American Journal of
Biomedical Science & Research

www.biomedgrid.com
ISSN: 2642-1747

Research Article

Brain Activity During Biofeedback Training and Self-Regulation Mechanisms

Olga Jafarova*, Kseniya Mazhirina, and Elena Danilenko

Institute of Molecular Biology and Biophysics, Federal Research Center of Fundamental and Translational Medicine, Russia

***Corresponding author:** Olga Jafarova, Biofeedback Computer Systems Laboratory, Institute of Molecular Biology and Biophysics, Federal Research Center of Fundamental and Translational Medicine, Address: 2, Timakova Str., Novosibirsk, 630117, Russia.

To Cite This Article: *Olga Jafarova*, Kseniya Mazhirina, and Elena Danilenko. Brain Activity During Biofeedback Training and Self-Regulation Mechanisms. Am J Biomed Sci & Res. 2023 19(5) AJBSR.MS.ID.002621,* DOI: 10.34297/AJBSR.2023.19.002621

Received: July 21, 2023; **Published:** July 25, 2023

Abstract

Today, functional magnetic resonance imaging is a technology closely related to the medical science and practice. The continuing process of further development of new ways of its application allows us to gain more and more data. The current paper we devoted to investigation of the specialties of the central organization of the self-regulation processes supported by the heart rate biofeedback with game plot that models a stressful situation as a sport competition, and analysis of the dynamics of the psycho-emotional state of a person in the process of mastering the skills of self-regulation by this training. It was shown that the development of self-regulation skills of psychophysiological functions was accompanied by the activation of sensory and higher integrative structures of the cortex, and the success of correcting excessive stress response depended on joint work with both the cognitive and emotional spheres.

Keywords: Biofeedback, Functional magnetic resonance imaging, fMRI, Brain activity, Self-regulation, Anxiety, Neuropsychic tension, Stress response, Cognitive, Higher integrative structures

Abbreviations: fMRI: Functional Magnetic Resonance Imaging; AA: Areas of Activation; BA: Brodman Area; HR: Heart Rate; RR: Cardiointerval, Inter-Beat Interval; NPN: Neuro-Psychic Tension

Introduction

The aim of the work is a comprehensive study of the features of the organization of the processes of self-regulation of psychophysiological functions through neurotechnologies, mainly biofeedback and Functional Magnetic Resonance Imaging (fMRI). Despite the growing popularity of activation studies that outline the topography of the brain response to certain stimuli, there are few studies that search for brain structures that are markers of self-regulation of functions.

Analyzing the studies presented in the world science devoted to the phenomenon of self-regulation, it can be noted that representatives of various scientific directions turn to this topic. These are traditional studies of the regulation of states in the psychophysiological and physiological sciences, decision-making psychology, medicine, pedagogy, etc. However, studies of the phenomenon of self-regulation within the framework of neurosciences are few. For example, studies evaluating neural correlates of self-regulation using fMRI usually associate self-regulation processes with self-control. A fairly common model for studying such processes is the Stroop test (*Rachel Marsh, Hongtu Zhu, et al.,* 2006*; Stroop J.,* 1935*; Vendrell P, Junque C, et al.,* 1995). Self-regulation, in this case, is aimed at suppressing more automatic behavior (reading a word) in favor of a less automatic one (designating the colour of letters). Imaging studies of brain activity during color coding of mismatched stimuli have demonstrated activation of large areas of the anterior cingulate gyrus, prefrontal cortex, and striatum (*Carter JS, et al.* 2000*; Leung HC, Skudlarski P, et al.,* 2000*; Macdonald AM, Botvinick M, et al.,* 2000). Another popular model for studying the ability of participants to self-regulate is the management of emotions. The ability to enhance positive and reduce negative emotions in real time is assessed. During the task, participants view negative (eg, injured, crying person), positive (eg, flowers, puppies), and neutral images (eg, hair dryer, fire hydrant) selected from a commonly used and well-reviewed image repository (International Affective Picture System; IAPS). Such works show that emotional reactivity is associated with activation of the orbitofrontal cortex, dorsal anterior cingulate gyrus, and ventromedial prefrontal cortex (*Wallis JD, Dias R, et al.,* 2001*; Rubia K, Smith AB, et al.,* 2003).

The use of fMRI technology, which allows on-line visualization of the process of performing brain operations, in our study will provide a non-invasive dynamic assessment of the activity of brain structures involved in the process of forming self-regulation skills. The main task, the solution of which should be found in the work, is the localization of self-regulation mechanisms in the vocabulary of brain neural networks. We planned to evaluate the features of the functional reorganization of neural networks and their associations with emotional variables in a sample of highly anxious and conditionally healthy subjects.

Despite significant progress in the localization of individual zones associated with the implementation of mental functions, achieved with the help of neuroimaging technologies, primarily fMRI, the pathophysiological mechanisms and morphological basis of these changes in emotional deviations, including high anxiety, remain unclear.

Research Hypotheses

The psycho-emotional state of a person changes in the course of biofeedback training: the level of anxiety, neuropsychic tension decreases, and the emotional state as a whole improves. The fMRI data allowed us to visualize the underlying cerebral network as a set of voxels in the Areas of Activation (AA). Despite the growing popularity of activation studies that outline the topography of the brain's response to the certain stimuli, studies that search for brain structures - markers of self-regulation of functions - are rare [1,2].

Materials and Methods

The study was conducted on volunteers, after their written consent and instructions from the Ethics Committee of the Federal Research Center of Fundamental and Translational Medicine were obtained. 20 healthy men aged 18 to 30 years, with high personality and situational anxiety and high scores on the neurotic scale, without any prior experience of self-regulation and unfamiliar with the technology of biofeedback, took part in the study. The participants of the experiment were selected according to the method of determining the level of anxiety by Spielberger-Khanin technique. At the first stage, the 'VIRA-RALLY' test was used [3]. Training course included 10 sessions of heart rate biofeedback with game plot that models a stressful situation as a sport competition [4]. The games were controlled by player's heart rate using 'BOS-Pulse' device, manufactured by Comsib Ltd. Before and after the training course subjects of the group demonstrated ineffective and intermediate strategies of self-regulation [3] at 'Vira-Rally' test at the beginning stage took part in the fMRI-study - the game 'Vira!' imitating underwater diving competition of two divers was used, it included 5-7 trials.

fMRI-study was carried out using the Achieva Nova Dual (Philips, the Netherlands) MRI system with the magnetic field induction equal to 1.5 T. Statistical analysis and obtaining the fMRI images was performed using the software package Matlab (Mathworks Inc.) + SPM8 (Wellcome Trust Centre for Neuroimaging UC London, Statistics 9.0 package).

The assessment of psycho-emotional status before and after the training course, the following methods were used: The scale of anxiety by the Spielberger-Khanin method; The method of assessment of neuropsychic tension (NPN test of T.A. Nemchin). Wilcoxon's pairwise comparison test was used to compare the changes in the above pre- and post-training tests.

Results and Discussion

At the beginning of the course the participants showed increased non-productive neuro-psychic tension and reduced performance. By the end of the training the ability for long-term volitional efforts, working capacity, and self-regulation skills increased. As a result of the training the level of neuro-psychic tension according to the NPN test decreased significantly ($p<0.001$). The analysis of the effect of biofeedback training on mental state showed that situational anxiety decreased after the biofeedback training ($p<0.001$).

Ineffective and intermediate strategies of self-regulation demonstrated 12 participants of the group at the beginning of the experiment, 4 of them - ineffective ones. By the end of the course more than a half of them improved their self-regulation strategies to more effective; just one subject demonstrated an ineffective strategy at 'Vira-Rally' test twice. All this subgroup was provided with fMRT study during 'Vira' biofeedback session at the beginning and the end of training course.

The analysis of the dynamics of vegetative indexes like RR averaged over each biofeedback trial and RR-increase during the game as well its matching to the fMRI data allowed us to visualize the underlying cerebral network as a set of voxels in the Areas of Activation (AA). It was shown that the "epicenters" of the AAs were prone to shift into the cerebellum and the brainstem at the same time that optimal HR regulation strategy was found by the subject. The growth of the AAs quantity and volume indicate the successive involvement of the "newborn" networks or/and recruiting the existing ones. The projection of biofeedback dynamics onto the map of architectonic areas of the cortex, according to Brodmann, was as follows: it was mainly the 37^{th} area during the first stage, areas 2, 7, 39 and 44 with the second and the third stages characterized by further involvement of activation areas of the cortical structures of areas 6, 9, 19, 22 and 40. During the subsequent stages, the activation volumes declined and AA were maintained in the areas 6, 7, 37 and 40. After the training course the main areas of activity involved the same areas of the brain, but the number of activated voxels decreased, which indicated a decrease in the level of emotional response.

Thus, at the initial stages, BAs associated with the motor, visual analyzer, acoustic-gnostic center of speech, processing of proprioceptive information are activated; subsequently, the activation of the BA responsible for the functions of attention, as well as the premotor area, in which, as is known, motor planning and processing of emotional stimuli is carried out, increases. At the last stage, the functional affiliation of these areas is reduced mainly to sensorimotor integration. The obtained results can be explained as follows: achieving the goal of the training involves tracking feedback signals about the effectiveness of one's own attempts to find effective self-regulation strategies. In addition, winning requires non-trivial, innovative solutions from the test subject, so the game can be qualified as a creative productive activity, the attractiveness of which also lies in the unforeseen end result.

It is interesting to analyze the differences within the microgroup that demonstrated ineffective strategies in the Vira-Rally test, where three people (No. 6, No. 13, No. 1) improved their self-regulation skills as a result of training, and one (No. 24) at the retest stage still showed a reduced level of stress tolerance. As a result of the expert assessment, a number of anatomical structures were identified that were much more activated by the end of the training in the "unsuccessful" participant. Figure 1 shows some of those structures (Figure 1).

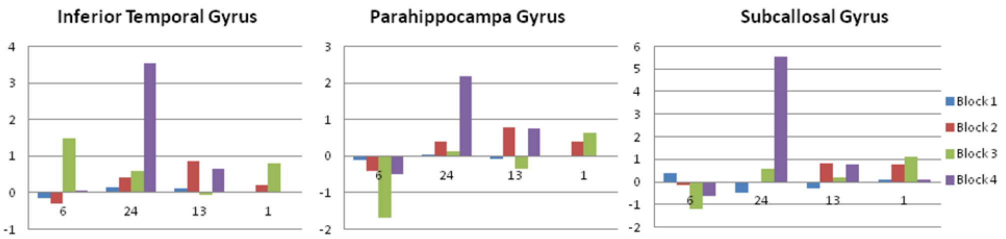

Figure 1: The level of activation of Inferior Temporal Gyrus, Parahippocampa Gyrus, Subcallosal Gyrus during interactive diagnostics using fMRI before and after a course of game biofeedback.
The horizontal axis is the patient numbers.
Block 1 and Block 2 - testing BEFORE the training.
Block 3 and Block 4 - testing AFTER the training.

Functionally, the structure Inferior Temporal Gyrus takes part in the work of the cognitive control system, which, in particular, blocks automatic ("motor") reactions, activity in this area is also responsible for the integration of various signals, the formation of appropriate sensations, the implementation complex analytic-synthetic functions, control of voluntary motor movements. Mirror neurons in this region are involved in the system of observing other people's actions and imitation, this fact is explained in the self-reports of subjects who noted that they associated themselves with the diver on the screen and imagined his movements. Participant No. 24, who, as a result of the training, could not demonstrate an improvement in the skill of self-regulation, at the last stage of the retest demonstrates a significant increase in activity in this region - and, consequently, the tension of these functions.

Our integrated behaviour and complex mental activity require many tasks to be performed simultaneously, and it is hypothesized that the prefrontal cortex may have a generalizing function in managing many cognitive operations and tasks at the same time. As in the case of Parahippocampa Gyrus, the level of activation of Subcallosal Gyrus, related to the Prefrontal Cortex, of participant No. 24 in Block 4 was more than 2 times higher than that of participant No. 13 with an intermediate pendulum strategy. In subjects No. 1 and No. 6, who changed their unsuccessful strategy to a successful one after the training, this structure was not activated or even deactivated in the tomograph at the end of the session.

In the case of the described participant, activity in these areas increases significantly by the end of the training, which can be explained by the maximum stress of cognitive functions, a decrease in adaptive abilities at all levels of the psychophysiological organization.

Conclusion

The use of neuroimaging technologies (fMRI) in the work provided a completely new dimension of psychophysiological phenomena, providing a deeper insight into the essence of the tasks. Thus, we can conclude that the course of game biofeedback helps to reduce situational anxiety, reduce neuropsychic stress, increase the activity of mental processes, i.e. positively affects the general mental state. The anatomical affiliation of cerebral structures accompanying the integrative activity of the brain in the course of game biofeedback training was determined. The integrative brain activity related to the course of the biofeedback training points to the fact that developing of the skills of physiological functions self-regulation is accompanied by the activation of the sensory and associative (prefrontal and parietal) cortical areas, subcortical regions (the cerebellum) and is not limited to the cerebral structures that are traditionally considered as cognitive ones. During the learning to self-regulate the heart-rate AAs shifted to the sensory brain areas.

It should be pointed out that the effects of game training are not necessarily reduced only to an increase or decrease in the duration of the cardiointerval, and, as a result, the acquisition of the skill of self-regulation. In the context of the study, perhaps more informative is the concept of improvement, which correlates not only with the category of the goal of the game (learn to reduce heart rate), but also with the category of means (methods, strategies of self-regulation) to achieve the goal. The results of our work [3-5] suggest that, using the modern capabilities of fMRI intrascopy, it becomes possible to visualize intracerebral structures that provide a particular strategy of self-regulation, the mechanism of each of which, obviously, is dictated by the psychophysiological features of the phenomenon of self-regulation of functions.

Acknowledgement

Many thanks to Prof. Mark Shtark, Academician of Russian Academy of Sciences, for his inspiring ideas and continued support.

The study was supported by project FGMU-2022-001.

Conflict of Interest

Authors declare no conflict of interest exist.

References

1. Marc G Berman, John Jonides, Derek Evan Nee (2006) Studying mind and brain with fMRI. Soc Cogn Affect Neurosci 1(2): 158-161.
2. Mark B Shtark, Mariya Rezakova, Kseniya Mazhirina, Andrey Savelov, Olga Jafarova, et al. (2014) Neuroimaging phenomenology of the central self-regulation mechanisms. Journal of Behavioral and Brain Science 4(1): 58-68.
3. Olga Jafarova, Kseniya Mazhirina, Estate Sokhadze, Mark Shtark (2020) Self-regulation Strategies and Heart Rate Biofeedback Training. Appl Psychophysiol Biofeedback 45(2): 87-98.
4. Mazhirina KG, Jafarova OA, Pervushina ON, Redko NG (2010) Development and improvement of self-regulation skills in the process of game biofeedback: psychological analysis. Bulletin of Siberian Medicine 9(2): 129-133.
5. Bezmaternykh DD, Melnikov ME, Petrovskii ED, Mazhirina KG, MB Shtark, et al. (2023) Directional interrelationship of the amygdalas, dorsomedial prefrontal and subgenual anterior capital cortex: validization of models of regulation of positive social emotions for real-time fMRI. Bulletin of Experimental Biology and Medicine 175 (4): 488-493.