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NEUROPHYSIOLOGOCAL AND COGNITIVE MECHANISMS UNDERLYING LEARNING BIASES IN TRAIT ANXIETY AND BIPOLAR AFFECTIVE DISORDER

Thesis Summary for the Purpose
of Obtaining the Academic Degree
of Doctor of Philosophy in Cognitive Sciences

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Table of Contents

General Characteristics of the Study

Relevance of the Research

Mental disorders represent one of the most significant challenges in modern healthcare. According to the World Health Organization, in 2019, one in eight people suffered from a mental disorder, totaling 970 million individuals. The lifespan of a person with a mental disorder is, on average, reduced by 10 to 20 years[1].

At the same time, global healthcare lacks sufficient capabilities for diagnosing mental disorders. Currently, there are no highly reliable diagnostic methods, except for a psychiatrist's observation and interaction with the patient, which can lead to potential errors due to the human factor and, in general, lacks sufficient accuracy. To optimize psychiatric diagnosis, diagnostic guidelines such as the Diagnostic and Statistical Manual of Mental Disorders (DSM) [2] and the International Classification of Diseases, 11th Revision (ICD-11) [3] have been developed. They contain information on the diagnostic criteria for mental disorders and their interpretation in practice. However, psychiatric diagnosis still relies exclusively on the psychiatrist's subjective assessment of the patient's condition, even when based on diagnostic criteria.

Moreover, treatment options for mental disorders are often selected empirically, as the same medications may improve the condition of some patients while having no effect on others with the same disorder. As a result, the selection of psychiatric medications is highly individualized. In many cases, multiple medications need to be tried before the patient experiences improvement, which can negatively impact their motivation to continue treatment [4].

Psychotherapy is a widely popular treatment method for mental disorders today and has proven effective for several conditions. However, disorders such as schizophrenia or bipolar disorder cannot be managed solely through psychotherapy. Additionally, there are many different approaches to psychotherapy, and the choice of treatment largely depends on the therapist's experience and personality [5].

Our study focuses on conditions such as bipolar affective disorder and high trait anxiety. Bipolar affective disorder is a mood disorder characterized by alternating periods of mania and depression, interspersed with episodes of euthymia [6]. High trait anxiety, while not a standalone mental disorder, often serves as a foundation for the development of anxiety disorders and can reduce a person's quality of life [7,8].

As of 2019, approximately one in 150 adults (40 million people, or 0.53% of the global population) suffered from bipolar disorder [9], whereas anxiety disorders are the most common type of mental disorders worldwide; in 2019, 301 million people suffered from them. [10].

Computational psychiatry is a new field of neuroscience aimed at addressing the problems described above [5]. Computational psychiatry involves the application of computational modeling and theoretical approaches to psychiatric questions. Over the past decades, many mathematical and statistical methods applicable to the study of mental disorders have been developed. Additionally, significant advancements have been made in neuroimaging techniques, which have propelled neuroscience forward as a whole, as well as computational and neuropsychiatry in particular.

Computational psychiatry aims to understand how and why information processing in the nervous system becomes disrupted, leading to a range of psychopathological conditions and behaviors. Its goal is to elucidate the mechanisms underlying these dysfunctions, as well as to classify, predict, and treat them [5].

In light of the above, conducting research in the field of computational and neuropsychiatry is highly relevant. Neuropsychiatric studies have the potential to shed light on the mechanisms underlying the development and functioning of psychiatric disorders, and understanding these mechanisms will contribute to more effective methods of diagnosis and treatment.

Our study falls within the domain of computational psychiatry, as we employ computational modeling of cognitive processes, applying these methods to our behavioral and neuroimaging data. Thus, our research is of great significance, as it is aimed at uncovering the mechanisms of mental disorders to ultimately improve their diagnosis and treatment.

Object and Subject of the Study

The object of our study is the cognitive and neurophysiological processes underlying learning impairments in bipolar affective disorder during remission and high trait anxiety.

The subject of the study includes the neurophysiological and cognitive mechanisms associated with learning impairments, as reflected in magnetoencephalography (MEG) and behavioral data, and characterized using the Hierarchical Gaussian Filter (HGF) modelling framework. [11,12].

Research Goals and Objectives

The goal of the present study is to investigate the cognitive and neurophysiological mechanisms underlying learning impairments in trait anxiety and bipolar affective disorder (BD), using MEG and computational modeling based on the HGF, as well as to develop and test an experimental task with musical reinforcement for its further application in psychiatric research.

Research objectives:

1. To conduct a literature review on current theoretical approaches to studying impairments in probabilistic learning in trait anxiety and BD, as well as the use of MEG and computational modeling (including HGF) for analyzing these processes.
2. To design and modify probabilistic learning tasks that are sensitive to HGF parameters, including versions with a motor component and musical reinforcement.
3. To conduct behavioral and neurophysiological studies involving:

- healthy participants with varying levels of trait anxiety (high and low);
- patients with BD in a state of remission and a matched control group;
- healthy participants in conditions comparing monetary and musical reward.

4. To record and preprocess MEG data, including filtering, artifact removal, rejection of bad channels, and other steps.

5. To analyze MEG data using the MNE-Python software package, methods of functional connectivity, and statistical analysis.
6. To perform computational modeling of behavioral data using HGF and statistical methods to assess learning parameters and their relationship to anxiety levels and psychiatric symptoms.
7. To interpret the obtained behavioral and neurophysiological results, present them at scientific conferences, and prepare them for publication in peer-reviewed journals.

Research Methods

In this study, three experiments were conducted: two neuroimaging experiments using MEG and one behavioral experiment. Each of the three experiments involved a probabilistic reinforcement learning task. All experiments were approved by the Commission for University Surveys and Ethical Evaluation of Empirical Research Projects at the National Research University Higher School of Economics. The study involving the clinical group of individuals with bipolar affective disorder was also approved by the Local Ethics Committee at the Sechenov First Moscow State Medical University, Ministry of Health of Russia.

Neuroimaging methods

In the aforementioned experiments, MEG was used to record neurophysiological activity. MEG is a non-invasive method of recording the magnetic activity of the brain based on the assessment of magnetic fields generated by the electrical activity of neurons. MEG recordings were performed using the Electa Neuromag VectorView system (306 channels, 102 magnetometers, 204 gradiometers), located at the Neurocognitive Research Center (MEG Center) of the Moscow State University of Psychology and Education.

In addition to MEG, electrocardiography (ECG) and electrooculography (EOG) were recorded to remove corresponding artifacts from the neural signal.

Behavioral tasks

All three experiments employed a similar probabilistic learning task, modified slightly across studies. Participants learned stimulus–outcome or action–outcome associations governed by changing probabilities, with outcomes being monetary (in all tasks) and, in the third experiment, musical (consonance/dissonance). For instance, one stimulus might yield a reward 70% of the time and another 30%, with these probabilities changing across trials to create environmental volatility—a key experimental feature that allowed us to assess how participants estimated and adapted to such volatility.

The first and second experiments included 320 trials each, as participants performed the tasks during MEG acquisition, requiring more trials for robust analysis. In contrast, the third experiment involved 80 trials per condition (monetary and musical), with longer trial durations (over 10 seconds) and a within-subject design assessed across two sessions one week apart.

Scientific Novelty

The scientific novelty of this study lies in the following aspects:

1. Application of computational modeling using the HGF method for analyzing cognitive processes and belief updating mechanisms in patients with BD and individuals with high and low trait anxiety. This approach allowed for the identification of specific changes in model parameters, such as the assessment of estimates of environmental volatility (μ3) and informational uncertainty (σ2), which had not been previously studied in these populations.
2. Identification of specific neurophysiological correlates of HGF model parameters, particularly precision-weighted prediction errors (pwPE), in brain regions involved in decision-making under uncertainty. These results demonstrate that areas such as the anterior cingulate cortex and medial prefrontal cortex play a key role in prediction and adaptation processes in anxiety states and bipolar disorder.

3. Testing a new experimental paradigm with musical reinforcement, which for the first time showed that musical preferences (preference for consonant or dissonant endings) can modulate behavioral strategies and HGF model parameters. It was found that a higher consonance preference index is associated with greater stochasticity in behavior and faster belief updating ($\omega 2$) in the task with musical reinforcement.

Thus, this research makes a significant contribution to the development of neurocognitive models of learning, expands the understanding of adaptive behavior mechanisms in mental disorders, and offers new approaches to analyzing neurophysiological data using modern computational methods.

Theoretical Significance of the Study

This study contributes to the rapidly developing field of computational psychiatry, which integrates neuroimaging methods and computational modeling to study mental disorders. The main theoretical value of this work lies in uncovering new aspects of the cognitive and neurophysiological mechanisms underlying learning process disturbances in bipolar affective disorder during remission and in individuals with high trait anxiety.

The application of the HGF [11,12] as a behavioral learning model allowed for the identification of specific parameters reflecting the characteristics of cognitive processes in the aforementioned groups. In particular, it was shown that patients with bipolar disorder and participants with high trait anxiety exhibit:

1. Increased prior expectations of environmental volatility (parameter $\mu 3$ in the HGF model), indicating an overestimation of perceived environmental instability;

2. Altered neural representation of precision-weighted prediction errors (pwPE), indicating disruptions in the mechanisms of adaptive belief updating.

These findings are significant for theoretical neuroscience as they complement contemporary theories of predictive coding, which suggest that the process of learning and decision-making is based on weighing prediction errors in light of the precision of those predictions. Frequency-specific neurophysiological markers of such disturbances were demonstrated for the first time, expressed in a reduction of gamma activity (30 – 100 Hz) and an increase in alpha (8-13 Hz) /beta (14 – 30 Hz) activity in the anterior cingulate cortex (ACC), medial prefrontal cortex (mPFC), and orbitofrontal cortex (OFC) in patients with bipolar disorder, and an increase in gamma activity during the encoding of prediction errors (500–1000 ms after feedback) in these regions in participants with high anxiety. These findings expand existing theoretical models of anxiety and affective disorders, linking them to disruptions in predictive coding mechanisms and cognitive control.

Additional theoretical significance lies in the validation of a new experimental paradigm in which participants' learning was accompanied by musical reinforcement. It was shown that learning from monetary and musical reinforcement was equivalent, supporting similar decision-making processes. However, preferences for consonant and dissonant musical endings were shown to modulate to some degree learning parameters and decision-making strategies. Specifically, participants with high tolerance for dissonance exhibited greater stochasticity in decision-making and faster belief updating. This result opens new avenues for exploring the role of aesthetic preferences in cognitive processes and emotional regulation. Using the obtained data, we can apply this experimental paradigm to study clinical groups, particularly patients with bipolar disorder.

Thus, this work expands existing knowledge on decision-making and learning mechanisms under uncertainty, complementing them with neurophysiological markers and computational model parameters. This is important for the development of both fundamental science and clinical psychiatry.

Practical Significance of the Study

The practical significance of this study lies in the potential application of the obtained results in the fields of diagnosis, prediction, and treatment of mental disorders. In particular, the identified neurophysiological and behavioral markers of learning disturbances in bipolar affective disorder and anxiety can be used as potential biomarkers for the objective assessment of anxiety levels and susceptibility to cognitive impairments.

It has been shown that increased prior expectations of volatility (μ3) and altered representation of prediction errors may serve as indicators of maladaptive learning in unstable environments. These parameters, derived from the HGF model, can be applied to monitor the dynamics of cognitive states in patients and assess the effectiveness of psychotherapeutic and pharmacological interventions. Furthermore, the developed experimental paradigm with musical reinforcement provides a new tool for assessing cognitive strategies related to learning and decision-making, which is especially relevant when studying affective disorders.

The obtained data also have practical value in the field of neurotherapy and cognitive training. Understanding how individual differences in volatility estimation and prediction error processing relate to anxiety and affective disorders may contribute to the creation of personalized cognitive correction programs. For example, training aimed at improving adaptive volatility estimation could be beneficial for patients with anxiety disorders and bipolar disorder.

Additionally, the results of the study may be useful in developing new approaches to psychotherapy, particularly within the framework of cognitive-behavioral therapy. Understanding how cognitive processes are disrupted in anxiety states and bipolar disorder will allow therapists to develop more targeted and effective strategies for correcting thought patterns and patient behavior.

Finally, the identified neurophysiological markers can be incorporated into neuroimaging protocols for refining the diagnosis of mental disorders. This is particularly valuable given the limited objectivity of existing diagnostic methods, which are primarily based on subjective psychiatric assessments.

Thus, the results obtained have high practical significance, opening up new opportunities for the diagnosis, treatment, and prevention of mental disorders such as bipolar disorder and anxiety states.

Author's Contribution to the Research

The author of this work made the following contribution to the conducted research:

Stage I (Experiment 1): conceptualization of the research, development of the experimental design, collection of behavioral and magnetoencephalographic data, analysis of part of the behavioral data, analysis of magnetoencephalographic data, participation in writing the article.

Stage II (Experiment 2): conceptualization of the research, development of the experimental design, collection of behavioral and magnetoencephalographic data, analysis of part of the behavioral data, analysis of magnetoencephalographic data, participation in writing the article.

Stage III (Experiment 3): conceptualization of the research, analysis of part of the behavioral data, participation in writing the article.

Statements to be Defended

1. The registration of MEG in participants with high and low levels of trait anxiety and the use of computational behavior models in decision-making tasks allowed us to identify behavioral and neural correlates of impaired biased belief updating in high-anxiety participants. Specifically, we showed that oscillatory activity in the medial prefrontal cortex (mPFC), anterior cingulate cortex (ACC), and orbitofrontal cortex (OFC) is associated with anxiety-induced changes in learning. During a probabilistic reinforcement learning task, high trait anxiety hindered learning due to an overestimation of environmental volatility, leading to accelerated belief updating, more stochastic decisions, and a pronounced tendency to shift strategy after a loss (lose-shift). At the neural level, we observed increased gamma activity in the ACC, dmPFC (dorsomedial prefrontal cortex), and OFC during the coding of precision-weighted prediction errors (pwPE) in high-anxiety participants, accompanied by suppression of alpha/beta activity in the ACC. Our results confirm the relationship between learning and belief updating impairments in anxiety and changes in gamma and alpha/beta activity in the ACC, dmPFC, and OFC.

2. The registration of MEG in patients with bipolar affective disorder and healthy participants, as well as the use of computational behavior models in decision-making tasks, allowed us to identify behavioral and neural correlates of impaired biased belief updating in bipolar disorder patients. Our study showed that bipolar disorder participants expect higher environmental volatility, leading to a more stochastic relationship between their beliefs and actions. This was accompanied by lower reward rates and a reduced tendency to repeat rewarded actions compared to healthy participants. We also found that bipolar disorder participants were slower in adjusting their expectations about the probabilistic relationships between actions and outcomes. At the neural level, while healthy participants showed suppression of alpha/beta activity and increased gamma activity during belief updating, these effects were attenuated in bipolar disorder participants and spread to the PFC, OFC, and ACC regions. These effects were accompanied by an abnormally increased flow of directed information in the beta range in bipolar disorder patients. Thus, the results suggest that patients with bipolar disorder in remission expect environmental changes without properly assimilating them, contributing to maladaptive belief updating.
3. We investigated how different types of rewards—money and music—affect decision-making and learning in environments with probabilistic variability. Using computational behavior modeling, we found that learning patterns were generally similar for both types of rewards, indicating comparable adaptability. However, in the music task, individual preferences for consonance influenced the dynamics of learning: participants more tolerant to dissonance showed more stochastic decision-making and overestimated volatility, while those who disliked dissonance demonstrated increased tonic volatility, leading to larger belief updating steps regarding reward trends. This experimental paradigm may be used in further clinical research, for example, with participants with bipolar

disorder. However, when expanding this paradigm to clinical samples, it should be considered that preferences for consonance can influence decision-making behavior.

Presentations of the Study and Publications

The main results of the study were presented at the following conferences:

1. **Forth International Conference Neurotechnologies and Neurointerfaces (CNN) (2022), Kaliningrad, Russia**
   Oral presentation. *Motor Learning and Decision Making in Volatile Environment in Bipolar Disorder.*
2. **Fifth International Conference Neurotechnologies and Neurointerfaces (CNN) (2023), Kaliningrad, Russia.**
   Poster presentation. *Decision Making, Belief Updating and Motor Performance in Bipolar Disorder: an MEG Study.*
3. **36th ECNP Congress (2023), online.** Poster presentation. *Decision making, belief updating and motor performance in bipolar disorder: an MEG study.*
4. **The 30th Jubilee International Annual ISBS "Stress and Behavior" Neuroscience and Biological Psychiatry Conference (2024), Erevan, Armenia.** Poster presentation. *Motor learning and belief updating in bipolar disorder*.

The results of the study were published in the following journals:

1. **Ivanova M.,** Germanova K., Petelin D., Ragymova A., Kopytin G., Volel B., Nikulin V., Herrojo Ruiz M. Frequency-specific changes in prefrontal activity associated with maladaptive belief updating in volatile environments in euthymic bipolar disorder // **Translational Psychiatry**. 2025. Vol. 15, № 1. P. 13. (Q1, List A)
2. Kopytin G., **Ivanova M.,** Herrojo Ruiz M., Shestakova A. Evaluating the Influence of Musical and Monetary Rewards on

Decision Making through Computational Modelling // **Behavioral Sciences**. 2024. Vol. 14, № 2. P. 124. (Q3, List C)

3. Hein T., Gong Z., **Ivanova M.,** Fedele T., Nikulin V., Herrojo Ruiz M. Anterior cingulate and medial prefrontal cortex oscillations underlie learning alterations in trait anxiety in humans // **Communications Biology**. 2023. Vol. 6, № 1. P. 271. (Q1, List A)

Content of the Study

Introduction

The **Introduction** justifies the relevance of the research conducted within the framework of this dissertation, formulates the objective, sets the tasks of the work, and presents the scientific novelty, theoretical, and practical significance of the presented work.

Chapter I

In the first chapter, we investigate participants with high and low trait anxiety using magnetoencephalography (MEG) and computational modeling with the Hierarchical Gaussian Filter (HGF) method [11,12].

The anxiety level of participants was assessed using the State-Trait Anxiety Inventory (STAI) by Spielberger [13]. Participants scoring 45 or higher were included in the high trait anxiety group (19 participants), and those scoring less than 35 were included in the low trait anxiety group (20 participants).

Participants performed a probabilistic reinforcement learning task in a volatile environment. In the task, participants were sequentially presented with two stimuli and asked to choose the one they believed would lead to a reward. The stimuli provided rewards with a certain probability. The volatile environment was created by changing the reward probability for the stimuli (blue/orange) every 26–38 trials (0.1/0.9, 0.3/0.7, 0.5/0.5). Behavioral data were analyzed using the HGF, where various model parameters characterizing the participant's learning were evaluated, primarily the estimates of environmental volatility (μ_3) and informational uncertainty (σ_2). During the task, participants were inside the MEG scanner, and their brain activity was recorded. Additionally, participants underwent structural magnetic resonance imaging (MRI) to combine MRI and MEG data. Neuroimaging data were analyzed in the following regions of interest: the anterior cingulate cortex (ACC), orbitofrontal cortex (OFC), and medial prefrontal cortex (mPFC).

Behavioral analysis results showed that participants with high trait anxiety scored lower during the experimental task than participants with low trait anxiety;

their performance was worse, particularly in the first block of the task. In the second block, the scores of participants in both groups were similar.

Neurophysiological activity analysis revealed that gamma activity (60–100 Hz) was enhanced in the anterior cingulate cortex, dorsomedial prefrontal cortex, and orbitofrontal cortex in participants with high trait anxiety during the processing of precision-weighted prediction errors between 1000 and 1600 ms after the outcome presentation. Stronger suppression of alpha and beta rhythms (10–16 Hz) was observed in the anterior cingulate cortex in participants with high trait anxiety during precision-weighted prediction error encoding, indicating an imbalance between descending predictions and ascending errors. Meanwhile, in the lateral orbitofrontal cortex, participants with high anxiety showed an increase in alpha and beta activity (10–22 Hz) during prediction error encoding. Furthermore, enhanced gamma activity in the anterior cingulate cortex correlated with higher precision-weighted prediction error values and more frequent decision shifts.

Our study showed that key brain regions associated with anxiety and decision-making exhibit changes in oscillatory activity, which may explain the behavioral and computational effects of anxiety within the Bayesian predictive coding model. We demonstrated that high trait anxiety impairs overall performance in reinforcement learning tasks, which was related to biased estimates of different forms of uncertainty. These changes were driven by overestimated environmental volatility, which aligns with previous data suggesting that anxious participants tend to overestimate volatility under any conditions. Participants with high trait anxiety, who showed higher estimates of volatility, also exhibited noisier decisions and a pronounced tendency to shift strategies after failure (lose-shift).

Chapter II

The second chapter is dedicated to the study of bipolar affective disorder in a euthymic (remission) state. We had two groups of participants: healthy individuals without any diagnosed psychiatric or neurological pathologies (27 people), and participants with bipolar disorder of both types without comorbid pathologies (22 people). Participants with bipolar disorder were selected with the help of psychiatrists from the First Moscow State Medical University (Sechenov University). The experimental task was similar to the one used in the first phase of the research (with anxiety), except that instead of pressing one button, participants had to press four buttons sequentially, thus learning a motor sequence.

As in the first phase, we used magnetoencephalography (MEG) to record neurophysiological data and Hierarchical Gaussian Filter (HGF) for modeling behavioral data.

Behavioral data analysis showed that bipolar disorder patients performed worse on the experimental task, scoring lower on average than healthy participants. Additionally, patients with bipolar disorder exhibited reduced win-stay behavior (meaning that if a stimulus wins, they are less likely to choose the same one again, which is maladaptive compared to healthy participants). Furthermore, bipolar disorder patients overestimated the volatility of the environment, which manifested in more stochastic decision-making and more frequent switching between stimuli.

Neurophysiological analysis revealed that during the encoding of prediction errors, weighted by precision (0.5–0.9 sec after outcome presentation), both healthy participants and bipolar disorder patients showed suppression of alpha and beta activity (8–30 Hz) in the prefrontal, orbitofrontal, cingulate, and motor cortices. This suppression was less pronounced in bipolar patients. Additionally, bipolar disorder patients exhibited less gamma activity (60–100 Hz) compared to healthy participants in the same time window and regions of the brain. Suppression of alpha and beta activity and enhancement of gamma activity in the literature is associated with encoding precision-weighted prediction errors, which suggests that such oscillatory changes may reflect altered processing of these prediction errors. Furthermore, we observed altered functional connectivity measures in bipolar patients compared to healthy participants. To assess functional connectivity, we used the time-reversed Granger causality (TRGC) method. Using TRGC to evaluate directed influences in frequency-domain activity, we found a more pronounced flow of directed activity in the beta range in bipolar patients compared to healthy controls. This flow was observed from the caudal part of the anterior cingulate cortex to the rostral part of the anterior cingulate cortex, as well as from the rostral middle frontal gyrus and superior frontal gyrus to the caudal part of the middle frontal gyrus during trials with large unsigned precision-weighted prediction error values. TRGC values increased in bipolar patients but decreased in healthy participants, which corresponds to findings from primate studies where causal relationships in the beta range in the prefrontal cortex decrease during unpredictable trials—a pattern indicative of normative responses [14].

Overall, our results highlight significant changes in belief updating in bipolar patients during the euthymic period while learning probabilistic associations based on rewards in a volatile environment. It is important to note that the identification of amplitude changes in frequency domains and functional connectivity underlying these computational maladaptations provides crucial insights for improving relapse prediction and monitoring treatment responses in future studies.

Chapter III

The third chapter is dedicated to the testing of a new paradigm – reinforcement learning with musical reinforcement. The study was conducted on healthy participants with the aim of expanding this paradigm to clinical samples. The essence of the study was the same as in the first and second phases: probabilistic reinforcement learning was conducted, but with two conditions: musical reinforcement and monetary reinforcement. The study was purely behavioral, without neuroimaging. For behavioral modeling, the same model as in the first and second phases was used – the Hierarchical Gaussian Filter (HGF).

The results of the study showed that musical reinforcement is as effective as monetary reinforcement in terms of reinforcement learning. Also, the parameters of the HGF model were comparable in both the musical and monetary reinforcement conditions. However, we found that individual music preferences influenced the learning outcomes. In particular, a lower preference for consonance over dissonance was associated with greater stochasticity in decision-making.

Conclusion

The Conclusion briefly summarizes the main scientific findings of the dissertation, its novelty and practical significance, and directions for future work.

This dissertation presents a comprehensive investigation of impaired learning in affective states within the framework of computational psychiatry. The work outlines a unified trajectory—from high trait anxiety as a subclinical feature, through bipolar disorder as a clinical condition, to the potential modulation of learning via affectively meaningful stimuli such as music. The methodological foundation of all studies is the model of probabilistic learning in a volatile environment (HGF); in the first two studies, magnetoencephalography (MEG) was additionally employed.

In the anxiety study, overestimation of environmental volatility, increased uncertainty, and greater behavioral stochasticity were observed. At the neurophysiological level, enhanced gamma-band activity and suppressed alpha/beta oscillations were found during the processing of precision-weighted prediction errors (pwPEs), indicating a disruption in the mechanism of their adaptive weighting.

In bipolar disorder, elevated prior expectations of volatility, slowed belief updating, weakened representation of pwPEs in the prefrontal cortex, and impaired functional connectivity were identified.

In the third study, musical and monetary reinforcement demonstrated comparable learning efficiency. Individual differences in sensitivity to dissonance influenced the HGF model parameters: high tolerance was associated with greater behavioral stochasticity, while low tolerance was linked to more pronounced belief updates.

Thus, the work demonstrates the applicability of computational modeling and magnetoencephalography for studying affective dysfunction and highlights the potential of using neurocognitive markers and musical stimulation in the diagnosis and treatment of affective disorders.

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