PSYCHOPHYSIOLOGY

Research article
UDC 159.91
https://doi.org/10.21702/rpj.2024.3.10

The Effect of Self-Reflection on Electrophysiological Activity of the Brain Depending on the Level of Anxiety

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Abstract

Introduction. High levels of anxiety are often associated with abnormal activity in the brain areas involved in emotional processing, cognitive control, and reduced connectivity in the default mode network (DMN). Studies also show that the activation of the DMN increases during self-reflection processes, especially positive self-reference, suggesting the possibility of using self-reflection to reduce anxiety. This study aims to test this hypothesis on the basis of EEG dynamic data before and after tasks that engage in self-reflection. Methods. The study population comprised 127 participants (mean age 25 ± 8 years). The sample was divided into low- and high-anxious groups and into experimental and control subgroups. Experimental subgroups were subjected to an Imaginary and Self-Reflective Resource (ISRR) technique developed by the author to engage participants in self-reflection. The control groups completed tasks in a disciplinary academic field – a standard cognitive load. EEG recordings were made before and after the tasks were completed. Results. The results showed that high levels of anxiety tend to lead to cognitive fatigue when completing typical cognitive tasks. At the same time, the self-reflection process combined with high levels of anxiety does not lead to a serious cognitive fatigue, but rather reflects the attention process. Low anxiety is generally associated with lower cognitive fatigue. In low-anxious subjects, the completion of self-reflection tasks involves a significant brain activation that characterizes attention processes. Discussion. The results obtained are consistent with those of other researchers and generally confirm the hypothesis of the study. Positive self-reflection can reduce high levels of anxiety due to the DMN activation.

Keywords

self-reflection, anxiety, self-reference, EEG, electroencephalogram, alpha rhythm, theta rhythm, cognitive processes

Funding

Supported by the Laboratory for Convergent Research of Cognitive Processes, Federal Scientific Center for Psychological and Interdisciplinary Research, created as part of a competition of the Ministry of Education and Science of the Russian Federation.

For citation

Sizikova, T. E., Leonov, S. V., & Polikanova, I. S. (2024). The effect of self-reflection on electrophysiological activity of the brain depending on the level of anxiety. *Russian Psychological Journal*, *21*(3), 172–189. https://doi.org/10.21702/rpj.2024.3.10

Introduction

Under modern conditions, the search for new ways to cope with stress and anxiety continues. Attention to self-reflection possibilities is a relatively new direction of research. The need to confirm the validity of self-reflective methods is undisputed. Knowledge of psychological and physiological reactions of the body to self-reflection helps to apply methods that help reduce anxiety and organize the conditions for the self-reflection process more correctly.

Anxiety is an experience of emotional discomfort associated with an expectation of trouble and imminent danger (A Dictionary of Psychology, 2008). The difference between anxiety and fear is that anxiety is associated with uncertain threats, and fear arises as a response to specific dangers. An optimal level of anxiety is necessary to adapt effectively to reality. However, excessively high or low levels of anxiety can lead to maladaptive reactions.

Anxiety is the basis for any mental state and behavior related to stress experiences. The following factors are most often distinguished as stress resistance: "The individual's energy potential; the level of development of intuition; the level of development of logical abilities; the individual's emotional maturity; the level of emotional stability and emotional control; the plasticity (flexibility, individual willingness to change); a strong type of temperament (according to I. P. Pavlov); the high level of self-reflection, etc." (Grekhov, Suleimanova, & Adamovich, 2017, p. 62). A stress resistance factor such as a high level of self-reflection has been highlighted in recent decades in research on the role of self-reflection in self-regulation, self-organization and individual self-development (Karpov, 2012; 2018; Maslova & Pokatskaya, 2019; Lysenko, 2022; Yasko et al., 2023).

Anxiety is a predictor of the development of stress-related states: "… More anxious people have fewer adaptive capabilities and are therefore more vulnerable to the stressful effects of extreme situations. <…> The impact of a traumatic event weakens personal adaptability and, consequently, contributes to increasing the level of personal anxiety" (Bykhovets & Padun, 2019, p. 80).

According to a number of neurological studies, high anxiety levels are often associated with abnormal activity and hypoconnectivity in the brain areas involved in the processing of emotions (including the limbic system, especially amygdala), cognitive control, and the so-called default mode network (DMN) (Imperatori et al., 2019; Saviola et al., 2020; Wang et al., 2021; Xu et al., 2019). The latter is named because the medial prefrontal cortex (Brodmann area 10 or MPFC/BA 10) exhibits coherent activity when the brain is not engaged in specific tasks, for example during long rest periods or short breaks between experiments (Damoiseaux et al., 2006; Fox et al., 2005; Fransson, 2005). People with high levels of anxiety often lack the DMN functional connectivity during rest, which is normally observed (Imperatori et al., 2019; Wang et al., 2021).

A number of studies have also shown an increase in the DMN activity during self-reflection and self-reference processes (Beer et al., 2010; D'Argembeau et al., 2007; Hu et al., 2016; Kim & Johnson, 2015a; Kircher et al., 2002; Morin, 2007; Mu & Han, 2010a; Ochsner et al., 2005; Shi et al., 2011a). This region is activated when participants reflect on their identity ((Jenkins & Mitchell, 2011), reflect on their emotions (Ochsner et al., 2005), reflect on their personal problems (Kuiken & Mathews, 1986), reflect on the objects that they own (Kim & Johnson, 2015b), present possessive words such as "me" or phrases that contain them (Shi et al., 2011b), and imagine themselves in the past or future (Araujo et al., 2013; Spreng & Grady, 2010). The DMN is sensitive to increased self-awareness periods throughout a person's life (Pfeifer et al., 2009; Sebastian et al., 2008; Somerville et al., 2013).

Self-reference is understood as focusing on personality traits, especially certain characteristics or physical properties. Thus, self-reference is regarded as an aspect of self-reflection (Sizikova et al., 2024).

In the context of our work, studies that show the positive relationship between the characteristics of self-reference (e.g., positive self-reference versus biased negative self-reference) and the level of anxiety are of particular interest (Abraham et al., 2013; Tracy et al., 2021). These results may indicate that an appropriately structured self-reflection or self-reference process can be associated with a lower level of anxiety. Furthermore, studies showing the link between the reflective process (self-reference, meditation, etc.) and electrophysiological parameters (e.g. the synchronization of the alpha and theta rhythms) are important (Aftanas & Golocheikine, 2001; Aftanas et al., 2001; Asada et al., 1999; Fossati et al., 2004; Knyazev, 2013).

This hypothesis suggests that self-reflection can affect brain electrophysiological dynamics differently depending on the level of anxiety.

Methods

Participants

The study population comprised 127 participants (mean age 25 ± 8 years). The sample was divided into a "low-anxious group" and a "high-anxious group" depending on the measures of trait anxiety and state anxiety and the integrated assessment of the level of anxiety (Table 1). The average level of anxiety was excluded from the experiment. No significant differences were found in trait anxiety and state anxiety scores in each group. This enabled an integrated assessment of the level of anxiety – high and low.

Both groups were also divided into experimental and control sugroups (Table 1). The experiment was carried out during a standard university class and lasted 1.5 hours. During this period, the participants in the experimental group were subjected to the Imaginary and Self-Reflective Resource (ISRR) technique (Sizikova, 2018) aimed at engaging them in self-reflection. The control group completed assignments in the academic discipline. At the beginning and end of the class, the two groups recorded background EEGs with closed and open eyes.

Table 1

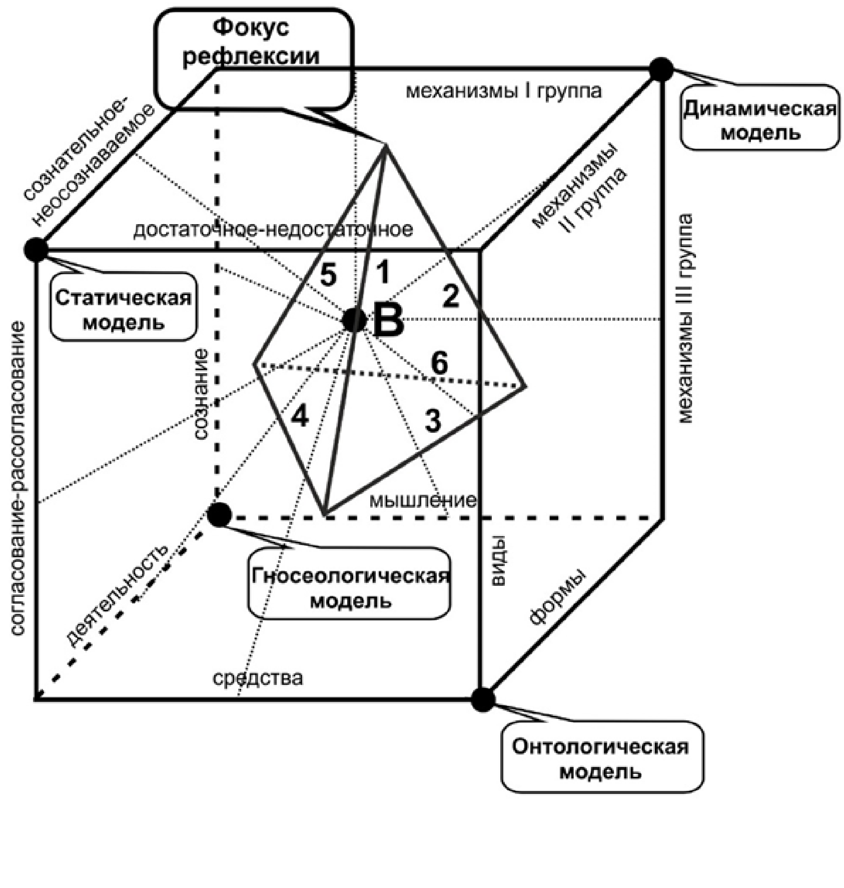
Descriptive characteristics of the subject groups

	Experimental group	Control group
Low-anxious group	Group 1 N = 25 (mean age 24 ± 9)	Group 2 N = 29 (mean age 28 ± 9)
High-anxious group	Group 3 N = 35 (mean age 24 ± 7)	Group 4 N = 28 (mean age 24 ± 8)

Conditions for the self-reflection process

In the meta-model of reflection (Sizikova, 2018), self-reflection is one of the types of reflection. For the act of reflection, any distinction is conditional. The scientific concepts of the whole paradigm enable us to consider an element as a whole, in which the larger whole is the whole object. Self-reflection reflects all other types of reflection, including its forms, means, mechanisms, etc. The meta-model is a certain constructor – a centraur of five models, four of which are built within the framework of the non-classical paradigm, the fifth corresponds to the post-non-classical paradigm (Fig. 1. Sizikova, 2018, p. 23).

Figure 1
Meta-model of reflection in meta-ontology



Note: *1 – Focus of reflection on self and another person, 2 – Focus on development or "staying stuck", 3 – Focus on creativity, 4 – Type of processing information, 5 – Types of work with information, 6 – Self-development of reflection.*

The reflection model, in the form of a cube, reflects the potential state of reflection, and in the form of a tetrahedron reflects the actual state. The current situation is recorded on 12 faces of the cube. When choosing (in the figure, a tetrahedron), a decision is made, which is extended to action. The direction of reflection (intentionality) is the characteristic of the whole object. The focus of reflection on self (in the model, focus of reflection on self and another person), the content of personality that is removed from attention and becomes the object of reflection we call self-reflection.

The Imaginary and Self-Reflective Resource (ISRR) technique developed by the authors refers to projective methods. Its task is to create conditions for self-reflection aimed individual understanding of self and the world. The imaginal layer of consciousness is actualized with the help of tasks for associations of abstract pictures related to archetypal images, the reflective layer – with the help of tasks for transferring the analysis of associations to personal life. The path from the general to the particular enables the individual to expand his/her boundaries. The main purpose of the focus of self-reflection is to make a choice. Association creates a field of possibilities, the choice narrows them down to a solution. The solution is transferred to self-analysis. The self-analysis of personality is performed in writing. Written speech structures internal speech.

The ISRR technique can be analyzed from the perspective of the meta-model of reflection. We attribute this analysis to the epistemological aspect of reflection, as well as to the ontological aspect, the basis of which is the modal idea of the psyche and reflection (Sizikova, 2019; Sizikova & Durachenko, 2020 (a, b); Sizikova & Kudryavtsev, 2023 (a, b)).

The experimental procedure. In the first phase of the study, the experimental group participants were asked to look at cards showing abstract archetypes, such as the Fire Spirit, the Water Spirit, the Smell Spirit, the Mountains Spirit, the Earth Spirit, the Air Spirit, the Nature Spirit, and the World Tree Spirit (the cards and the procedure are presented in: Sizikova, 2018). The names of archetypes direct consciousness and perception into the realm of mythology. The appeal to archetypes refers to the symbolic regulation of personality and its behavior. L. S. Vygotsky (Vygotsky, 1982; 1984) argued that the selection of symbols is the mastery of the universal in specific terms, and defined their nominal functions in the development of language and thought, forming a complex and the symbol becoming an equivalent of the universal in an object class. Abstraction refers to a higher form of thought development; the symbol acquires the alienated individual as a universal content. Then the analysis of the association restores its connection to personality. The ranking of archetype picture cards from "like" to "dislike" includes analysis, and the combination series from 1 to 5 associations present the personal world in duality. The procedure for distributing rows in blocks according to the proposed criteria (fundamental – not fundamental, dynamic – not dynamic, realistic – imaginative, resourceful – not resourceful, neutral) enabled respondents to structure associations and transfer this structure to their real world by performing self-analysis, which is the main task of the technique. A characteristic of self-analysis is to write it as a recommendation to a friend, in which in addition to describing life, an answer to the question "How to make life more interesting and productive?" is given. The use of decentration in self-analysis enabled respondents to take two positions in self-reflection, which facilitates the transition from personal participation in experiences to their objectification.

In the second phase of the study, all procedures were repeated, but the stimulus material changed. The respondents worked with picture cards with philosophical and metaphysical content – life, love, spark of creativity, light, and flow.

The third phase of the study was the last one. The subjects were asked to choose the most resourceful card from all the pictures and to think about how this resource could be applied in life. Therefore, the logic of the ISRR technique allowed for the use of the entire meta-model of reflection.

The State-Trait Anxiety Inventory. To determine the level of anxiety, the Spielberger State-Trait Anxiety Inventory (STAI) was used (Spielberger Ch. D. & Khanin Yu. L., 2000). The questionnaire was developed by Ch. D. Spielberger and modified by Yu. L. Khanin. It is an informative way of self-assessing the level of anxiety at the moment (reactive anxiety as a state) and trait anxiety (as a stable characteristic of a person).

Trait anxiety is a persistent individual characteristic that manifests itself in the tendency of the subject to worry and see many situations as threatening. This characteristic is activated when perceiving stimuli that may damage self-esteem. State anxiety is an emotional state characterized by stress, anxiety, and nervousness in response to a stressful situation. The intensity and dynamics of this state may vary. Anxiety diagnosis is necessary when conducting research using projective self-reflection methods in order not only to determine the state but also to reduce the high levels of anxiety during the experiment. The subject answers questions and, through understanding his/her state, has the opportunity to regulate his/her stress caused by new experimental conditions.

EEG recording

The electroencephalogram (EEG) recording was performed with the BOSLAB-14 hardware and software system (Novosibirsk) monopolarly from the Pz-lead. An ear electrode was used as a reference. The location of the Pz was chosen because the characteristics of alpha activity in the parietal-occipital region are the most stable and reproducible in repeated measurements, as well as the least variable (Thatcher et al., 2008; Bazanova, 2011; Balioz, 2012). EEG recordings were performed in a resting state with eyes closed (2 min) and eyes open (30 seconds). To monitor eye movements, electromyograms (EMGs) were recorded from the forehead muscles. The analysis of electroencephalographic data included artifact-free EEG epochs, which were divided into four-second segments and rapidly subjected to Fourier transforms at a bandwidth of 3–20 Hz with the Hann window. The output data were analyzed using a specialized Win EEG program (Mitsar, St. Petersburg), compiled with accepted signals analysis standards, and presented as a 1Hz EEG spectral power table. To analyze electrophysiological characteristics, the absolute and relative power values of the main EEG rhythms were used: theta rhythm (4–8Hz), alpha rhythm (8–13Hz), and beta rhythm (13–20Hz).

Data analysis

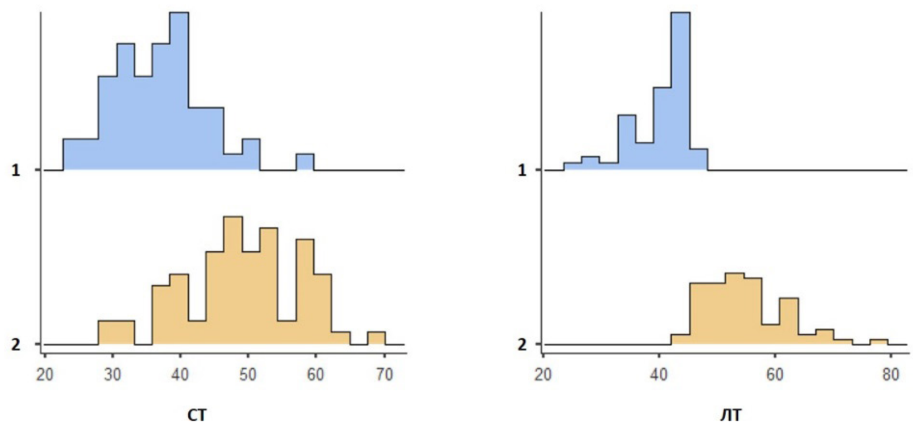
The comparative analysis was carried out using Jamovi 2.4.1. The Shapiro-Wilk test for normality showed that in some EEG parameters the sample was not characterized by a normal distribution. Therefore, we decided to use the non-parametric Wilcoxon test (α=0.05) for intragroup comparisons within each subgroup.

Results

Anxiety study

The sample was divided into a "low-anxious group" and a "high-anxious group" depending on trait and state anxiety scores, based on an integrated assessment of the level of anxiety. Figure 2 shows histograms of the distribution of state anxiety (SA) and trait anxiety (PA) scores in the low-anxious (top) and high-anxious (bottom) groups.

Figure 2
Histograms of the distribution of anxiety levels (trait anxiety and state anxiety)

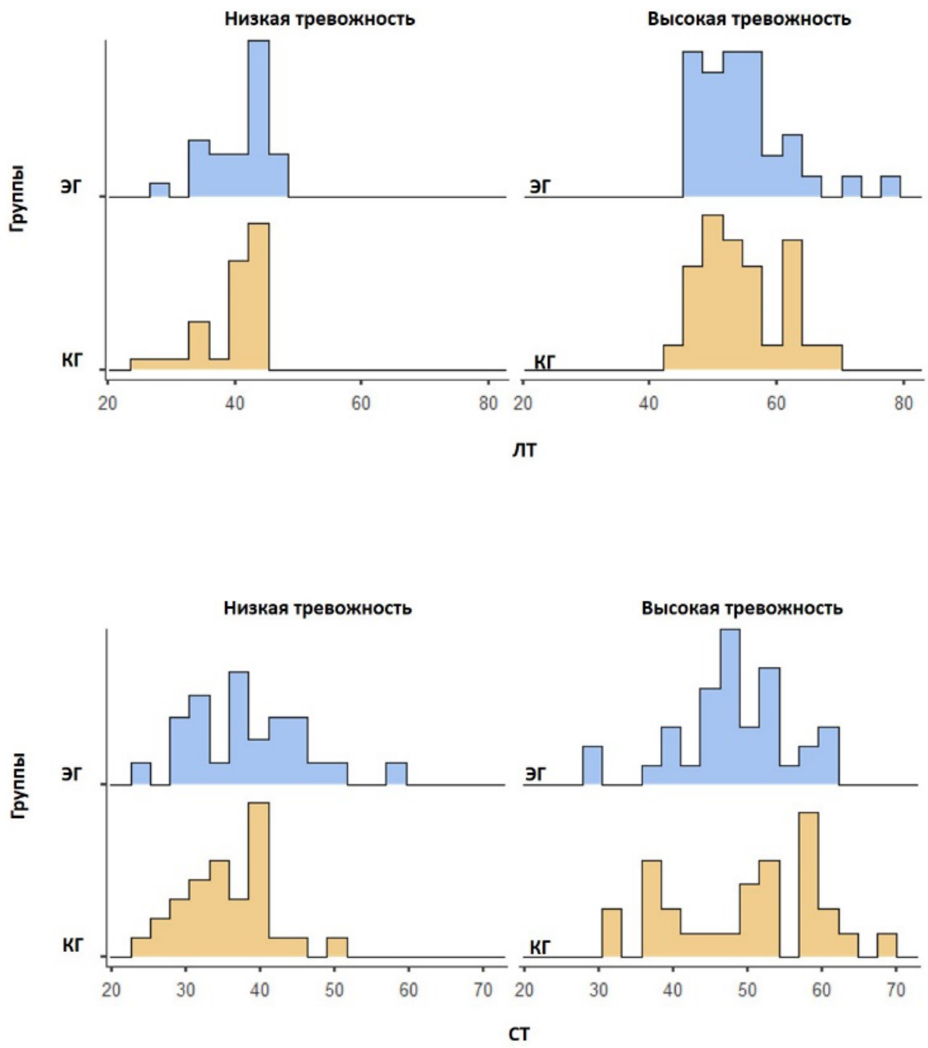


Note: *1 – low anxiety, 2 – high anxiety, SA – state anxiety, TA – trait anxiety.*

The groups were also divided into experimental and control subgroups. Figure 3 shows the histograms of the levels of anxiety in four groups. The distribution into EG and CG according to the anxiety level is generally the same.

Figure 3

Histograms of the distribution of anxiety levels (trait anxiety and state anxiety) for experimental and control groups



Note: *EG – experimental group, CG – control group, SA – state anxiety, TA – trait anxiety*

Indicators of brain electrical activity

Significant statistical differences in the dynamics of electrophysiological indicators before and after completing the self-reflection task for groups with high anxiety levels are shown in Table 2.

Table 2
Statistical analysis of comparison of electrophysiological indicators before and after completing the self-reflection task (high-anxious group)

		BEFORE median	BEFORE SD	AFTER median	AFTER SD	p	Cohen's d
EG	Absolute alpha power (8-9.5 Hz), eyes closed	25.64	34.53	32.04	39.61	0.002	-0.6**
	Relative alpha power (8-9.5 Hz), eyes closed	16.22	10.57	19.90	14.24	0.004	-0.56**
CG	Absolute alpha power, eyes closed	51.35	48.12	64.07	47.91	0.011	-0.62*
	Absolute alpha power (8-9.5 Hz), eyes closed	18.44	25.34	23.73	31.46	0.022	-0.57*
	Absolute alpha power (9.5-11 Hz), eyes closed	18.25	17.29	26.16	21.68	0.003	-0.71**
	Relative alpha power (9.5-11 Hz), eyes closed	18.78	13.65	23.5	15.15	0.01	-0.63*
	Relative alpha power (9.5-11 Hz), eyes open	8.43	4.5	10.83	4.79	0.006	-0.66**
	Relative theta power (4-5.5 Hz), eyes closed	11.81	5.56	9.63	4.62	0.007	0.65**
	Relative theta power (7-8 Hz), eyes open	12.16	6.77	15.01	4.61	0.005	-0.49**

Note. *EG – experimental group, CG – control group, BEFORE – EEG recordings before completing the task, AFTER – EEG recordings after completing the task. * p < .05, ** p < .01, *** p < .001*

The experimental group with high anxiety showed a significant increase in alpha (8-9.5 Hz) frequency band, both for absolute and relative power. At the same time, the control group was characterized by a larger dynamic change after completing the self-reflection task in both alpha and theta frequency bands. At the same time, in alpha frequency band, power (absolute and relative) in all alpha sub-bands was significantly increased, except in a high-frequency band (11-13 Hz). A decrease in relative power was observed in theta band.

Significant differences in the dynamics of electrophysiological parameters before and after the self-reflection task for low-anxious groups are presented in Table 3. Low-anxious CG showed a significant reduction in a high-frequency alpha band (11–13 Hz) with open eyes. Low-anxious EG also showed a significant decrease in alpha band (11–13 Hz) with closed eyes and a significant increase in absolute and relative power in alpha band (8–9.5 Hz). In addition, the group showed a significant reduction in relative power in a low-frequency theta band (4–5.5 Hz).

Table 3
Statistical analysis of comparison of electrophysiological indicators before and after completing the self-reflection task (low-anxious group)

		BEFORE		AFTER		p	Cohen's d
		median	SD	median	SD		
EG	Absolute alpha power (8-9.5 Hz), eyes closed	17.45	19.31	24.26	27.43	0.014	-0.6**
	Relative alpha power (8-9.5 Hz), eyes closed	15.65	12.15	18.62	15.77	0.035	-0.52**
	Relative alpha power (11-13 Hz), eyes closed	17.38	16.12	15.88	15.96	0.046	0.5*
	Relative theta power (4-5.5 Hz), eyes closed	11.37	7.32	8.51	4.24	0.029	0.54*
CG	Absolute alpha power (11-13 Hz), eyes open	8.44	10.20	6.20	6.86	0.006	0.59**

Note. *EG – experimental group, CG – control group, BEFORE – EEG recordings before completing the task, AFTER – EEG recordings after completing the task. * p < .05, ** p < .01, *** p < .001*

Discussion

We initially assumed that the control group – CG (with high and low levels of anxiety) – performing a relatively standard cognitive load would show EEG dynamics close to cognitive fatigue (CF). CF is usually characterized by an increase in power in alpha and theta bands (Polikanova & Leonov, 2016). The dynamics of electrophysiological parameters in CG with a high level of anxiety generally correspond to the literature data. Particularly we observed an increase in power in all alpha sub-bands except for a high-frequency band (11–13 Hz), and also an increase in power in a high-frequency theta band (7–8 Hz) (Aftanas & Golocheikine, 2001; Aftanas et al., 2001; Asada et al., 1999). At the same time, a decrease in power was observed in a low-frequency theta band. Lower values in theta band indicate worse memory processes (Klimesch et al., 1999). There are also suggestions that a decrease in power in theta band correlates with cognitive aging (Cummins & Finnigan, 2007).

In the high-anxious experimental group, much less shifts in the EEG were observed after the self-reflection task was completed, indicating that this process is first and foremost significantly less associated with the development of cognitive fatigue. In addition, the increase in power in a low-frequency alpha band (8–9.5 Hz) during the self-reflection process (in our case, the completion of the self-reflection task) or self-reference as one of the manifestations of self-reflection indicates that the attention processes are more involved (Doppelmayr et al., 2002).

In low-anxious groups, the results showed other patterns.

The low-anxious EG showed greater changes in the EEG after the completion of the ISRR technique, partly overlapping with the results of the CG (although this pattern is observed only with open eyes in the CG), namely, a decrease in power in high-frequency alpha band (11–13 Hz).

Literature data show that spectral power in the upper alpha band (10.5–13 Hz) contains information about where attention is turned – outwards or inwards (Doppelmayr et al., 2008; Klimesch, 2012). This alpha band identifies internal and external attention (Salvador et al., 2020). In particular, it is known that when a person watches an external object carefully, his high-frequency alpha power decreases; α-blockade is observed (Benedek et al., 2014; Klimesch, 2012; Ray & Cole, 1985). There is evidence that α-blockade is observed in various tasks requiring external attention, such as sentence processing (Bastiaansen et al., 2002; Bastiaansen, Hagoort, 2006) and social tasks such as observing other people's behavior (Perry et al., 2011; Salvador et al., 2020).

An increase in power in a low-frequency alpha band indicates the involvement of attention processes in self-reflection. A decrease in power in a high-frequency theta band may indicate the reciprocal nature of the relationship between alpha and theta rhythms previously described during cognitive load (Klimesch, 1999).

Conclusion

Therefore, our research shows that after completing the self-reflection task (in our case, the ISRR technique), the level of anxiety has a significant impact on the dynamics of electrophysiological parameters. Low anxiety is mainly associated with a lower development of cognitive fatigue; the low-anxious control group showed minimal changes in EEG. After completing the self-reflection task, the low-anxious group (group 1) showed EEG shifts that characterize the external rather than internal attention process (reduction in high-frequency alpha power (11–13 Hz) and reduction in low-frequency alpha power (8–9.5 Hz), reduction in high-frequency theta activity (7–8 Hz). This is due to the fact that the tasks of the ISRR technique were completed in writing and involved decentration. These results are consistent with previous results (Sizikova, Leonov, Polikanova, 2024).

High levels of anxiety are associated with more significant EEG changes associated with cognitive fatigue in the context of cognitive load (group 4). Implementing the ISRR technique (even in high levels of anxiety) significantly reduces the development of cognitive fatigue. The main shifts are associated with an increase in low-frequency alpha power associated with the attention process.

It is clear that our hypothesis has been confirmed that, depending on the level of anxiety, self-reflection has different effects on the dynamics of brain electrophysiological activity. Furthermore, positive self-reflection has a significant therapeutic value in reducing the level of anxiety due to the activation of the DMN – a brain network characterized by the absence of a coherent activation in people with high levels of anxiety.

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Received: May 22, 2024
Revised: August 12, 2024
Accepted: August 19, 2024

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Conflict of Interest Information

The authors have no conflicts of interest to declare.