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MECHANISMS OF THE INFLUENCE OF ENVIRONMENTAL STRESS ON THE NERVOUS SYSTEM

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ABSTRACT

This review article examines the impact of environmental stress on the development of the nervous system from the perspective of modern interdisciplinary research. Key mechanisms of stress-induced effects on neurodevelopment are analyzed, as well as critical periods of ontogenesis characterized by increased vulnerability of the nervous system. Particular attention is paid to the role of socioeconomic status as a factor in cumulative stress load and the family environment as a risk modifier that can both amplify and mitigate the adverse effects of environmental exposures. It is shown that considering the interaction of biological, social, and family determinants is fundamental for assessing the risk of neurodevelopmental disorders and developing preventive strategies.

МЕХАНИЗМЫ ВЛИЯНИЯ ЭКОЛОГИЧЕСКОГО ПЕРЕНАПРЯЖЕНИЯ НА НЕРВНУЮ СИСТЕМУ

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ABSTRACT

В обзорной статье рассматривается влияние экологического стресса на развитие нервной системы с позиций современных междисциплинарных исследований. Проанализированы ключевые механизмы стресс-индуцированного воздействия на нейроразвитие, а также критические периоды онтогенеза, характеризующиеся повышенной уязвимостью нервной системы. Особое внимание уделено роли социоэкономического статуса как фактора кумулятивной стрессовой нагрузки и семейной среды как модификатора риска, способного как усиливать, так и смягчать неблагоприятные эффекты экологических воздействий. Показано,

что учет взаимодействия биологических, социальных и семейных детерминант имеет принципиальное значение для оценки риска нарушений нейроразвития и разработки профилактических стратегий.

Introduction. Environmental stress is considered a significant risk factor for neurodevelopmental disorders, particularly during periods of high sensitivity in early ontogenesis. Current research shows that chronic exposure to adverse environmental factors is associated with changes in cognitive, emotional, and behavioral development, leading to long-term health consequences [1,2]. The severity and direction of the impact of environmental stress are largely determined by the social context of a child's development. Low socioeconomic status and unfavorable living conditions increase the cumulative stress load, while a supportive family environment can partially offset the negative impact of environmental factors [3,4]. In this regard, family and social conditions are considered key modifiers of the risk of neurodevelopmental disorders.

Despite a significant number of studies, data on the interactions between environmental stress, family environment, and socioeconomic status remain scattered and require systematization. The aim of this review article is to analyze the influence of environmental stress on the development of the nervous system, with an emphasis on the role of the family environment and socioeconomic status. Exposures and critical periods of neurodevelopment. The impact of environmental and psychosocial stress is cumulative and is most significant during periods of heightened sensitivity of the developing nervous system. Environmental stressors, including unfavorable living conditions and anthropogenic loads, create persistent strain on adaptive mechanisms, influencing psychoneurological status and quality of life [12]. The prenatal period is the first critical stage during which stressful influences from the external and social environment can program the functional reactivity of the nervous system. Early stress is associated with long-term changes in neuroendocrine regulation and increased vulnerability to adverse factors in subsequent periods of development, as supported by experimental and clinical data [9,11,14].

The next "window of vulnerability" occurs in early childhood and is associated with the high plasticity of the nervous system. An unfavorable socioeconomic context and a lack of a supportive family environment are associated with characteristics of the development of cognitive and emotional functions, as well as with changes in the neural correlates of brain development [15,7,1]. Adolescence is characterized by a repeated increase in sensitivity to stressful influences against the background of neurobiological restructuring and the formation of self-regulation mechanisms. Chronic technogenic and

social stress at this age is accompanied by a decrease in adaptive resources and an increase in psychoemotional stress, which is reflected in domestic and international studies [3,5,8]. The prenatal stage, early childhood, and adolescence represent key windows of vulnerability, during which the cumulative impact of environmental stress can have the most pronounced impact on the development of the nervous system.

Environmental Stress and the Development of the Nervous System. The impact of environmental and psychosocial stress on the nervous system is realized through the activation of stress-mediating and immune mechanisms, leading to persistent changes in neuroendocrine regulation. Chronic stress is accompanied by strain on adaptive systems and a decrease in stress resistance, which increases the vulnerability of the central nervous system, especially during periods of active development [2]. A key link in the stress response is the hypothalamic-pituitary-adrenal axis, the prolonged activation of which leads to an imbalance of stress hormones and impaired neural plasticity. Coffman et al. (2022) demonstrated that early stress can program the reactivity of the nervous and immune systems, creating persistent changes in regulatory mechanisms [14]. Inflammatory reactions are considered a mediator of the damaging effects of chronic stress on nervous tissue.

The long-term nature of stress-induced changes is largely due to epigenetic mechanisms. Ortega et al. (2021) emphasize that early life stress is associated with changes in the expression of genes involved in the regulation of stress response and neural development [16].

The functional consequences of these mechanisms are manifested primarily in the area of cognitive and emotional development. According to Olson et al. (2021), adverse socioeconomic conditions are associated with features of the formation of neural networks involved in the regulation of emotions and executive functions [10, 13, 15]. Tian et al. (2021) showed that stress hormonal responses mediate the impact of social adversity on the development of amygdala-prefrontal connections in children [17]. The main mechanisms of environmental stress and their functional effects are summarized in Table **1.**

1. Key mechanisms of the influence of environmental stress on the nervous system

Mechanism	Main link	Functional consequences
Stress system	HPA axis	Impaired self-regulation
Inflammation Immune	activation Increased	vulnerability of the central nervous system
Neuroendocrine effects	Hormonal imbalance	Decreased neuroplasticity
Epigenetic changes	Regulation of gene expression	Long-term effects
Neural networks	Functional reorganization	Cognitive and emotional impairment

Family and Socioeconomic Status as Risk Modifiers of Neurodevelopmental Disorders. Family socioeconomic status is a significant background factor determining

the cumulative stress load on the developing nervous system. Low material and educational resources are associated with chronic exposure to unfavorable environmental conditions and a decrease in the adaptive potential of children and adolescents, as demonstrated in the studies of Zeveleva and Kokunov (2024), as well as in the systematic review by Olson et al. (2021) [1,15]. The cumulative impact of an unfavorable socioeconomic context is realized through increased stress reactivity and impaired mechanisms for regulating emotions and behavior. Tian et al. (2021) demonstrated that socioeconomic disadvantage mediates its impact on neurodevelopment through stress hormonal reactions and changes in functional neural connections [17]. Similar provisions are reflected in Russian studies considering social conditions as a factor enhancing the impact of environmental stress [12].

Family environment, unlike socioeconomic status, performs a modifying function and can act as both a risk and a protective factor. An unstable emotional climate and maladaptive parenting styles are associated with impaired development of self-regulation mechanisms and emotional resilience in children, as demonstrated by Menshikova et al. [7]. At the same time, a supportive and predictable family environment helps reduce chronic stress and increase adaptive resources, even in the presence of an unfavorable socioeconomic background [2,6]. Socioeconomic status shapes the level of baseline stress, while family environment determines the individual's sensitivity to environmental stress and the trajectory of neurodevelopment.

Conclusion. The impact of environmental stress on the development of the nervous system is cumulative and is most significant during critical periods of neurodevelopment. Socioeconomic status determines the level of background stress, while family environment is a key factor modifying the risk of adverse neurodevelopmental outcomes. Taking into account the interaction of environmental, family and social factors is a prerequisite for an objective risk assessment and the development of preventive measures.

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