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Effects of Musical Acoustic Signals Controlled by the Subject's EEG Oscillators

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We report here studies of the effects of two methods of musical EEG biocontrol in which the subject's dominant spectral EEG components (EEG oscillators) were transformed into music-like signals with flute-like timbre. In some cases, the pitches and intensities of these sound signals varied smoothly depending directly on the ongoing EEG amplitudes of the EEG oscillators. In other cases, variation in the pitch and intensity of flute sounds were supplemented by another musical characteristic – rhythm. Single exposures were found to produce modifications to the bioelectrical activity of the subject's brain, which were accompanied by improvements in the subjects' psychophysiological status. Effects were particularly marked when the musicality of exposures were increased by adding the property of rhythmicity.

Keywords: electroencephalogram (EEG), EEG oscillators, transformation of the EEG into musical-acoustic stimuli, rhythm.

In the conditions of contemporary scientific and technical progress, the human body experiences continuous stressors – industrial, social psychoemotional and others [1]. Furthermore, increases in the numbers of emergencies of various types, acts of terrorism, and armed conflicts have the result that the problem of stress associated with lethally dangerous states acquires particular relevance, as these involve significant loss of the body's functional reserves and have long-term consequences [8]. Information management systems directed at reducing stress-induced functional impairments and returning humans to an optimum state are therefore in great demand [9].

Despite a wide spectrum of such influences, even the most developed lack efficacy because they have significant limitations. Thus, music therapy is increasingly popular and is used for correcting many functionality disorders [17]. However, the main limitation of music therapy is the fact that an individual's personal characteristics significantly modulate neuronal responses to emotions expressed musically [21]. The problem of selecting musical influences appropriate to each patient in order to increase the efficacy of the therapeutic procedure is therefore central to music therapy [23]. Biocontrol with feedback via the electroencephalogram (EEG-BCF), which is widely used in correcting various functional impairments of the central nervous system, also has serious limitations [19]. The main problem of EEG-BCF is the difficulty of recognizing and making an active choice of feedback signals from brain biopotentials which are not evolutionarily developed for voluntary control [10]. Furthermore, serious disadvantages of the method significantly limiting its effectiveness come from the use of traditionally defined EEG rhythms instead of individually identified narrow-band spectral EEG components [18].

We have previously [11, 13] suggested combining the advantages of the two approaches described above, minimizing their drawbacks. The basic concepts of a musical EEG biocontrol methodology combining the ease of unconscious perceptions of the stimuli used in music therapy with individualized EEG-BCF were formulated. Theoretically, it should be possible to obtain significant increases in the ef-

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fectiveness of EEG-BCF in correcting adverse functional states by deriving the feedback signal from brain biopotentials to produce musical or music-like stimuli. In place of the excessively wideband traditional EEG rhythms employed to date, use should be made of narrow-band EEG oscillators extracted in real time and typical of and meaningful for the individual to control the stimuli.

In the present study, experimental testing used a version of musical EEG biocontrol in which the subject's dominant spectral EEG components (EEG oscillators) were converted to music-like signals with a flute-like timbre. In some cases, these sound signals varied smoothly in pitch and intensity depending on the ongoing amplitude of the EEG oscillator. In other cases, variations in the pitch and intensity of the flute tones were supplemented by inclusion of another musical element – rhythm. The task of the study was to analyze the effects recorded on presentation of these two types of music-like signals.

Methods

A total of 17 subjects aged 23–55 years (employees of the Pushchino Scientific Center, Russian Academy of Sciences) took part in the study and gave voluntary consent to take part in the two experiments. Studies were carried out in compliance with the Helsinki, Finland Declaration of June 1964, reviewed in Edinburgh, Scotland in 2000, and adopted by the Ethics Committee of the Institute of Cell Biophysics, Russian Academy of Science. Informed consent was obtained from every participant.

At the beginning of each study, psychophysical status was assessed using a brief questionnaire and initial testing using the WAM scale, in which the subject gave assessments of ongoing wellbeing, activity, and mood [3]. EEG probes (active electrodes at lead Cz and reference and ground electrodes on the ear lobes) were then positioned and headphones were applied (sound level 0–40 dB, frequency 100–2000 Hz). Subjects were asked to sit calmly with the eyes closed throughout the procedure and "listen to their own brains working."

The experiment started after a 30-sec baseline EEG recording, during which an original modification of dynamic spectral analysis based on fast Fourier transformation [12] was used to identify the individual's dominant narrow-frequency (0.4–0.6 Hz) spectral component in the EEG α range (8–13 Hz). The operating regime was then applied for 10 min, where the ongoing amplitude of the EEG oscillator thus identified was converted to music-like signals. This was performed by real-time normalization of digitized EEG values where the most negative values of the EEG signal corresponded to the lowest tone and intensity and the most positive to the highest tone and intensity of the computer-generated sounds with a timbre reminiscent of the sounds of a flute. In one of these studies (control), these sound signals were tones varying smoothly in pitch (100–2000 Hz) and intensity (0–40 dB) depending directly on the ongoing amplitude of the EEG oscillator. In the second trial (experimental), variations in tone and intensity were supplemented by adding another musical element – a rhythm consisting of soft (about 10 dB) clicks at 1 Hz.

At the end of each experiment, subjects were asked about the effects experienced and were again tested with the WAM questionnaire. Results were analyzed statistically in Origin 6.0. group means (M) were calculated, along with standard errors (m) and Student's t test. The results obtained in a single group (changes in indicators from baseline) were assessed by calculating the t parameter as M/m.

Results

The effects of music-like stimuli automatically controlled by the subject's EEG oscillators were assessed by analyzing the power of the main EEG rhythms before and during the experimental procedure. However, the high level of individual variability of these parameters hindered quantitative evaluation of the effects of interest. Changes (with signs) in the power levels of the main EEG rhythms during stimulation relative to baseline were therefore calculated for each subject and expressed as percentages. Mean values are presented in Table 1.

Analysis of EEG measures (Table 1) showed that presentation of musical-acoustic signals obtained by transforming the EEG into flute sounds varying smoothly in pitch and intensity led to some decrease in the strength of the θ rhythm and increases in the power levels of the α and β EEG rhythms. However, there were no significant changes in the initial extent of the EEG rhythms during exposure to these stimuli. At the same time, addition of a 1-Hz rhythm to the transformed signal led to a significant increase in power in all EEG ranges, especially the α and β rhythms, whose values relative to baseline increased significantly ($p < 0.01$).

Questioning subjects about their subjective feelings on presentation of the two types of musical-acoustic signals revealed individual features in subjects' responses to presentation of unusual sounds. Some subjects (three of 17) did not note any differences in the acoustic stimuli presented during the two trials. Signals reminiscent of flute-like sounds changing smoothly in pitch and intensity evoked characteristic sensations in 10 of the 17 subjects – from orientational reactions and alertness to clear emotional impressions. Most subjects (12 of 17) found that addition of a 1-Hz rhythm to the sound stimuli presented to the subjects promoted increases in their "musicality" and more positive perception. Changes in subjects' psychophysiological state in response to the procedures were analyzed in terms of changes in measures on the WAM questionnaire after each trial as compared with baseline (Table 2).

Analysis of subjective characteristics (Table 2) showed that stimuli derived by transformation of the EEG into flute sounds varying smoothly in pitch and intensity produced small positive changes in wellbeing and mood, while activity decreased. Addition of a 1-Hz rhythm to the transformed signals led to significant increases in WAM results compared with baseline, particularly marked and significant for

TABLE 1. Changes in the Extents of the θ, α, and β EEG Rhythms Relative to Baseline on Presentation of the Two Types of Musical-Acoustic Signals

EEG measures, %	Transformation of EEG into flute sounds varying smoothly in pitch and intensity	The same EEG transformation but with addition of an additional element – a 1-Hz rhythm
Changes in θ	–1.3 ± 3.5	6.1 ± 3.2
Changes in α	7.4 ± 4.2	15.3 ± 4.5*
Changes in β	3.1 ± 4.5	14.6 ± 4.3*

*$p < 0.01$.

TABLE 2. Changes on the WAM Test (points) after Stimulation Relative to Baseline Values for the Two Types of Musical-Acoustic Signals

WAM test measures	Transformation of EEG into flute sounds varying smoothly in pitch and intensity	The same EEG transformation but with addition of an additional element – a 1-Hz rhythm
Wellbeing	0.3 ± 0.8	3.4 ± 0.8*
Activity	–0.5 ± 1.2	2.2 ± 1.2
Mood	1.1 ± 1.0	2.3 ± 0.5*

*$p < 0.01$.

wellbeing and mood. Use of a more marked rhythmicity had particularly strong effects on activity in the WAM test, which in this case not only not decreased, but clearly increased.

Discussion

The results obtained here provide evidence that transformation of the ongoing EEG into music-like signals constitutes a useful approach to organizing biocontrol procedures with feedback derived from the EEG leading to directed changes in subject's brain bioelectrical activity and improvements in psychophysiological state after single sessions. The effects of the two musical-acoustic stimuli used here had some specific characteristics. Smooth variation in music-like signals based on the ongoing amplitude of the EEG oscillator induced mainly relaxation reactions in the nervous system. These were apparent as reductions in the extent of the θ EEG rhythm and increases in the power of the α and β rhythms, along with increases in assessments of wellbeing and mood on the background of decreased activity. Addition of a 1-Hz rhythm to the music-like signals presented to the subjects led to an increase in their "musicality" and more positive perceptions. There was an increase in the effectiveness of the stimulation in terms of both objective (changes in EEG parameters) and subjective (changes in measures on the WAM test) characteristics.

The literature contains data showing that music has the ability to "express the inexpressible" and to act on the body's basic functions; among all forms of art, music has increased in "consumption" over the last 20 years from fourth to first place [2]. It is therefore not surprising that an increase in musical stimuli in biocontrol procedures with feedback has great potential as an approach to non-medication-based regulation of a person's functional state [15]. The approach in which musical or music-like stimuli are organized in strict correspondence with the characteristics of brain biopotentials has particular potential. In this situation, music individually adapted to the brain's rhythm can act on pathologically altered oscillator patterns and induce neuroplastic rearrangements in the brain [20].

It is important to emphasize that the priority in this direction of research belongs to Russian scientists. Thus, the term "brain music" was coined for a method of treating sleeplessness [6]. The method consists of recording a subject's EEG during nocturnal sleep and identifying the EEG patterns in the different sleep phases, transforming them into music, and recording the result on audio cassettes. The author showed that listening to particular fragments before sleeping decreases the time taken to go to sleep, increases the duration of sleep, and improves patient's wellbeing after waking. In the bioacoustic correction method, computerized transformation of the ongoing EEG into music-like acoustic signals allows brain activity to be heard – brain music – in real time [4]. One feature of the method is that there is no restructuring of the actual EEG – only the need to "listen to your brain working" [14]. The possibility of using this method to regulate the functional state of humans and modulate the activity of the auditory and visual analyzers has been demonstrated [5].

In our study, music-like stimuli were generated in strict accordance with a significant bioelectrical characteristic of the individual's brain – narrow-frequency EEG oscillators. In this situation, the optimal conditions for tuning the parameters of musical stimuli to the individual properties of the subjects' nervous system were created and the positive effects seen with these stimuli were evidently due to the involvement of sensory processes, along with the processes of attention, perception, and memory, multisensory integration, and activation of the emotional domain in the integrative activity of the brain.

The question of the occurrence of more marked changes in the subjects' objective and subjective characteristics on delivery of musical signals including the property of rhythmicity is of particular interest. According to current concepts, rhythm perception is an innate and fundamental ability of humans and is based on neuronal resonance at the stimulation frequency [16]. Cortical rhythms can be adapted to structured acoustic signals such that neuronal responses can demonstrate selective amplification at the stimulation frequency [22]. The amplification of the main EEG rhythms on addition of the 1-Hz rhythm to the music-like signal noted here can therefore be explained in terms of resonance phenomena at the harmonic components of the stimulation rhythm. As regards the significant positive changes in assessments of subjects' wellbeing, activity, and mood, the main role was played by the increase in the musicality of the stimuli due to addition of the clear rhythmicity.

It should be noted that the 1-Hz rhythm used here corresponds to mean pulse frequency in healthy humans. This suggests that this way of organizing music-like stimuli, controlled not only by brain biopotentials but also by the subject's cardiac activity, has potential. Previously developed methodologies for the discrete monitoring and telemetry of the heart rhythm could be used for this purpose [7].

Conclusions

Experimental testing of two versions of the musical EEG biocontrol method showed that the transformation of an individual's ongoing brain biopotentials is a potential approach to organizing procedures for the non-medication-based correction of functional state in humans. The result of single sessions of stimulation was modification of subjects' brain bioelectrical activity, accompanied by improvements in their psychophysiological state. Particularly marked effects were seen when the musicality of the stimulation was increased by adding the property of rhythmicity.

These effects were based on the presentation of music-like signals in strict accordance with significant bioelectrical characteristics of the individual's brain. This situation creates the optimum conditions for the involvement of integrative, adaptive, and resonance mechanisms of central nervous system activity in complex body reactions to the influences of low-intensity environmental factors. Operating via sensory processes, as well as the processes of attention, perception, and memory, multisensory information and activation of the emotional domain, these stimuli have positive influences on functional state in humans, improving mental health and the individual's quality of life. Thus, this method may find uses in the prevention and timely correction of functional deviations evoked by stress, which leads to the development of a number of stress-related diseases – heart disease, chronic fatigue syndrome, hypertension, ulcer disease, sexual dysfunctions, etc. The main targets of such corrective procedures are neuropsychic disorders, depressive states, and pathological anxiety, post-traumatic and examination stress, panic attacks, and other functional disorders induced by stress. The main contingent of patients are those undergoing courses of post-operative rehabilitation, specialists in extreme professions, sportsmen, leaders, and high-level managers, dispatchers, and transport, aviation, atomic and other power station operators, etc.

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