Neurointerface with Double Feedback from Subject's EEG for Correction of Stress-Induced States

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The aim of the study is a comparative evaluation of the effectiveness of the neurointerfaces using single (sound) or double (light-sound) feedback from the human EEG when suppressing stress-induced states.

Materials and Methods. In one of the three experiments, 16 stressed volunteers were presented with classical music (control). In the other two experiments, either single feedback was used, in which subjects are presented with sound stimuli obtained by converting the current values of EEG oscillators into music-like signals, or double feedback, in which the described music-like signals were supplemented by rhythmic light stimuli controlled by the raw EEG of the subject.

Results. The most pronounced effects — a significant increase in the alpha EEG power relative to the background and significant positive shifts in subjective indicators — were noted under double feedback from subject's EEG due to the involvement of integrative, adaptive and resonance mechanisms of the central nervous system in the processes of functional state normalization.

Conclusion. The use of the double audio-visual feedback from the human EEG appears to be a promising way to improve the effectiveness of neurointerfaces in correcting stress-induced functional states.

Key words: neurointerface; electroencephalogram; EEG; double feedback; EEG transformation into music-like signals; photostimulation, controlled by brain biopotentials; correction of functional disorders.

Introduction

Technologies of neurointerfaces, including the brain–computer interface and neurofeedback technology, have recently been widely used to suppress stress-induced states [1–4]. However, the effectiveness of existing technologies is still inadequate and often undergoes reasonable criticism [5, 6]. Analysis of the literature shows, that in order to increase the efficiency of neurointerfaces, it is necessary to organize optimal feedback signals from human bioelectric processes [7].

Earlier, for this purpose, an approach was theoretically justified, suggesting the use of musical or music-like feedback signals from the electroencephalogram (EEG), facilitating the patient's perception of feedback and thus increasing the effectiveness of therapy [8]. This

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approach has been successfully tested to correct stress-induced disorders through musical stimuli controlled by subject's EEG oscillators [9], and also by transforming brain biopotentials into music-like feedback signals [10].

Another approach to increase the efficiency of the neurointerfaces may be a doubling of the feedback from the EEG, in which some EEG characteristics are converted into sound (music-like), and others — into light stimuli. Such bisensory feedback from the EEG is more in line with the conditions of daily life, where simultaneous processing of multimodal signals is common [11], and may have certain advantages.

The aim of the study was to test this hypothesis experimentally by comparing the effects observed when stress-induced states are suppressed by means of neurointerface using single (sound) or double (light-sound) feedback from the EEG. As a control, listening simply to music without feedback was used.

Materials and Methods

The study involved 16 subjects aged 18 to 60 years, employees of the Pushchino Scientific Center of the Russian Academy of Sciences, who turned to the psychological relief office about psychoemotional stress and voluntarily agreed to participate in 3 surveys. The study was carried out in accordance with the Helsinki Declaration (2013) and approved by the Ethics Committee of the Institute of Cell Biophysics of the Russian Academy of Sciences. Informed consent has been obtained from each subject.

At the beginning of each examination, the initial testing was conducted to assess the psychophysiological state of the subjects using three tests:

SAN test, in which subjects give an assessment of their current state of health, activity, and mood [12];

UED test, which makes it possible to determine the current level of emotional disadaptation [13];

US test — a modification of the UED test, which allows one to assess the level of stress of a person [14]. In this test, instead of adjectives that characterize the degree of emotional maladjustment, adjectives that describe the level of stress are used.

After initial testing, EEG sensors (active electrode in lead Cz, reference and grounding on ears), stereo headphones (Philips SBC HL140 sound level 0–40 dB, frequency 100–2000 Hz), and red LEDs glasses with a power not exceeding 100 μW were installed. The subjects were asked to sit still with their eyes closed during all the examinations. Each experiment began with a 30-second recording of the background electrical activity with an EEG filtering range of 2–32 Hz and a sampling frequency of 100 Hz.

The further course of the survey depended on the experimental conditions, which for each subject were alternated in a random order.

In the experiment with sound feedback from the EEG ("Sound" series) the narrow frequency (0.4–0.6 Hz) spectral component dominating in the subject was measured in the alpha-rhythm (8–13 Hz) range of the EEG during the background recording. Then, for 10 min, the operating mode was switched on, where the current amplitude of the detected EEG oscillator was converted into music-like signals with a timbre resembling the flute sounds, which varied in pitch and intensity according to the current amplitude of the EEG oscillator and were accompanied by weak clicks at a frequency of 1 Hz.

In the experiment with double feedback from the EEG (series "Sound + Light"), the described sound stimulation was supplemented by varying intensity LED stimulation, which was carried out in strict accordance with the current values of the raw EEG of the subject. This was achieved by normalizing the digitized EEG values, in which the largest negative EEG signal value corresponded to the minimum, and the largest positive value — to the maximum luminescence of the LEDs.

In the control experiment without feedback from the EEG ("Control" series), the subjects were presented with a 10-minute composition from the popular classical music of Tchaikovsky, Mozart, Bach, and Schubert, pre-recorded on the hard disk of the computer.

At the end of each experiment, EEG recording continued for 2 min to measure aftereffects and repeated testing and questioning of subjects about their feelings during treatment sessions were conducted.

The statistical processing of the results was carried out using the Sigma-Plot 11.0 software package. The mean values (M) and standard errors (m) were calculated for the groups. To determine the significance levels of p differences of each indicator before and after exposure, a nonparametric Wilcoxon–Mann–Whitney (or rank sum) test was used.

Results

Evaluation of the effects in the control (listening to music without feedback) and two experimental series ("Sound" and "Sound + Light") was carried out by comparing the main indicators recorded before and after the treatment (see the Table).

The data in Table show that after all treatments the alpha EEG power increases. However, a significant increase was noted only in the experimental series with feedback from the EEG and was more significant with double ("Light + Sound") feedback. It can also be seen that as a result of therapeutic procedures with feedback from the EEG, positive changes occur in the subjective indicators of health and mood in the SAN test. Under the influence of all three treatment procedures, there was a decrease in the levels of emotional disadaptation (UED test) and stress (US test) of the subjects. However, these changes have reached a level of significance only in a series with the double feedback from the EEG.

The questioning of subjects about subjective sensations during the experiments revealed their positive attitude to the treatment sessions, lowering

Mean values (M) and standard errors (m) of the indicators recorded before and after treatment in three series of experiments

Indicators	Series					
	Control — music without feedback		Sound feedback from EEG oscillator		Double sound-light feedback from the EEG	
	before	after	before	after	before	after
Alpha EEG power (relative units)	117.0±11.0	123.0±12.0	**120.0±10.0**	**151.0±11.0**	**118.0±10.0**	**154.0±12.0**
SAN test — health (scores)	46.1±0.9	45.2±0.8	**46.5±1.1**	**50.6±1.1**	**46.5±1.2**	**51.6±1.5**
SAN test — activity (scores)	42.1±0.8	41.6±1.1	43.7±1.0	44.7±1.0	42.9±1.0	44.0±1.3
SAN test — mood (scores)	47.1±0.5	47.5±0.7	**49.1±1.2**	**51.8±1.0**	**46.4±1.2**	**51.2±1.3**
UED test — emotional disadaptation (scores)	1.7±0.3	1.2±0.3	1.7±0.3	1.2±0.3	**1.8±0.3**	**0.9±0.1**
US test — level of stress (scores)	1.3±0.4	1.2±0.4	1.2±0.3	0.6±0.2	**1.4±0.4**	**0.4±0.2**

N o t e: the compared pairs of values with a significance level of $p<0.05$ are marked by bold pattern.

the level of stress and improving the emotional state. Especially positive were the experiments with double feedback from the EEG, where the music-like sound stimuli were supplemented by pleasant overflows of a multicolored background, which appeared when the light flickers formed on the basis of the EEG were perceived through closed eyes.

Discussion

The obtained data demonstrate that significant changes in objective and subjective indices are observed only in the presence of feedback from the EEG, i.e. in cases where the management of sensory stimulation is carried out directly by the subject's EEG. In these cases, a significant increase in alpha EEG power relative to the background is noted, accompanied by positive emotional reactions and shifts in the functional state of the subjects.

Earlier we showed that the transformation of current values of patient's EEG oscillators into music-like signals provides an opportunity for rapid and effective correction of unfavorable changes in its functional state [15]. Judging by the results obtained in this study, doubling the feedback from the EEG characteristics of subjects by introducing an additional contour of light stimulation controlled by brain biopotentials leads to an increase in the effectiveness of therapeutic procedures due to the resonant interaction between light rhythmic stimuli and bioelectric processes of the human brain. It is known that rhythmic photostimulation with the frequencies of endogenous EEG rhythms causes resonant responses of the cortical visual regions by the mechanism of involving (capturing phase) oscillations of brain biopotentials by rhythmic sensory stimuli and is accompanied by pronounced behavioral effects [16].

It is important to emphasize that the double feedback from the EEG used by us corresponds to the current trends in the development of neurointerface technologies, suggesting the perspectives of creating hybrid or multisensory neurointerfaces [17]. The literature indicates that such neurointerfaces have a number of advantages, including feedback enrichment [18], an increase in the number of control commands [19] and a more active involvement of the subject in rehabilitation processes [20].

Conclusion

Doubling the feedback from subject's EEG, in which the conversion of the current values of EEG oscillators into music-like signals is supplemented by rhythmic light stimuli controlled by subject's EEG, seems to be a promising way to improve the effectiveness of neurofeedback procedures for correcting stress-induced functional disorders. With such treatments, optimal conditions are created for involving the integrative, adaptive and resonance mechanisms of the central nervous system in the processes of normalization of organism functional state.

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Conflicts of interest. The authors declare no conflicts of interest related to this study.

References

1. Kotozaki Y., Takeuchi H., Sekiguchi A., Yamamoto Y., Shinada T., Araki T., Takahashi K., Taki Y., Ogino T., Kiguchi M., Kawashima R. Biofeedback-based training for stress management in daily hassles: an intervention study. *Brain Behav* 2014; 4(4): 566–579, https://doi.org/10.1002/brb3.241.

2. Dillon A., Kelly M., Robertson I.H., Robertson D.A. Smartphone applications utilizing biofeedback can aid stress reduction. *Front Psychol* 2016; 7: 832, https://doi.org/10.3389/fpsyg.2016.00832.

3. Phneah S.W., Nisar H. EEG-based alpha

neurofeedback training for mood enhancement. *Australas Phys Eng Sci Med* 2017; 40(2): 325–336, https://doi.org/10.1007/s13246-017-0538-2.

4. Subhani A.R., Kamel N., Mohamad Saad M.N., Nandagopal N., Kang K., Malik A.S. Mitigation of stress: new treatment alternatives. *Cogn Neurodyn* 2018; 12(1): 1–20, https://doi.org/10.1007/s11571-017-9460-2.

5. Thibault R.T., Lifshitz M., Raz A. The self-regulating brain and neurofeedback: experimental science and clinical promise. *Cortex* 2015; 74: 247–261, https://doi.org/10.1016/j.cortex.2015.10.024.

6. Slutzky M.W., Flint R.D. Physiological properties of brain-machine interface input signals. *J Neurophysiol* 2017; 118(2): 1329–1343, https://doi.org/10.1152/jn.00070.2017.

7. Fedotchev A.I., Parin S.B., Polevaya S.A., Velikova S.D. Brain-computer interface and neurofeedback technologies: current state, problems and clinical prospects (review). *Sovremennye tehnologii v medicine* 2017; 9(1): 175, https://doi.org/10.17691/stm2017.9.1.22.

8. Fedotchev A.I., Radchenko G.S. Music therapy and "brain music" state of the art, problems and perspectives problems and perspectives. *Uspekhi fiziologicheskikh nauk* 2013; 44(4): 35–50.

9. Fedotchev A.I., Oh S.J., Semikin G.I. Combination of neurofeedback technique with music therapy for effective correction of stress-induced disorders. *Sovremennye tehnologii v medicine* 2014; 6(3): 60–63.

10. Fedotchev A.I., Bondar A.T., Bakhchina A.V., Grigorieva V.N., Katayev A.A., Parin S.B., Radchenko G.S., Polevaya S.A. Transformation of patient's EEG oscillators into music-like signals for correction of stress-induced functional states. *Sovremennye tehnologii v medicine* 2016; 8(1): 93, https://doi.org/10.17691/stm2016.8.1.12.

11. Roy C., Lagarde J., Dotov D., Dalla Bella S. Walking to a multisensory beat. *Brain Cogn* 2017; 113: 172–183, https://doi.org/10.1016/j.bandc.2017.02.002.

12. Doskin V.A., Lavrent'eva N.A., Miroshnikov M.N., Sharay V.V. Test for differential self-assessment of functional state. *Voprosy psikhologii* 1973; 19(6): 141–145.

13. Grigorieva V.M., Tkhostov A.Sh. *Method for assessing human emotional state*. Patent RU 2291720 C1. 2007.

14. Kataev A.A., Bakhchina A.V., Polevay S.A., Fedotchev A.I. Connection between subjective and objective estimates of hunan functional state (approbation of rapid test for measurement of stress level). *Vestnik psikhofiziologii* 2017; 2: 62–68.

15. Fedotchev A.I., Bondar' A.T., Bakhchina A.V., Parin S.B., Polevaya S.A., Radchenko G.S. Music-acoustic signals controlled by subject's brain potentials in the correction of unfavorable functional states. *Uspekhi fiziologicheskikh nauk* 2016; 47(1): 69–79.

16. de Graaf T.A., Gross J., Paterson G., Rusch T., Sack A.T., Thut G. Alpha-band rhythms in visual task performance: phase-locking by rhythmic sensory stimulation. *PLoS One* 2013; 8(3): e60035, https://doi.org/10.1371/journal.pone.0060035.

17. Choi I., Rhiu I., Lee Y., Yun M.H., Nam C.S. A systematic review of hybrid brain-computer interfaces: taxonomy and usability perspectives. *PLoS One* 2017; 12(4): e0176674, https://doi.org/10.1371/journal.pone.0176674.

18. Sollfrank T., Ramsay A., Perdikis S., Williamson J., Murray-Smith R., Leeb R., Millán J.D.R., Kübler A. The effect of multimodal and enriched feedback on SMR-BCI performance. *Clin Neurophysiol* 2016; 127(1): 490–498, https://doi.org/10.1016/j.clinph.2015.06.004.

19. Hong K.S., Khan M.J. Hybrid brain-computer interface techniques for improved classification accuracy and increased number of commands: a review. *Front Neurorobot* 2017; 11: 35, https://doi.org/10.3389/fnbot.2017.00035.

20. Gui K., Liu H., Zhang D. Towards multimodal human-robot interaction to enhance active participation of users in gait rehabilitation. *IEEE Trans Neural Syst Rehabil Eng* 2017; 25(11): 2054–2066, https://doi.org/10.1109/tnsre.2017.2703586.