The Effect of Exercise on Learning and Memory

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Abstract: Learning and memory is the most complex neural activity process in humans and animals, which reflects the brain's ability to gain knowledge. Many studies have confirmed that, besides its function of delaying aging and promoting growth, exercise also has an extremely important effect on the learning and memory functions of the brain. Recent studies have shown that the effect of exercise on learning and memory varies according to its intensity, timing and age of the exercising population. This paper combines our own research work to analyze and summarize the multiple factors that influence exercise on learning and memory.

1 INTRODUCTION

Humans and animals can use new knowledge and experiences to change their behavior and gain new information to adapt to their environment, a process called learning memory (Elshaw, 2010). Learning memory is a very complex neural activity, one of the higher functions of the brain, which is crucial to the evolution of the whole species and therefore has been a hot topic of scientific research (Herszage, 2018). Many studies have confirmed that exercise, besides its functions of delaying aging and promoting growth, also has an extremely important effect on the learning and memory function of the brain (Li, 2019). It has been shown that physical exercise has the effect of improving learning memory (Cassilhas, 2012). Recent studies have also shown that exercise can affect learning memory through different pathways and mechanisms, which are related to various factors, such as exercise intensity, choice of exercise timing, and age of the exercising population (Ogonovszky, 2005; Labban, 2011; Tsai, 2018). In this paper, we review the latest research progress on the effects of exercise on learning and memory.

2 THE INFLUENCE OF DIFFERENT EXERCISE INTENSITY ON LEARNING AND MEMORY

Exercise has a modulatory effect on neuroplasticity and is closely related to learning and memory function (Yamada, 2018). It has been established that different exercise intensities stimulate the brain differently and produce different effects on learning-memory functions. Exercise intensity, which includes load volume and load intensity, refers to the degree of physiological stimulation of the body by physical exercises and is one factor that makes up the volume of exercise (Bai, 2001).

It is commonly accepted in academia that low-intensity exercise can have beneficial effects on the brain, while high-intensity exercise can cause neurological damage, such as increased inflammatory response and cell death (de Almeida Alexandre Aparecido, 2013). For example, aerobic and fatigue exercise models were established in mice by swimming endurance training and combined with the Morris water maze method to assess the learning and memory ability of mice. The results showed that high-intensity fatigue training impaired spatial cognition in mice, whereas intensity aerobic training promoted learning memory (Sun, 2002). However, it is possible that this is not exactly the case, and possibly even the

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opposite. In a 2005 study, Ogonovszky et al. examined the effects of moderate load intensity (MT), strenuous load (ST) and overload (OT) training on memory and its activity of lipid peroxidation, protein oxidation, DNA damage, 8-oxoG-DNA glycosylate (OGG1) and brain-derived neurotrophic factor (BDNF) in the rat brain. The assessment of the passive avoidance test showed that memory was enhanced in the ST and OT groups of rats, while BDNF levels were elevated only in the OT group. Lipid and DNA oxidative damage did not change significantly during exercise and the activity of DNA repair enzyme OGG1 did not change with exercise training. In contrast, the content of reactive carbonyl derivatives (RCDS) decreased in all groups, with a significant decrease in the ST and OT groups. In addition, proteasome complex activity was enhanced in the brains of rats in the OT group (Ogonovszky, 2005). These results suggest overload exercise training was not only more effective in enhancing the learning and memory capacity of adult rats compared to moderate and vigorous exercise training, but also increased the rate of protein degradation in the brain without causing significant brain damage. After experiments using different exercise intensities on obese mice maintained on a high-fat diet, it was found that high-intensity exercise significantly increased BDNF levels in the brains of the mice and improved their learning memory ability in the water maze. In another study, although no improvement in learning and memory capacity was found with high-intensity exercise, BDNF levels were also significantly increased. This suggests that high-intensity or even overload exercise training does not cause oxidative stress in the brain, but may be more conducive to improved learning memory capacity, and that this process may be associated with increased BDNF levels. In addition, it has been found that exercise-induced changes in BDNF and cell proliferation levels in the hippocampus are related to both exercise intensity and developmental period (de Almeida Alexandre Aparecido, 2013).

Other studies have shown that different exercise intensities also have different effects on working memory. Wang et al. divided female Wistar rats into low-intensity, medium-intensity, and high-intensity treadmill exercise training for 30 minutes, and then used the T-maze delayed spatial alternation (DSA) task to evaluate the working memory and spatial memory of each group. The results show that exercise can improve long-term spatial memory and working memory. Low-intensity exercise is beneficial to short-term delayed working memory, while moderate and high-intensity exercise is beneficial too long-term delayed working memory, and there is an inverted U-shaped effect between exercise intensity and memory effect. Relationship, the improvement effect of moderate-intensity exercise is better than low-intensity and high-intensity exercise (Wang, 2016). In addition, the study by Weng et al. also supports that brain mechanisms related to working memory selectively benefit from moderate-intensity exercise (Weng, 2015). It can be seen that moderate-intensity exercise improves working memory.

3 THE INFLUENCE OF EXERCISE TIMING ON LEARNING AND MEMORY

The effect of exercise on learning and memory has a temporal selection effect, and the extent to which exercise affects memory function may depend on the relationship between exercise and the learning task; exercise performed before, during, and after learning will have different effects on memory function (Frith Emily, 2017).

A study by Labban and Etnier (Labban, 2011) found that exercise before memory formation showed better performance in long-term memory than a control group that exercised some time after memory formation and no exercise. Recently, Frith et al. (Frith Emily, 2017), in order to investigate the temporal effects of high-intensity exercise on the effects of short-term and long-term memory, 88 young adult subjects, randomly divided into four groups: control, pre-learning exercise, exercise during learning, and post-learning exercise groups, Short-term and long-term memory were also assessed using the Rey Auditory Verbal Learning Test(rey auditory verbal learning test), where short-term memory was assessed with a 20-minute delay and long-term memory was assessed with a 24-hour follow-up. The findings suggest that high-intensity exercise prior to memory formation is more effective in enhancing long-term memory than high-intensity exercise during memory formation and consolidation. This suggests that the timing of high-intensity exercise may play an important role in promoting long-term memory. Sng (Sng, 2018) et al. further investigated the temporal effect of acute exercise on the effect of situational memory and found that 15 minutes of moderate-intensity treadmill walking exercise before memory formation was also significantly more effective in enhancing learning and long-term situational memory than the effect of receiving the same stimulus during memory formation and memory consolidation, showing that not only high-intensity exercise but also moderate-intensity exercise was more effective in promoting long-term memory before memory formation.

Both studies were randomized controlled trials conducted among subjects. To reduce the effect of individual differences during the assessment, James et al. (Haynes, 2019) used within-subjects controlled experimental design, arranging 24 subjects aged 18-35 years to undergo four tests sequentially, including exercise before memory formation, exercise during memory formation, exercise after memory formation, and a no-exercise self-control, all with a 15-minute moderate The results of the memory function assessment, which followed the same method as the previous two studies, showed that moderate-intensity exercise stimulation before memory formation had a better effect on both short-term and long-term memory compared to the other tests (exercise during memory formation, exercise after memory formation, and self-control without exercise). The above series of findings provide firm evidence to support the temporal selection effect of acute exercise on memory.

4 THE INFLUENCE OF SPORTS ON LEARNING AND MEMORY IN DIFFERENT AGE GROUPS

Learning memory capacity varies between ages, and hippocampus-dependent memory function changes with age, gradually increasing from early to middle age and then gradually decreasing again from middle age to old age, showing an inverted U-shaped change (Ludyga, 2016). Studies have shown that exercise can promote hippocampal neurogenesis and reduce memory deficits caused by aging (van Praag Henriette, 2005), but the effects of exercise on learning and memory may be different in different age groups.

Among the symptoms of age-related cognitive decline, the decline or even loss of learning and memory function is one of the most significant problems. Because the hippocampus is an important region responsible for learning and memory function and the first area of the brain to show age-related structural and functional changes, it has become an important structure for studying age-related learning memory deficits. Many studies have shown that exercise can improve memory function (Liu, 2009), but the effects of exercise may be different at different ages. Tsai (Tsai, 2018) scheduled three groups of mice aged 3 months (adult), 9 months (middle-aged) and 18 months (elderly) for 6 weeks of moderate intensity treadmill exercise. One day after the exercise, the learning and memory ability of the three age groups of mice was examined by Morris water maze and object recognition test, respectively, while neurons in CA1 region of hippocampus were fluorescently labeled, neuronal morphology was observed, and neuronal long-range synaptic plasticity was examined. The results showed that the memory ability and the dendritic complexity and spine density of neurons in the CA1 region of the hippocampus decreased with age, while the long-range synaptic plasticity and related protein expression were not affected by age. After 6 weeks of moderate-intensity motor stimulation, the long-range synaptic plasticity and dendritic complexity of neurons in the hippocampal CA1 region increased in all age groups, and the learning and memory abilities of middle-aged and old mice were significantly improved. In addition, 6 weeks of moderate intensity exercise upregulated the expression of BDNF and mono carboxylate transporter-4 (MCT-4) in the hippocampus of middle-aged mice, glutamine synthetase (GS) in aged mice, and BDNF receptor pro myosin receptor kinase B (TrkB) in middle-aged and aged mice B (tropomyosin receptor kinase B, TrkB) expression, where BDNF-TrkB signaling has been an important regulator of exercise on regulating brain function (Yang, 2015), while MCT-4 and GS are associated with neuroplasticity. This study showed that long-term moderate-intensity exercise effectively enhanced hippocampal neuroplasticity in mice in adulthood and enhanced learning memory capacity in middle and old age.

The decline in learning and memory function with increasing age may be associated with certain biochemical changes. Part of hippocampal function depends on the activity of key enzymes, such as sodium potassium adenosine triphosphatase (Na^+, K^+-ATPase), an important transmembrane enzyme responsible for electrochemical gradients across the cell membrane. It has been shown that impairment of Na^+, K^+-ATPase is associated with spatial learning and memory deficits (Moseley, 2007), and it has been found that Na^+, K^+-ATPase activity increases in the hippocampus while spatial task training (Heo, 2012). Vanzella et al. (Vanzella, 2017) divided age 3 months (adult), 6 months (middle age) and 22 months (old age) of Wister rats, randomly divided into a control group (no exercise and cognitive training), a sedentary group (no exercise but cognitive training) and an exercise group (20 minutes of treadmill exercise at 60% of maximal oxygen uptake three times a week for 4 weeks while receiving cognitive training). The spatial memory ability of each group after receiving the conditioned stimuli was examined by Morris water maze, and Na^+, K^+-ATPase activity was also measured. The results showed moderate treadmill exercise prevented spatial learning and memory deficits in aged rats, while water maze training alone increased Na^+, K^+-ATPase activity in aged rats, and treadmill exercise combined with cognitive training further increased Na^+, K^+-ATPase activity, which significantly enhanced the working memory capacity of aged rats. This suggests that the activity of Na^+, K^+-ATPase may be related to the memory ability of aged rats. Based on the above findings, we believe moderate exercise not only has a facilitative effect on learning and memory capacity in adulthood, but also significantly improves learning memory function deficits caused by aging.

We investigated the effects and mechanisms of experiencing voluntary exercise on learning and memory capacity in mice during development by behavioral, membrane clamp and histological methods. Our results showed that mice experiencing voluntary running-wheel exercise during development induced enhanced spatial learning and memory ability in adulthood, accompanied by increased excitatory synaptic transmission and increased neuronal dendritic spine density in the hippocampal DG region (unpublished data). This result suggests that voluntary exercise experienced during development may enhance spatial learning and memory capacity by enhancing synaptic transmission in the hippocampal DG region of mice.

5 CONCLUSIONS

The effect of exercise on learning and memory has been proved by many studies, and among the effects of exercise intensity on learning and memory, different intensities of exercise have positive effects on learning and memory, and many studies have shown that moderate intensity exercise produces the best effect on learning and memory ability, although many studies have been conducted, some effects are still controversial, for example, some studies have shown that high-intensity exercise has damage on learning and memory ability For example, some studies have shown that high-intensity exercise is detrimental to learning and memory, but the detriment may not be caused by the exercise itself, but by the negative effects of psychological stress, and different results may be obtained from different research perspectives, i.e., high-intensity exercise has also been shown to enhance learning memory ability. Regarding the timing of exercise, although different timing choices have an enhancing effect on learning and memory capacity, exercises performed before memory formation have the best effect. In contrast, among the different age stages of exercise, appropriate exercise has a positive effect both in young and middle age and old age, and the effect is most pronounced in old age (Figure 1).

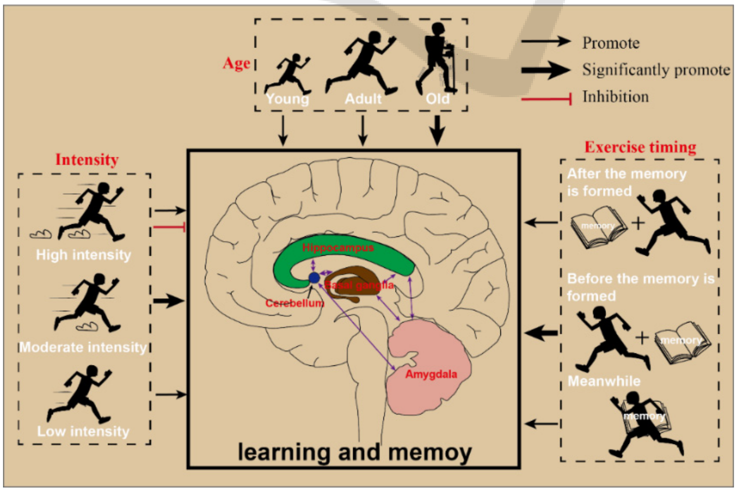

Figure 1 Among the effects of exercise intensity on learning and memory, moderate intensity exercise had the best effect on enhancing learning and memory ability. In the influence of exercise on age, exercise has the best effect on the improvement of learning and memory ability of the elderly. In the choice of exercise timing, exercise before learning and memory is the best effect.

In this paper, we combine our experimental work to provide a theoretical basis for exercise to enhance learning memory capacity and improve learning disability by analyzing and summarizing the different influences of exercise on learning and memory capacity. In addition, the brain has multiple memory systems, such as the hippocampus, basal nucleus, amygdala and cerebellum, and more mechanisms of the interaction between each memory system and the effect of exercise on learning and memory are still to be explained, such as the mechanism of the temporal effect of exercise on learning and memory, the improvement of memory dysfunction caused by aging by exercise, the effect of exercise on learning and memory ability during the developmental period of the brain, and so on. With the continuous improvement of neurobiology, molecular biology and other research techniques, these issues will eventually be unveiled, and new research findings will further reveal the mechanism of exercise for brain function enhancement and provide a theoretical basis for guiding exercise training practice.

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