The effect of aerobic exercise on attentional functions and its physiological mechanism at high altitude

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Abstract: High altitude can negatively affect attentional functions, and whether exercise, as an effective means to improve attentional functions in the plain, can also be applied to high altitude has attracted attention from researchers. A large number of studies have shown that exercise at high altitude affects attentional functions, and the degree of influence is related to altitude level, task type, exercise intensity and individual differences. Neurotrophic factor theory and brain oxygenation theory have been used to explain the effect of exercise on attentional functions.

Keywords: Aerobic exercise; High altitude; Attentional functions; Moderator; Physiological mechanism

1.Introduction

With the development of economy, more and more people are going to the plateau for work, training and study. However, human brain and nervous system can be negatively affected by high altitude, leading to impairment of cognitive functions such as memory, attention, and cognitive control. In addition, attentional function is particularly sensitive to high altitude exposure. As a key factor guiding the allocation of cognitive resources in response to changing environmental demands, impairment of attentional functions may significantly reduce people's work efficiency. Therefore, finding a method that can counteract the negative effects of hypoxia on attentional function is of great theoretical and practical significance. In the plains, aerobic exercise has been shown to significantly improve human attentional functions and delay the decline of attention function with age. Currently, researchers have not reached a consistent conclusion on whether aerobic exercise can improve attentional functions at high altitude. A review with meta-analysis showed that aerobic exercise at high altitude improved attentional functions more than cognitive functions such as information processing1. However, a field study has shown that aerobic exercise at the intensity of 40-60% heart rate reserve impaired information processing speed and attentional functions. From the perspective of influencing factors, it may be related to experimental conditions, cognitive tasks, individual characteristics, exercise intensity. From the perspective of the mechanism of altitude exercise, it may be related to the changes of brain oxygenation and neurotrophic factors. Therefore, in this paper, we will start from the effects of exercise on attentional functions and its influencing factors, and summarize the previous literature. And on this basis, we will propose the potential mechanisms of aerobic exercise at high altitude on attentional functions. This paper will help to provide the basis for issuing "exercise prescription", and improve the plateau people's mental health level and quality of life.

2.The effect of aerobic exercise on attentional functions at high altitude

Attentional functions refer to the cognitive process of preparing and processing certain aspects of the external physical environment or subjective memory storage, and is an important psychological property that allows all mental processes to arise and proceed. Impaired attentional functions can directly affect the quality of daily life and the development of physical and mental health. Therefore, how to improve attention function has become the focus of researchers.

High altitude exposure can impair individual's attentional functions, while aerobic exercise can positively contribute to attentional function. Therefore, can aerobic exercise counteract the impairment of attentional functions caused by high altitude? Jung et al. used meta-analysis to investigate the effects of exercise in a low-oxygen environment on cognitive function, and the results of the study showed that aerobic exercise at high altitude had a stronger effect on the improvement of attentional function1. However, other studies have reached inconsistent conclusions. Shannon et al. required participants to perform aerobic exercise for 45 minutes at 35% VO2max after 150min exposure under simulated hypoxia conditions of 3000m and 4300m. The results of the study showed that the reaction time of the subjects in the rapid visual information processing task became longer both during and after the exercise, and the reaction time became further longer with the increase in altitude. The impairment of exercise at high altitude on attentional functions may only exist in acute altitude exposure, while for acclimatized lowlanders, aerobic exercise can improve attentional functions. A recent study conducted low -, moderate- and high-intensity aerobic exercise intervention on acclimatized lowlanders and found that regardless of the exercise intensity, aerobic exercise can significantly improve the attentional functions in acclimatized lowlanders2. The reason for the inconsistent results of the above studies may be the difference in cognitive tasks, with the latter using the Attentional Network Test capable of refining the three subnetworks of attentional function, which may be relatively more sensitive. Another reason may be altitude acclimation, individuals' cognitive function is not stable after entering the altitude environment. For example, Davranche et al. found that individuals' cognitive function was impaired in the first few hours after entering the high-altitude area, but this impairment disappeared after two days. Likewise, the physiology of the individual is altered upon entering to high altitude. Therefore, the effects of aerobic exercise at high altitude on cognitive function may be different in different populations.

Aerobic exercise can selectively improve executive control of attentional functions. Therefore, researchers also explored the relationship between aerobic exercise and three sub-functions of attentional functions at high altitude.

Currently, there are few studies on the effects of aerobic exercise on cognitive flexibility at high altitude. Kim et al. found that high altitude exposure decreased both brain oxygenation and cognitive task performance, while low-intensity exercise further decreased brain oxygenation but did not affect cognitive flexibility.

Studies on aerobic exercise and working memory have shown that high-altitude exposure impaired individual's working memory and that exercise did not counteract this impairment. Studies have shown that 30 minutes of exercise had no effect on individual's working memory at high altitude3. Similarly, a study used the delay matching sample task to explore whether low and moderate intensity exercise at four altitudes (2438m, 3048m, 3658m, 4267m) would have an impact on the working memory of pilots. The research results also showed that no matter what altitude, low and moderate intensity exercise would not affect the working memory of pilots. However, Walsh et al. used the number symbol switching task to test the cognitive function of participants before and after exercise, and the results indicated that the performance of the participants in cognitive tasks became worse after exercise, indicating that exercise impaired the processing speed, working memory and visual attention at high altitude4. The different cognitive tasks and experimental settings may have contributed to the inconsistent results of the above studies, so whether it was the type of task or the experimental setting that caused the inconsistent results needs to be further investigated in subsequent studies.

In 2013, Ando found for the first time through GNG task that moderate-intensity aerobic exercise could improve inhibition control in male individuals under simulated hypoxia conditions (1300m, 2600m). Follow-up studies found that the improved inhibitory control effects of exercise were independent of altitude, gender, and cognitive tasks at high altitude. For example, Komiyama found that exercise improved an individual's inhibitory control even at 3800m. Another study using the Vienna test system found that moderate-intensity aerobic exercise improved inhibitory control in women at altitudes of 4,000 meters. While many studies have demonstrated that exercise improves inhibitory control of individuals at high altitude, others have come to the opposite conclusion. For example, a single session of 10-minutes of aerobic exercise reduced individuals' performance on the color-word Stroop task significantly. In addition, inhibitory control injury remained one hour after exercise under moderate hypoxia conditions. In addition, high-intensity intermittent aerobic exercise can also lead to a decrease in the accuracy of GNG task. The reason for the inconsistent results may be due to different time windows of cognitive testing. Most studies conducted at the same time of cognitive testing and exercise found that exercise at high altitude improved individuals' inhibitory control ability. However, most studies that performed cognitive tests after exercise have shown that exercise can inhibit response. This may be because exercise is a source of arousal for the body, and the level of arousal brought by exercise improves individuals' performance in cognitive tasks. However, after exercise, the physiological changes caused by exercise dominate the cognitive influence, which leads to the reduction of individual inhibitory control.

3.The physiological mechanism of exercise at high altitude affecting attentional functions

Researchers have conducted further exploration on the mechanism behind the relationship between aerobic exercise and cognitive function at high altitude, and proposed the neurotrophic factor theory and brain oxygenation theory.

3.1 Brain-derived neurotrophic factor

Brain-derived neurotrophic factor (BDNF) is directly involved in the survival and remodeling of neurons and the formation of synapses, and plays a key role in the development and maturation of the central nervous system. BDNF can also induce the expression of monocarboxylic acid transporters, enabling lactic acid to be used by the body as an alternative energy source. Both acute and long-term aerobic exercise can be effective in raising peripheral BDNF concentrations, and athletes have higher BDNF levels compared to people who do not exercise regularly. So how does exercise affect BDNF concentrations? Exercise causes the body to produce NO, which is thought to be a stimulus produced by BDNF in the brain. Not only does exercise increase BDNF levels, extreme intensity or prolonged exercise can greatly increase blood cortisol levels, while high cortisol levels inhibit BDNF production in the brain. In addition, there is a relationship between altitude exposure and BDNF levels. Some studies have shown that 72 hours of high altitude exposure significantly increases BDNF levels in individuals, which may be due to the compensatory response of the brain oxygenation organism that occurs in individuals with reduced altitude. Exercise at high altitude can also affect the BDNF level. For example, exhaustive exercise under mild hypoxia can increase the blood BDNF concentration of individuals5. However, researchers have found that long-term regular aerobic exercise (3 times/week x 4 weeks) intervention improved cognitive performance in older adults, but did not change BDNF levels. The relationship between aerobic exercise and BDNF concentration at high altitude, as well as the relationship between BDNF level and cognitive function need more research, because the increase of blood BDNF concentration may be caused by the increase of blood-brain barrier permeability caused by excessive exercise.

3.2 Brain oxygenation

No matter what environment a people is in, its cognitive function is related to whether the cerebral vessels supply sufficient oxygen to the various tissues of the brain. When arousal levels in the brain increase, cerebral blood flow must increase to meet neuronal and metabolic oxygen needs, a process also known as neurovascular coupling (NVC). NVC plays a decisive role in the cognitive performance of individuals, and adequate oxygen supply is a prerequisite to ensure the optimal level of NVC. In addition, exercise may further reduce blood oxygen saturation, exacerbating the threat of hypoxia to an individual's level of brain oxygenation and thus affecting cognitive performance4. Studies have shown that the decrease of brain oxygenation caused by moderate intensity exercise under hypoxia conditions is significantly higher than that caused by moderate intensity exercise under normal oxygen conditions. This may be because moderate intensity exercise leads to a decrease in the amount of oxygen-carrying hemoglobin and an increase in the amount of deoxygenated hemoglobin at high altitude. Similarly, Kim et al. found that the level of brain oxygenation decreased significantly under hypoxia conditions, and the level of brain oxygenation decreased further after exercise, and there was no significant difference between left and right brain regions. All of these studies found that although exercise under hypoxic conditions resulted in decreased brain oxygenation, cognitive performance was not affected, suggesting that exercise did not further exacerbate the cognitive damage caused by hypoxic conditions. However, other studies have shown inconsistent results, suggesting that moderate-intensity exercise in hypoxic conditions leads to decreased brain oxygenation, which in turn may lead to decreased cognitive performance. Through CWST task and functional near infrared technology, Ochi et al. found that exercise under hypoxic conditions would lead to the injury of executive function, which might be caused by the decreased activity of left dorolateral prefrontal cortex (DLPFC) caused by exercise. Therefore, the effect of exercise on cognitive function at high altitude is related to the degree of brain oxygenation, which may be manifested in the DLPFC region of the brain, but this decrease in brain oxygenation does not necessarily lead to a decline in cognitive performance. In addition to the different experimental conditions (such as exposure duration, type of cognitive function and task difficulty), the effects exercise on cognitive function at high altitude may be influenced by a variety of different neurophysiological mechanisms, which need to be further demonstrated.

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