-activity, *Sciences of Europe*, **21**(1): 16–22.
32. Shpenkov O.O., Tukaiev S.V., Zyma I.G., Kryzhanovskyi S.A. (2014), EEG dynamics during the listening to the rock music with modified frequency structure, *Bulletin of the Cherkasy Bohdan Khmelnytsky National University. Biological sciences*, **2**: 121–128.
33. Smolen D., Topp R., Singer L. (2002), The effect of self-selected music during colonoscopy on anxiety, heart rate, and blood pressure, *Applied Nursing Research*, **15**(3): 126–136, doi: 10.1053/apnr.2002.34140.
34. Sulewski P. (2019), Modified Lilliefors goodness-of-fit test for normality, *Communications in Statistics – Simulation and Computation*, **51**(3): 1199–1219, doi: 10.1080/03610918.2019.1664580.
35. Taylor A.C., Dewhurst S.A. (2017), Investigating the influence of music training on verbal memory, *Psychology of Music*, **45**(6): 814–820, doi: 10.1177/030573561769024.
36. Trochidis K., Bigand E. (2012), EEG-based emotion perception during music listening, *Proceedings of the 12th International Conference on Music Perception and Cognition and the 8th Triennial Conference of the European Society for the Cognitive Sciences of Music*, pp. 1018–1021, Thessaloniki.
37. Ward L.M. (2003), Synchronous neural oscillations and cognitive processes, *Trends in Cognitive Sciences*, **7**(12): 553–559, doi: 10.1016/j.tics.2003.10.012.
38. Zhou Z., Zhou R., Wei W., Luan R., Li K. (2021), Effects of music-based movement therapy on motor function, balance, gait, mental health, and quality of life for patients with Parkinson's disease: A systematic review and meta-analysis, *Clinical Rehabilitation*, **35**(7): 937–951, doi: 10.1177/0269215521990526.