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Hypoxia and Psychology: Impact, Mechanisms, and Interventions

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Abstract

With the development of the central and western regions and population migration, the impact of high altitude hypoxia on mental health has become increasingly prominent. This article systematically reviews the effects of hypoxia on mood and sleep, as well as the moderating role of individual differences on high altitude mental health. It explores the impairment of psychological function through physiological mechanisms such as neurotransmitter disorders, HPA axis and SAM axis imbalances, and proposes comprehensive intervention strategies from multiple perspectives, including oxygen therapy, medication, psychological training, and exercise intervention. The aim is to provide theoretical basis and practical guidance for maintaining mental health among individuals living in high altitude areas.

Keywords

Hypoxia, emotion, sleep, mental health, stress, psychological intervention

1. Introduction

With the implementation of the Western Development Initiative and the new round of industrial transfer strategy to the central and western regions, an increasing number of people have migrated from low-altitude areas to high-altitude areas. As of 2010, approximately 12 million people had been residing permanently on the Tibetan Plateau, with the majority living in high-altitude areas above 3,500 meters. In addition to residents who have long lived on the Tibetan Plateau, there are also a large number of armed police officers, rescue forces, civil servants, college students, and tourists who travel to the region from inland areas. However, the high-altitude environment poses severe challenges to physical and mental health. Studies have shown that the increase in altitude leads to a decrease in partial pressure of oxygen in the air, causing insufficient oxygen supply to the body and resulting in a series of physiological diseases, such as chronic mountain sickness, pulmonary hypertension, and high-altitude heart disease. At the same time, it significantly affects cognitive function and mental health (Su, Jia, Zhang, Wang, Li, Zhang, Ma, & Su, 2024), mainly manifesting as decreased work and study efficiency, increased sleep and emotional issues. Hypoxia, as a psychological stressor, is a major factor that damages human mental health. Research has shown that hypoxia has a significant impact on breathing, diet, and sleep, and physical discomfort can exacerbate people's psychological burden, leading to a decline in mental health levels. Severe psychological problems can lead to suicide or self-mutilation behaviors. Therefore, safeguarding and improving the physical and mental health of plateau residents has become a major national demand, and strengthening efforts to improve the physical and mental health of plateau residents has risen to a national strategic level.

Although existing research has revealed the effects of hypoxia on the body and cognition, systematic answers to the three core questions of "what characteristic psychological changes hypoxia brings about," "how these changes occur," and "how we can effectively intervene" still need to be refined. Therefore, this article intends to focus on the following three research questions:

(1) What characteristic psychological changes does hypoxia bring about?

(2) How did these changes occur?

(3) How can we intervene effectively?

2. Characteristic Psychological Changes Brought about by Hypoxia

2.1 Emotional Changes

Hypoxia can lead to changes in mood. Studies have found that as altitude increases, mental health levels exhibit fluctuating trends, with a more pronounced bipolar expression of emotions and a significant rise in depression levels. Research has revealed a significant correlation between SCL-90 symptom scores and the severity of acute mountain sickness in patients. The more severe the acute mountain sickness, the higher the SCL-90 symptom scores, indicating that hypoxia not only damages mental health but also physical health, with the two influencing each other. Recent studies, consistent with previous findings, have shown that anxiety, depression, and other negative emotions are prevalent among individuals exposed to high altitude hypoxia for extended periods. These negative emotions intensify and positive emotions decline as the duration of high altitude exposure increases. Factors such as somatization, obsessive-compulsive disorder, interpersonal relationships, depression, and paranoid ideation have a strong correlation with the duration of high altitude exposure, aligning with previous survey results. The mental health levels of cadres assisting in Tibet decline as their time in Tibet increases, with an increase in the number of individuals exhibiting obsessive-compulsive disorder and depression, as well as significant manifestations of somatization and paranoid ideation. In summary, hypoxia can lead to an increase in negative emotions, thereby affecting mental health.

2.2 Sleep Disorders

Sleep quality is a crucial factor affecting mental health. The decline in sleep quality among individuals residing in high-altitude areas poses a significant threat to the physical and mental well-being of these migrants. The primary factor leading to this decline in sleep quality is hypoxia in the high-altitude environment. Mental health and sleep quality mutually influence each other. On one hand, changes in natural environment and social roles, coupled with physiological discomfort caused by hypoxia, have a profound impact on the psychology of aid workers in Tibet, leading to a decline in sleep quality and generating negative emotions such as anxiety or depression. On the other hand, negative emotions exacerbate physical discomfort, aggravating sleep disorders. Furthermore, sleep duration can affect sustained attention and responsiveness, thereby impacting the cognitive function of aid workers to varying degrees. Recent studies have revealed the cumulative effect of sleep quality over time in hypoxic high-altitude environments. As the duration of residence in the highlands increases, there is a trend towards improved sleep quality. However, in general, hypoxic high-altitude environments can lead to a decline in individual sleep quality, subsequently affecting mental health.

2.3 The Moderating Effect of Individual Differences

Personality, as a complex individual psychological trait, is shaped through social practice on the basis of genetics, forming relatively stable psychological characteristics. It influences cognitive styles, emotional tendencies, and behavioral patterns at different times and under various circumstances, determining an individual's psychological regulation ability and thus affecting their mental health. A well-developed personality serves a protective function for mental health and can alleviate the impact of negative events on one's inner self. For individuals newly arriving at high altitudes, neuroticism and psychoticism in their personality, as well as their subjective cognitive level towards physical symptoms caused by high altitude hypoxia, and the high altitude hypoxic environment are the main factors affecting their mental health. Early research has found that the score on the N scale of the Eysenck Personality Questionnaire in the acute severe high altitude reaction group is significantly higher than that in the acute mild high altitude reaction group, with individuals with more unstable emotions experiencing more severe high altitude reactions. Conversely, individuals with lower scores in the psychoticism and neuroticism factors exhibit personality traits such as emotional stability, strong adaptability to the environment, harmonious interpersonal relationships, a high degree of socialization, and less psychological states of tension and anxiety.

3. Physiological Mechanisms of Hypoxia Affecting Psychology

The hypoxic environment of the plateau affects central nervous system function through multiple complex physiological pathways, subsequently leading to changes in mood, cognition, and behavior. The mechanisms primarily fall into three categories: neurobiochemical disorders, endocrine and immune imbalances, and structural alterations in the central nervous system.

3.1 Neurobiochemical Mechanism

Dysregulation of the monoamine neurotransmitter system is one of the core mechanisms.

According to the monoamine hypothesis of depression, the deficiency of neurotransmitters (such as dopamine, serotonin, and norepinephrine) in the brain is a key factor leading to emotional disorders.

Serotonin, as an important "emotional neurotransmitter," is closely related to happiness and regulates sleep patterns and intestinal function. Hypoxia may inhibit the production of serotonin in the brain, and its reduced levels are closely associated with depressive symptoms. Furthermore, harsh natural conditions in high-altitude areas (such as feelings of isolation, strong ultraviolet radiation, cold and dry weather) can themselves induce unpleasant emotional states. These factors may collectively inhibit neurogenesis in the hippocampus, reduce the bioavailability of serotonin, disrupt circadian rhythms, and decrease melatonin secretion. It is noteworthy that in both animal and human studies, abnormal melatonin secretion has been linked to the occurrence of depression.

3.2 Endocrine and Immune Mechanisms

Hyperthyroidism-Pituitary-Adrenal-Testicular (HPA) axis overactivation: Chronic psychological stress and hypoxia, as stressors, can lead to sustained activation of the HPA axis. Patients exhibit elevated levels of corticotropin-releasing hormone and corticotropin (Holsboer, 2003), increased levels of glucocorticoids such as cortisol, enlarged adrenal glands, and enhanced pituitary activity (Pariante & Lightman, 2008). Chronic psychological stress can impair the control of glucocorticoid secretion by the HPA axis, potentially leading to elevated cortisol levels. High cortisol levels are also characteristic of depression, and it has been reported that they are resistant to the normal negative feedback regulation of glucocorticoids by the HPA axis (Carroll, Martin, & Davies, 1968).

Immuno-inflammatory response: Glucocorticoid resistance further modulates the immune system, inducing a pro-inflammatory state (Silverman & Sternberg, 2012). Elevated glucocorticoid levels may have neurotoxic effects, particularly in brain regions closely associated with anxiety and depressive disorders, such as the hippocampus (Sapolsky, 1996). Correspondingly, reports indicate that patients with long-term depressive disorders exhibit reduced hippocampal volume (Sapolsky, 1996).

Sympathetic nervous system: Regarding the sympathetic adrenal medulla (SAM) system, there is evidence suggesting that chronic stress may lead to enhanced expression of norepinephrine. When the HPA axis and SAM axis are already imbalanced due to stress, the addition of hypoxia as an additional stressor may further weaken the body's adaptability by exacerbating norepinephrine, cortisol levels, and inflammatory responses. It is worth noting that there is a bidirectional regulatory relationship between glucocorticoids and the hypoxia-inducible factor (HIF) signaling pathway, and this interaction may interfere with HIF-mediated physiological adaptation mechanisms at high altitudes (such as respiratory regulation (Moya, Go, Kim, Fu, Simonson, & Powell, 2020), metabolic adaptation (Seagroves, Ryan, Lu, Wouters, Knapp, Thibault, Laderoute, & Johnson, 2001), etc.).

3.3 Structural Changes in the Central Nervous System

Long-term or severe hypoxic exposure can cause substantial structural damage to the central nervous system, and these changes are typically irreversible, forming the pathological basis for psychological dysfunction.

Hippocampal damage: The hippocampus is one of the brain regions most sensitive to hypoxia and glucocorticoids. As mentioned earlier, long-term elevated levels of cortisol and inflammatory factors have toxic effects on hippocampal neurons, leading to reduced neurogenesis, neuronal atrophy, and even death, ultimately manifesting as a decrease in hippocampal volume (Sapolsky, 1996). The reduction in hippocampal volume is closely related to long-term depressive disorders and directly affects memory function and emotional regulation.

Prefrontal cortex and limbic system: In addition to the hippocampus, the regulation of stress response also involves a complex neural network including the amygdala and prefrontal cortex (Godoy, Rossignoli, Delfino-Pereira, Garcia-Cairasco, & de Lima Umeoka, 2018). The amygdala is a key structure for processing emotions and fear, and its excessive activation is associated with the pathogenesis of anxiety disorders. The function of the prefrontal cortex (especially the dorsolateral and anterior limbic regions), which is responsible for higher cognitive functions and emotional regulation, may be impaired under chronic stress and hypoxia, leading to weakened regulatory ability towards lower emotional brain regions such as the amygdala, and thus resulting in symptoms such as emotional dysregulation and decreased executive function.

Cerebrovascular and Microcirculatory Disorders: The longer the exposure to high altitude hypoxia, the more red blood cells the body compensates with, leading to increased blood viscosity. This can easily cause microcirculatory disorders and thrombosis, thereby exacerbating ischemia and hypoxia of brain cells and body tissues, forming a vicious cycle and aggravating brain function impairment from a vascular perspective. Furthermore, the decrease in oxygen partial pressure increases the excitability of the central nervous system, resulting in reduced sleep quality, and long-term insomnia may exacerbate depressive symptoms.

4. Intervention Strategies: From Physiological Support to Psychological Empowerment

Mental health is of utmost importance for individuals living in high-altitude areas. Studies have revealed significant differences in mental health and suicide-related characteristics between suicide victims in high-altitude regions and those in low-altitude regions (Reno, Brown, Betz, Allen, Hoffecker, Reitinger, Roach, & Honigman, 2018). To mitigate the promoting role of psychological factors in the occurrence and progression of high-altitude diseases and suicide, it is crucial to regulate the mental health levels of individuals entering high-altitude areas, reduce the impact of external environments on their psychological state, and improve adverse psychological stress. Effective intervention measures have been proposed to address the mental health issues of individuals living in hypoxic environments at high altitudes.

4.1 Physiological Basis Intervention

Oxygen therapy. Oxygen therapy is the most effective and intuitive therapeutic intervention for acute high altitude reaction, which can rapidly alleviate symptoms and stabilize emotions. Different oxygen therapy methods have varying effects. Higher concentrations of oxygen therapy are more helpful in improving symptoms and signs related to high altitude reaction, but excessive oxygen use can have certain adverse effects on the body's internal environment, leading to oxygen toxicity. Therefore, it is generally recommended to use oxygen with a concentration of 50% or below. However, for patients with relatively prominent high altitude reaction, the therapeutic effect still needs to be further improved. High-concentration oxygen therapy has good efficacy in treating acute high altitude reaction, significantly improving patients' cerebral blood flow status and effectively alleviating symptoms and signs of acute high altitude reaction.

Medication administration. Rhodiola contains active ingredients such as salidroside and salidrophenol, which exhibit multiple effects including antioxidant, anti-fatigue, anti-altitude sickness, and immune enhancement. Its anti-hypoxia, nervous system regulation, and cognitive function improvement have been verified by multiple clinical studies. Therefore, to prevent or urgently treat altitude sickness, it is advisable to prepare medications such as Rhodiola and Plateau An in advance. In case of altitude sickness, different treatment methods should be selected based on the symptoms and severity of the condition. For patients primarily experiencing headache, ibuprofen or acetaminophen can be taken to alleviate symptoms; for those primarily experiencing sleep disturbances, temporary administration of hypnotics may be considered. By administering medications that help alleviate altitude symptoms, one can indirectly improve individual psychological states.

Stepwise acclimatization. Stepwise acclimatization is an effective method to reduce the incidence of acute high altitude reactions. Studies have shown that by reasonably setting the process of entering the plateau, gradually and slowly ascending to the plateau, the psychological stress level of individuals entering the plateau can be effectively reduced. Using a low-pressure chamber on the plain to simulate the plateau environment for adaptive training, allowing individuals to experience the plateau environment in advance, can also increase their adaptability to the plateau environment and reduce the psychological stress level caused by the plateau environment after entering the plateau.

4.2 Psychological Intervention

Positive psychology-oriented group psychological training. This training, grounded in the theoretical frameworks of positive psychology and group dynamics, facilitates group members to enhance positive emotions, positive cognition, and positive personality through interpersonal interactions within the group. It aims to bolster their character strengths and developmental potential, and has been widely applied in various fields of psychological counseling. It represents an economical and effective approach. By designing group intervention programs related to the emotional distress and developmental themes of individuals living in high altitude areas, participants, under the guidance of the lead trainer, share their feelings, experiences, and insights within the group. Through methods such as emotional catharsis, hope infusion, rationalization, and focus shifting, negative emotions are alleviated. The group leader guides group members to leverage their own strengths and resources to find solutions to difficulties, fostering the development of diverse coping strategies, thereby enabling them to respond to various challenges with greater flexibility and resilience.

Mindfulness training. As an effective psychological intervention strategy, mindfulness training has been widely proven to enhance individuals' self-awareness ability, assist individuals in better managing stress and emotions, significantly improve sleep quality, and enhance mental health levels. Research on the impact of self-compassion intervention combined with mindfulness-based cognitive therapy on patients with generalized anxiety disorder has found that this intervention can significantly improve patients' mindfulness thinking level, effectively enhance patients' self-compassion level, anxiety state, sleep quality, and quality of life. This result is highly consistent with previous studies, confirming that mindfulness training can improve sleep quality and have a positive effect on mental health.

Willpower training. Research has found that positive coping, strength, and resilience are negatively correlated with anxiety levels, while negative coping is positively correlated with anxiety levels. These three factors, namely positive coping, strength, and resilience, have a positive effect on resisting anxiety and depression. In terms of psychological training, willpower training can be added to enhance resilience and improve psychological function. Through such psychological training, individuals in high-altitude hypoxic environments can improve their mental health and reduce negative emotions such as anxiety and depression.

4.3 Exercise Intervention

Hypoxic exercise can promote beneficial physiological training adaptations and positive health-related outcomes. Following acute exposure to high altitude hypoxia, individuals exhibit a state of tension and anxiety, with a significant increase in hostility, fatigue, depression, and frustration. However, after undergoing intermittent hypoxic training, the aforementioned emotions are significantly alleviated in subjects following acute exposure to high altitude hypoxia. This training enhances the body's ability to tolerate hypoxia, effectively reduces symptoms of acute high altitude reactions, alleviates anxiety and depression caused by hypoxic exposure, improves sleep disorders induced by hypoxia, and mitigates the decline in executive control ability under hypoxia. Exercise intervention can alleviate psychological issues caused by hypoxia to a certain extent, thereby improving individuals' mental health status.

5. Summary

This article systematically expounds the extensive impacts of hypoxic environments on mental health, including emotional fluctuations, sleep disorders, and the regulatory role of individual differences, revealing the underlying neurobiochemical and endocrine mechanisms. Based on this, a comprehensive intervention strategy combining physiological support (such as oxygen therapy, medication), psychological training (such as mindfulness, group intervention), and exercise adaptation (such as intermittent hypoxic training) is proposed. Future research should further clarify the applicable populations and long-term effects of different intervention methods to enhance the psychological adaptability and quality of life of individuals living at high altitudes.

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