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Effects of aerobic exercise on cognitive function in different populations

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Abstract: *Moderate exercise can improve the health level and cognitive function of individuals. Previous studies have shown that the improvement effect will vary with age and population, and the sensitivity of cognitive function to exercise in different groups is different. This paper will summarize the differences and similarities of exercise intervention effects and the mechanism behind it from four groups of people who have been paid a lot of attention by researchers, including children, adolescents, the elderly and patients with cognitive deficits, in order to find out suitable exercise ways for different groups of people to improve their cognitive function and provide help.*

Keywords: *Exercise; Cognitive function; Different people; Mode of movement*

1. Introduction

It seems to be accepted by everyday experience that moderate exercise can improve an individual's physical fitness. In addition, in the aspect of People's Daily behavior, such as cognitive function, there is evidence from modern scientific research that exercise can effectively improve individual cognitive function, and the improvement effect is universal in different populations [1-3]. Exercise can reduce the incidence of Alzheimer's disease, promote the development of cognitive function in children, and improve the level of cognitive function in the elderly [4, 5]. However, the results of studies on the effects of exercise on cognitive function in different populations are still controversial, and researchers are more focused on how to find a reasonable exercise regimen to improve cognitive function for those who need it.

Aerobic exercise refers to the exercise in which aerobic metabolism is the main way to provide energy [6]. It is the most important way of daily exercise for people, and there are various ways of exercise. Exercise has many good effects on human body. Studies have pointed out that aerobic exercise can directly affect the oxygen uptake capacity of the brain, improve the utilization rate of oxygen and glucose, and maintain the stable circulation of blood. Exercise can also promote the content of nerve chemicals, such as the synthesis of brain-derived neurotrophic factor and insulin-like growth factor, and improve synaptic plasticity. It is beneficial for neuronal survival [7, 8]. Randomized controlled trials or cross trials are often used by researchers for comparative analysis in the study of cognitive function. Previous studies mostly focused on the influence of aerobic exercise on different subfunctions of cognitive function or the dose effect of exercise (different exercise intensity, different exercise mode, and different total exercise time) to discuss the difference of the influence of exercise on cognitive function [9, 10]. Starting from the moderating variables of aerobic exercise affecting cognitive function to study the results of exercise intervention, this idea has been adopted by many scholars to prescribe appropriate "exercise prescription" for various groups, which is an effective method. Starting with another key regulatory factor, this paper will review the differences and similarities of the effects of aerobic exercise on cognitive function of different groups of people, such as children, adolescents and people with cognitive disabilities, in order to provide theoretical reference for different individuals to improve cognitive function. At the same time, explore the mechanism behind it, and finally, on this basis, speculate which exercise mechanisms may be universal in different age groups and people, and which may be specific in different age groups or people.

2. Effects of exercise on cognitive function in children

Compared with other groups, the most significant characteristic of children is that their bodies are in a period of rapid growth and their brain functions are constantly developing, resulting in a variety of cognitive functions of children are relatively vulnerable to external influences. Most of the existing exercise intervention studies on children's cognitive function select children aged 6 to 12 years old, and most aerobic exercise is moderate and mild aerobic exercise. Chen et al. (2014) recruited 83 minors (10.2 ±0.7) years old to conduct a randomized controlled trial (RCTS) for 32 weeks, in which the experimental group ran for 30 minutes at 60% ~ 70% HRmax (maximum heart rate), while the control group read for 30 minutes [11]. By Flanker task, N-back task, and More-odd task tests, inhibition, working memory, and conversion function were significantly improved after intervention (P < 0.05). The study also found that the combination of less exercise time and more complex forms of aerobic exercise had a better effect on cognitive function in the adolescents. It can be seen that children's cognitive function is relatively sensitive to exercise intervention. Similarly, Schmidt et al. (2014) recruited 104 (7.9 ±0.4) year old minors (including 57 females) to conduct a randomized controlled trial (RCTS) [12]. The experimental group performed 20 min of running and jumping exercises at 60% ~ 70% HRmax, and the control group performed 20 min of storytelling. The Flanker task and N-back task tests showed that inhibition, working memory and switching abilities were significantly improved after intervention ($P < 0.05$). It can be seen from the above experimental intervention results that the form of aerobic exercise can be single or diversified, which will have a good influence on the juvenile population. Experimental studies have shown that less exercise time often requires greater intensity, and a combination of various forms of exercise can produce better effects on minors.

Fewer published studies have examined the relationship between aerobic exercise and cognitive outcomes in preschoolers. Carson and his colleagues reviewed seven experimental studies, six of which had a beneficial effect on at least one cognitive outcome. And no studies have shown that exercise damages preschoolers' cognitive abilities [13]. In addition, Zeng et al reviewed five randomized controlled trials of the effects of PA on cognitive development in children aged 4 to 6 years. Four of the five studies (80%) observed positive effects of aerobic exercise on attention, memory, language and academic achievement [14]. Again, they concluded that there was only preliminary evidence to support a positive effect of exercise on cognition in early childhood. Other studies have discussed the effect of high cognitive involvement during aerobic exercise on intervention outcomes, in which sensorimotor learning during exercise is considered to be a key mechanism linking training and cognitive enhancement [15], Cognitively engaged exercise is thought to have a stronger impact on children's executive function than simple exercise [16, 17], cognitively engaged exercise (i.e., tennis) intervention improved inhibitory control in overweight children without being affected by aerobic fitness gains [18], and high cognitively engaged exercise (team play) and low cognitively engaged exercise (simple aerobic exercise) had equally positive effects on individual children. However, greater cognitive flexibility was found only in team play and not in simple aerobic exercise [19]. In general, these findings suggest that more complex, cognitively engaged forms of physical activity have greater benefits in promoting the development of cognitive function in children.

3. Effects of exercise on cognitive function in adolescents

Youth is a period with the greatest individual differences, and the body functions related to cognition develop rapidly and tend to mature, so the definition of the age range is more complicated. At present, domestic and foreign studies on exercise intervention of youth cognitive function mostly select college students as subjects, generally aged between 17 and 23 years old. This paper also selects such studies when discussing the influence of exercise on adolescent cognitive function. Few rigorous experimental versus control studies have systematically evaluated cognitive function or academic achievement in adolescents. Despite these limitations, a recent meta-analysis combining existing similar experiments showed that two studies focused on aerobic exercise and cognitive outcomes. Esteban-Cornejo et al. (2015) observed mixed results, with 70% of studies observing a positive relationship between exercise (broadly defined as physical education, exercise, sport participation, and exercise behaviour) and cognitive or academic outcomes, 20% observing no relationship, and 10% observing a negative relationship [20]. Similarly, Ruiz-Ariza et al. (2017) observed a generally beneficial relationship between several health measures and cognitive outcomes [21]. Li et al. (2014) recruited 15 adult women (19-22 years old) for a crossover experiment [22]. The experimental group rode for 20 minutes at 60% ~ 70% HRmax, while the control group sat for 20 minutes. The modified N-back task, which tested working memory and MRI brain scans for 15 minutes, showed that aerobic exercise improved working memory

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at the neural level on a macro scale. MRI showed that aerobic exercise had a significant effect on brain activity, mainly resulting in increased activation of the anterior central gyrus, left inferior frontal gyrus, right paracentric lobule and right anterior lobe of the cerebral cortex.

Due to the limited number of rigorous randomized design studies, these findings should be considered preliminary. These experimental studies have consistently concluded that there is a positive link between movement and cognition in individuals during adolescence [23]. However, given the heterogeneity of this age group, evidence for the positive effects of exercise on cognition among adolescents is still considered limited.

4. Effects of exercise on cognitive function in older adults

Assessment of cognitive function in older adults is usually measured using scales, including the Minimum Mental State Examination (MMSE), Montreal Cognitive Assessment Scale, Alzheimer's Disease Assessment Scale and Mattis Dementia Rating Scale (Mattis DRS).

Chan et al. (2005) conducted an experimental study on the correlation between exercise habits (participation in physical and mental exercise, exercise to promote cardiovascular function, combination of two kinds of exercise and irregular exercise) and cognitive function in 140 adults over 56 years old, and found that simple exercise alone and exercise to promote cardiovascular function had the same overall cognitive function. The Mattis DRS scores were significantly better than those of irregular exercisers [24]. Hyodo et al. (2012) recruited 16 (3 females) elderly (69.3 ± 3.5 years old) for a crossover trial. The experimental group was cycling for 10 minutes at 50% VO_{2max} (maximal oxygen uptake), while the control group was resting for 10 minutes. The inhibition measurement of Stroop color-word task had a significant effect [25]. Terazona-Santabalbina et al. (2016) recruited 100 healthy elderly people (75-85 years old) for the experiment [26]. The exercise prescription used was a combination of endurance, strength, coordination, balance and flexibility exercise (10 ~ 15 min balance exercise + aerobic training starting from 40%HR_{max} and gradually increasing to 65% HR_{max} +25% strength training gradually increasing to 75% strength training + stretching exercise). The experimental group continued for 24 weeks. After 24 weeks, the exercise group measured by the Simple Mental State Assessment Scale (MMSE), which includes oriention, attention, memory, numeracy and recall, improved by 9% from baseline, which was significantly different from the control group. Cancela et al. (2007) randomly divided 62 elderly women into water exercise plus high-intensity strength training group and water exercise plus calisthenics training group. After five consecutive months of training every week, the results showed that the MMSE scores of the two groups were significantly improved [27]. Mortimer et al. conducted a randomized controlled trial on 120 elderly people and found that Taijiquan exercise lasting 40 weeks significantly improved Mattis DRS scores of the elderly [28].

The above studies of aerobic exercise on elderly people show that aerobic exercise has certain preventive effects on cognitive decline and brain aging in the elderly.

5. Summary

As for the mechanism of aerobic exercise affecting individual cognitive function, biomolecular theory has received most researchers' attention. Aerobic exercise causes significant biochemical changes in the brain of animals [29]. Currently, biochemical factors are widely studied in animal models: (1) brain-derived neurotrophic factor (BDNF), which is capable of initiating a series of downstream responses including the long-term enhancement and proliferation of neurons [30]; (2) vascular endothelial growth factor (VEGF), which can promote the survival and growth of blood vessels [31]. (3) insulin-like growth factor (IGF-1), which can affect a variety of nerve and angiogenesis processes [32]. In humans, studies of exercise-induced cellular or molecular changes have mostly focused on measurable analytes in blood or cerebrospinal fluid. For example, meta-analyses and reviews have shown increased BDNF levels in children, adolescents, and older adults after prolonged exercise, although results from individual studies have been somewhat inconsistent [33]. In addition, increased levels of BDNF circulation in humans contributed to statistically improved exercise-related executive function in adults over 71 years of age. The above evidence supports the hypothesis that BDNF may be a universal motor mechanism among different species and different age groups of humans. There is some evidence that IGF-1 levels also rise in older adults after exercise, but this effect has also been inconsistent across studies. Given the lack of studies on the relationship between exercise and IGF-1 levels in other age groups, it is unclear whether exercise affects IGF-1 levels throughout life.

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In addition, individual changes in arousal levels may be another explanation for the effects of aerobic exercise on cognitive function. When Colin Davey first explained the relationship between acute aerobic exercise and cognitive performance from a theoretical perspective, he started from the perspective of arousal and believed that exercise was a kind of stressor [34], which could activate the autonomic nervous system and improve the level of physiological and psychological arousal. During aerobic exercise, the human body will accelerate the body metabolism, increase the cerebral cortex blood flow and other physiological changes [35] to improve the arousal level of individual cognitive function, which can optimize the allocation of cognitive resources and promote the improvement of cognitive processing efficiency [36].

Given that exercise affects most organ systems in the body, its effects on individual cognitive function should be effected through multiple mechanisms rather than a single one [37]. It is logical to hypothesize that different mechanisms can act across age groups, brain regions, and subject groups. Equally important, the various modes, frequency, intensity, and duration of exercise may involve different pathways, and thus have different effects on individual cognitive function. These effects vary in different populations and should be treated differently. In addition, individual cognitive function is a large range including many directions such as attention, inhibitory control, memory, executive function, and so on [38]. We did not discuss cognitive function by case, but only focused on the overall cognitive function, which is a shortcoming of this study.

Future studies may focus on the following aspects: First, in terms of age groups, current studies on the influence of exercise on cognitive function focus on children, adolescents and the elderly, while there are few studies on normal adults and special groups. Future studies should set up more strict controlled trials in adults and special groups to determine the mechanism of its influence and the best way to intervene. Secondly, in terms of intervention methods, current studies on aerobic exercise are mainly limited to endurance training, treadmill training, dancing, walking or qigong exercise. However, there are always various types of aerobic exercise, suggesting that researchers can broaden the types of aerobic exercise in the future to provide evidence for the diversity of exercise in different groups. Second, in terms of intervention time, some of the longitudinal studies included in this paper ranged from 8 weeks to 1 year, but most of the studies were less than half a year. In fact, exercise should have a greater impact on cognitive intervention for at least half a year. Therefore, such studies should extend the intervention time as far as possible in order to achieve better results. Third, a multidisciplinary approach can be used to explore the mechanism by which aerobic exercise affects cognitive function. At present, the evidence to confirm the effect of acute aerobic exercise on cognitive function is mainly from the field of behavioral studies. However, the mechanism of aerobic exercise on cognitive function is not clear, and most of the existing theories have not been supported by strong evidence. Future studies can use brain imaging technology, EEG, and other research methods, and integrate the perspectives of behavioral science, bioengineering, neuroscience, and other disciplines, to find out the mechanism of the effect of aerobic exercise on the cognitive function of different people and find appropriate exercise programs for different people to improve the cognitive function.

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