

Long-Term Effects of Aerobics Training on Cognitive Function and Emotional Regulation

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Abstract

This paper explores the long-term effects of aerobic training on cognitive function and emotional regulation, highlighting the biological and psychological mechanisms involved. Regular aerobic exercise has been shown to enhance brain function through increased neurogenesis, improved blood flow, and enhanced synaptic plasticity, particularly in areas responsible for memory, attention, and emotional control. The psychological benefits, such as stress reduction and mood enhancement, are supported by the release of neurotransmitters like serotonin and dopamine. This paper also examines individual and demographic variations, demonstrating how age, gender, fitness levels, and genetic predispositions influence the cognitive and emotional outcomes of long-term aerobic training. Findings from longitudinal studies suggest that while both short-term and long-term aerobic exercise provide cognitive and emotional benefits, the most pronounced and sustained improvements are seen with consistent, long-term participation.

Keywords: aerobic exercise, cognitive function, emotional regulation, neurogenesis, BDNF

1. Introduction

Aerobic exercise, commonly referred to as “cardio,” involves continuous, rhythmic activities that engage large muscle groups and significantly raise heart and breathing rates for an extended period. It is distinct from anaerobic exercises, which rely on short bursts of intense effort, and focuses primarily on improving the efficiency of the cardiovascular and respiratory systems. Examples of aerobic exercises include activities such as running, cycling, swimming, rowing, and various forms of dance or group fitness classes. These activities are typically performed at moderate intensity, allowing individuals to sustain effort over longer periods while keeping oxygen consumption within

manageable levels. What defines aerobic exercise is the way the body generates energy—through oxygen. This process allows for sustained energy production, making it ideal for improving endurance and heart health. The nature of these activities not only improves physical endurance but also enhances coordination and muscle stamina.

The benefits of regular aerobic exercise extend far beyond improved endurance and cardiovascular health. One of the primary physical benefits is enhanced heart and lung function, which can significantly lower the risk of heart disease, stroke, and hypertension. By engaging in aerobic exercises consistently, individuals can improve their blood circulation,

lower blood pressure, and maintain healthy cholesterol levels. This, in turn, reduces the risk of developing chronic conditions such as type 2 diabetes and obesity. Aerobic exercise also plays a key role in weight management. It burns calories and boosts metabolic rate, making it an effective tool for both losing and maintaining weight. Moreover, consistent aerobic activity strengthens the immune system, making the body more resilient against infections and diseases. Improvements in physical endurance also lead to increased energy levels, which can positively impact daily activities.

On the mental health front, aerobic exercise has profound psychological benefits. One of the most well-documented effects is its ability to reduce symptoms of anxiety and depression. This is largely attributed to the release of endorphins during exercise, which act as natural mood enhancers. Aerobic exercise is also associated with a reduction in stress hormones such as cortisol, which helps the body to manage stress more effectively. This results in a calmer, more positive mental state. Over time, aerobic exercise has been shown to improve self-esteem and promote a more balanced emotional state, particularly in individuals dealing with chronic stress or mental health challenges. In addition to its mood-enhancing properties, aerobic exercise improves cognitive function. Research suggests that regular cardio activity stimulates the growth of new neurons and increases brain plasticity, especially in areas responsible for memory and learning, such as the hippocampus. This means that aerobic exercise not only improves short-term mental clarity but also provides long-term protection against cognitive decline. For older adults, aerobic training is linked to a reduced risk of dementia and Alzheimer's disease.

2. Mechanisms Linking Aerobic Exercise to Cognitive Function

2.1 Enhanced Brain Function Through Aerobic Exercise

Aerobic exercise has been shown to significantly enhance brain function through a variety of physiological mechanisms that promote brain health and cognitive performance. One of the primary benefits is the increase in blood flow to the brain during aerobic activities. This increased circulation ensures that the brain receives more oxygen and essential nutrients, such as glucose, which are vital for its optimal

functioning. The improved blood flow also aids in the removal of metabolic waste products from the brain, thus helping to maintain the health of brain tissue. Enhanced cerebral circulation is especially beneficial for regions like the prefrontal cortex, which is responsible for higher cognitive functions such as decision-making, planning, and impulse control, and the hippocampus, which is integral for memory formation and spatial navigation.

This rise in blood flow plays a protective role against cognitive decline, particularly as individuals age. Studies have shown that people who engage in regular aerobic exercise have a lower risk of developing neurodegenerative diseases such as Alzheimer's and other forms of dementia. This is partly because consistent aerobic activity helps slow down age-related atrophy in critical brain regions, preserving brain volume and density. In fact, in older adults, regular aerobic exercise has been linked to increased hippocampal volume, which is associated with improved memory and learning abilities. This suggests that aerobic exercise not only helps maintain brain health but may also reverse some aspects of age-related cognitive decline.

Another crucial mechanism through which aerobic exercise enhances brain function is neurogenesis, the process by which new neurons are generated. Neurogenesis is particularly active in the hippocampus, a brain region essential for learning, memory, and emotional regulation. Regular aerobic exercise has been shown to stimulate neurogenesis, thereby improving the brain's ability to adapt and form new memories. This increase in neuronal growth is crucial for maintaining cognitive flexibility, or the ability to switch between tasks and think creatively in problem-solving scenarios. More neurons also mean enhanced synaptic connectivity, which is vital for efficient communication between brain cells.

In addition to neurogenesis, aerobic exercise promotes synaptic plasticity, which refers to the brain's ability to reorganize itself by forming new synaptic connections. Synaptic plasticity is fundamental for learning, memory retention, and adapting to new experiences. With regular aerobic exercise, synaptic plasticity is enhanced, making the brain more efficient at processing information, retaining new knowledge, and responding to environmental changes. One of

the key factors involved in this process is the production of brain-derived neurotrophic factor (BDNF), a protein that plays a critical role in supporting the growth and survival of neurons. BDNF is often referred to as “fertilizer for the brain” because it encourages the development of new synapses and strengthens existing neural pathways, making cognitive processes more robust and efficient.

The benefits of increased BDNF levels extend beyond memory and learning. BDNF also supports brain resilience, helping individuals cope with cognitive stressors and recover from mental fatigue. Higher levels of BDNF, which are promoted by aerobic exercise, are linked to better emotional regulation and stress management. This means that people who engage in regular aerobic exercise are better equipped to handle both cognitive and emotional challenges, such as maintaining focus under pressure or recovering from stressful events.

Furthermore, aerobic exercise can improve the integrity of white matter in the brain. White matter consists of the nerve fibers that connect different regions of the brain, facilitating communication between them. Studies have shown that aerobic exercise can help maintain or even improve the integrity of white matter, which tends to decline with age. Better white matter integrity translates into faster and more efficient information processing, which is crucial for cognitive tasks that require quick thinking and coordination between different brain regions.

Additionally, aerobic exercise positively affects the brain's dopaminergic and serotonergic systems, which are responsible for regulating mood, motivation, and reward processing. By stimulating the release of dopamine and serotonin, aerobic exercise not only enhances mood but also reinforces learning and memory through reward-based mechanisms. These neurotransmitters play a crucial role in reinforcing positive behavior and motivation, making it easier for individuals to stick to a consistent exercise routine and reap the cognitive benefits over time.

2.2 Long-Term Effects on Cognitive Functions

The long-term effects of aerobic exercise have been widely recognized as particularly beneficial for improving and preserving cognitive functions, particularly in areas such as

memory, attention, and executive function. One of the most notable cognitive benefits of regular aerobic exercise is its positive impact on memory, specifically working memory and spatial memory. Working memory refers to the brain's ability to hold and manipulate information over short periods, which is crucial for tasks that involve reasoning, comprehension, and learning. Spatial memory, on the other hand, involves the ability to remember locations and navigate environments, a function largely attributed to the hippocampus. Research shows that regular aerobic exercise supports hippocampal health by increasing the production of new neurons (neurogenesis) and enhancing synaptic connections. This process not only aids in the formation of new memories but also strengthens the brain's ability to retrieve stored information. This is especially important as people age, as the hippocampus tends to shrink with time, leading to memory loss and cognitive decline. Aerobic exercise has been shown to slow this progression, reducing the risk of age-related conditions such as Alzheimer's disease and other forms of dementia.

Attention and focus are other cognitive areas significantly improved by long-term aerobic exercise. Attention is the ability to concentrate on specific stimuli while ignoring distractions, a skill critical in both academic and professional settings. Studies have consistently demonstrated that individuals who engage in regular aerobic exercise exhibit enhanced attentional control. They are able to sustain attention for longer periods, process information more efficiently, and transition between tasks with greater ease. These improvements in attention are likely due to enhanced synaptic plasticity and increased brain plasticity, which allow the brain to adapt more quickly and flexibly to new tasks and information. Improved attention span and focus are particularly important in preventing cognitive decline in older adults, as diminished attention control is one of the early signs of age-related cognitive impairment.

In addition to memory and attention, long-term aerobic exercise supports executive function, a set of cognitive processes that includes problem-solving, decision-making, planning, and organizing. These higher-order functions are essential for managing day-to-day tasks, making sound decisions, and regulating behavior in various situations. Executive function is primarily governed by the prefrontal

cortex, which is responsible for controlling impulses, weighing risks, and setting priorities. Regular aerobic exercise promotes the health of the prefrontal cortex by improving blood flow and synaptic activity, thus boosting its efficiency. Individuals who engage in long-term aerobic training have been shown to perform better on tests that measure executive function, such as those that involve task-switching, strategic thinking, and conflict resolution. For instance, they may exhibit enhanced ability to juggle multiple tasks, manage time effectively, and make quicker, more accurate decisions. These skills are invaluable in both personal and professional contexts, where the ability to handle complex situations with efficiency and clarity is essential.

Another significant benefit of improved executive function through aerobic exercise is better emotional regulation. The prefrontal cortex also plays a key role in managing emotions, particularly in inhibiting impulsive reactions and helping individuals respond to stress in a controlled manner. Long-term aerobic exercise strengthens the connections between the prefrontal cortex and other emotional centers of the brain, such as the amygdala, which is involved in the fight-or-flight response. This enhanced connectivity allows for more balanced emotional responses and better stress management. As a result, individuals who engage in regular aerobic activity are often better equipped to handle emotional challenges, exhibit greater patience, and maintain calm under pressure. This improvement in emotional regulation contributes to overall well-being and mental resilience.

3. The Role of Aerobics in Emotional Regulation

3.1 Aerobic Exercise and Its Role in Reducing Stress and Enhancing Mood

Regular aerobic exercise plays a crucial role in promoting emotional regulation by significantly aiding in stress management and mood enhancement. One of the most well-documented benefits of aerobic exercise is its ability to reduce stress and help the body better manage its physiological responses to stressors. During aerobic activities such as running, cycling, or swimming, the body releases endorphins, which are often referred to as “feel-good” hormones. These endorphins interact with the brain’s receptors to diminish the perception of pain,

induce a state of euphoria, and create an overall sense of well-being. This process is similar to the effects of morphine but is naturally induced, making aerobic exercise one of the healthiest ways to combat stress and anxiety. Endorphins not only provide immediate relief from stress but also create a lasting buffer against emotional tension, which is why individuals often report feeling calmer and more relaxed after an aerobic workout.

In addition to the release of endorphins, aerobic exercise significantly reduces cortisol levels. Cortisol, often referred to as the “stress hormone,” is produced by the adrenal glands during periods of heightened stress. While cortisol plays a vital role in the body’s fight-or-flight response, chronic elevated levels of cortisol can have detrimental effects on both physical and mental health. Prolonged exposure to high cortisol levels is associated with various negative outcomes, including weight gain, hypertension, weakened immune function, and mood disorders like anxiety and depression. High cortisol levels are also linked to cognitive impairment, particularly in areas related to memory and learning. Regular aerobic exercise lowers cortisol production and helps the body maintain a more balanced hormonal state. This reduction in cortisol not only alleviates the physiological symptoms of stress, such as muscle tension and headaches, but also supports better emotional resilience by making the brain less reactive to stressors. By promoting hormonal balance, aerobic exercise allows individuals to approach stressful situations with greater calmness and emotional stability.

Furthermore, aerobic exercise enhances mood regulation, a benefit closely tied to the production of important neurotransmitters such as serotonin and dopamine. Serotonin is a key neurotransmitter that plays a crucial role in stabilizing mood, regulating sleep cycles, and controlling appetite. Low levels of serotonin are commonly associated with mood disorders, particularly depression. Aerobic exercise stimulates the production of serotonin, which in turn elevates mood and reduces the likelihood of depressive episodes. This effect is particularly beneficial for individuals suffering from mood swings or seasonal affective disorder (SAD). Enhanced serotonin production during aerobic exercise not only improves mood during and immediately after the activity but also contributes to longer-lasting emotional balance.

People who engage in regular aerobic activities tend to report more consistent mood states and fewer fluctuations in emotional well-being.

Dopamine, another neurotransmitter significantly influenced by aerobic exercise, plays a key role in the brain's reward system. It is associated with feelings of pleasure, motivation, and reward. Consistent aerobic exercise increases dopamine levels, leading to an elevated sense of satisfaction and motivation. This boost in dopamine can enhance a person's ability to set and achieve personal goals, creating a positive feedback loop of accomplishment and improved emotional health. As dopamine levels rise, individuals are more likely to experience feelings of motivation and enthusiasm, which can help them maintain a positive outlook on life and stay committed to their health and fitness goals.

Aerobic exercise also contributes to psychological benefits such as increased self-efficacy and improved self-esteem. Engaging in regular physical activity provides individuals with a sense of accomplishment and progress, as they witness their physical endurance and fitness levels improve over time. This sense of achievement contributes to a more positive self-image, which in turn supports emotional well-being. When individuals meet their fitness goals—whether through improved stamina, weight loss, or simply mastering a new aerobic activity—they gain confidence in their abilities. This self-efficacy translates into other areas of life, empowering them to tackle challenges with more resilience and optimism. Additionally, achieving these fitness milestones can reduce symptoms of anxiety and depression by shifting the individual's focus away from negative thought patterns and toward productive, goal-oriented behavior.

Over the long term, the consistent engagement in aerobic exercise has been shown to reduce symptoms of depression and anxiety. This is particularly relevant for individuals who experience chronic stress or mood disorders. Aerobic exercise serves as both a preventive and therapeutic intervention, helping to stabilize emotions and promote a more positive outlook on life. Research indicates that individuals who engage in regular aerobic activities experience fewer episodes of depression and anxiety, likely due to the cumulative effect of neurotransmitter regulation, improved self-esteem, and enhanced stress resilience. Regular aerobic exercise also

helps to alleviate the symptoms of other mood-related conditions, such as panic disorder and social anxiety disorder, by promoting relaxation and improving overall mental health.

3.2 Biological and Psychological Mechanisms of Emotional Regulation through Aerobic Exercise

The relationship between aerobic exercise and emotional regulation is supported by both biological and psychological mechanisms, each playing a crucial role in how individuals manage emotions and maintain mental balance. On the biological side, regular aerobic exercise facilitates the regulation of essential neurotransmitters and hormones that influence emotional stability. One of the key biological effects of aerobic exercise is the increased production of brain-derived neurotrophic factor (BDNF), a protein that supports the survival and growth of neurons. BDNF is essential for maintaining and enhancing neuroplasticity, which refers to the brain's ability to adapt and reorganize in response to stress and learning experiences. With enhanced neuroplasticity, the brain can better cope with emotional stress and recover from emotional setbacks, such as anxiety or feelings of failure.

BDNF's impact is particularly pronounced in the prefrontal cortex, the area of the brain responsible for higher-order cognitive processes, including decision-making, impulse control, and emotional regulation. By increasing BDNF levels, aerobic exercise strengthens the neural connections within the prefrontal cortex, enhancing its ability to moderate emotional responses and reduce impulsive reactions. This means that individuals who regularly engage in aerobic exercise are better able to manage their emotions, avoid knee-jerk reactions to stressful situations, and maintain a sense of calm during challenges. Furthermore, aerobic exercise stimulates the production of mood-regulating neurotransmitters such as serotonin and dopamine, which help reduce symptoms of depression and anxiety. These neurotransmitters play a key role in maintaining emotional balance, promoting feelings of well-being, and reducing emotional volatility. The release of these neurotransmitters, coupled with increased BDNF levels, supports long-term emotional health, making aerobic exercise a vital tool in the prevention and management of mood disorders.

In addition to its biological effects, aerobic exercise also exerts a powerful influence on

emotional regulation through psychological mechanisms. One of the most significant psychological benefits of aerobic exercise is the sense of control and routine it provides. Engaging in regular physical activity offers individuals a structured outlet for releasing emotional energy, whether it be frustration, anger, or sadness. This release acts as a form of emotional cleansing, allowing individuals to vent their negative emotions in a constructive and non-destructive way. The repetitive nature of aerobic activities, such as running or cycling, can also foster a sense of mastery and progress, which contributes to a heightened sense of control over one's life. For individuals who struggle with anxiety or stress, this feeling of control can be incredibly empowering, providing a counterbalance to the feelings of helplessness often associated with these conditions.

Moreover, aerobic exercise can serve as a form of mindfulness in motion. During aerobic activities, individuals often focus on their breathing, bodily sensations, and movements, which encourages a present-moment awareness similar to meditation. This focus on the present can help break the cycle of rumination, which is a common feature of mood disorders like depression. Rumination involves continuously rehashing negative thoughts and emotions, which can perpetuate feelings of sadness, anxiety, or anger. By shifting attention to the immediate physical experience of exercise, individuals are able to reduce the mental noise of rumination, thereby promoting a more balanced emotional state. The rhythmic nature of many aerobic exercises also helps individuals achieve a meditative flow, where the repetition of movement creates a calming effect on both mind and body.

Additionally, aerobic exercise reinforces positive behavioral feedback loops that contribute to long-term emotional resilience. The act of setting and achieving fitness goals, such as improving endurance or completing a challenging workout, boosts self-efficacy and confidence. This sense of accomplishment reinforces a positive self-image and reduces feelings of inadequacy or low self-worth, which are often linked to depression and anxiety. As individuals experience these psychological rewards, they are more likely to continue engaging in aerobic exercise, creating a sustainable cycle of emotional regulation and mental well-being.

Over time, the combined biological and psychological effects of aerobic exercise contribute to a more resilient emotional system. The brain's enhanced capacity for stress management, bolstered by increased BDNF and neurotransmitter activity, allows individuals to cope with emotional challenges more effectively. Psychologically, the routine, mindfulness, and sense of control associated with regular exercise further promote emotional balance. Together, these mechanisms help individuals achieve better emotional control, reduce symptoms of mood disorders, and improve overall mental health outcomes.

4. Evidence from Longitudinal Studies

4.1 Key Findings from Longitudinal Studies on Cognitive and Emotional Health

Longitudinal studies have provided significant evidence supporting the positive long-term effects of aerobic exercise on both cognitive and emotional health. These studies typically follow individuals over extended periods, allowing researchers to observe how regular aerobic exercise influences brain function and emotional regulation over time. One of the key findings from these studies is the preservation of cognitive function, particularly in aging populations. Long-term aerobic exercise has been consistently linked to slower cognitive decline, with participants demonstrating better memory retention, improved attention, and greater problem-solving abilities compared to sedentary individuals. For example, research has shown that individuals who engage in regular aerobic exercise, such as walking or running, exhibit less shrinkage in the hippocampus—an area of the brain critical for memory—thereby reducing the risk of Alzheimer's disease and other forms of dementia.

In addition to cognitive benefits, longitudinal studies also highlight the emotional health advantages of regular aerobic exercise. Long-term exercisers tend to have lower levels of anxiety and depression, and they report greater emotional resilience when dealing with life's stressors. For instance, studies have found that participants who engage in sustained aerobic activities such as swimming or cycling show reduced levels of cortisol, the body's primary stress hormone, and experience a general improvement in mood stability. Over time, these individuals develop enhanced

emotional regulation skills, allowing them to manage negative emotions more effectively and recover more quickly from stressful events. These findings underscore the dual benefit of aerobic exercise in promoting both mental sharpness and emotional well-being across the lifespan.

4.2 Short-Term vs. Long-Term Benefits: Cognitive Resilience and Emotional Stability

While both short-term and long-term aerobic exercise offer cognitive and emotional benefits, long-term engagement leads to more pronounced and sustained improvements in cognitive resilience and emotional stability. In the short term, aerobic exercise enhances cognitive functions such as attention and memory through immediate physiological changes like increased blood flow to the brain and the release of endorphins, which improve mood and reduce stress. These immediate effects are beneficial but tend to be temporary, often lasting for a few hours or days after exercise. Short-term engagement in aerobic activities can also boost emotional well-being by providing quick relief from anxiety or depressive symptoms, but without sustained activity, these benefits may not lead to lasting emotional regulation or resilience.

In contrast, the long-term effects of aerobic exercise are more profound and enduring. Over months or years of consistent aerobic training, the brain undergoes structural changes, such as increased gray matter in areas responsible for memory and executive function, and improved neural connectivity. These changes contribute to long-term cognitive resilience, enabling individuals to better handle cognitive challenges, maintain sharper mental faculties, and protect against age-related cognitive decline. Emotionally, long-term aerobic exercise leads to more stable and regulated emotional responses. Regular aerobic activity over extended periods strengthens the brain's capacity to cope with stress and manage mood fluctuations, resulting in enhanced emotional stability. Unlike the fleeting mood boosts from short-term exercise, long-term exercisers develop a greater ability to maintain emotional balance even during periods of stress or adversity.

While short-term aerobic exercise provides immediate boosts to cognitive and emotional health, it is the long-term commitment to aerobic activity that yields the most significant and

lasting improvements. Cognitive resilience and emotional stability are best achieved through sustained participation in aerobic exercise, highlighting the importance of making aerobic activity a regular part of one's lifestyle for enduring mental and emotional well-being.

5. Individual and Demographic Variations in Outcomes

The cognitive and emotional outcomes of long-term aerobic training can vary significantly depending on individual and demographic factors such as age, gender, and fitness levels. Research has shown that the benefits of aerobic exercise on cognitive function, such as improvements in memory and executive function, tend to be more pronounced in older adults compared to younger individuals. This is because, as people age, their risk of cognitive decline increases, making the protective effects of aerobic exercise more impactful in slowing down age-related changes in brain structure and function. Older adults who engage in consistent aerobic exercise often demonstrate better memory retention and decision-making abilities than their sedentary counterparts, while younger individuals may experience more subtle improvements in cognitive performance due to their already robust cognitive capacities.

Gender also plays a role in the emotional outcomes of aerobic training. Studies have suggested that women may experience more significant mood improvements from aerobic exercise compared to men, particularly in the reduction of anxiety and depression. Hormonal differences, such as fluctuations in estrogen and progesterone, might account for some of these variations, as these hormones interact with neurotransmitters like serotonin, which are crucial for mood regulation. Moreover, fitness levels can moderate the extent of cognitive and emotional benefits. Individuals with higher baseline fitness levels may experience fewer dramatic improvements from aerobic exercise, as their bodies and brains are already well-adapted to physical stress. In contrast, those with lower fitness levels or who are starting from a sedentary lifestyle tend to exhibit more noticeable gains in both cognitive function and emotional stability after beginning an aerobic regimen.

Beyond these demographic factors, there are also several moderating factors that influence how individuals respond to long-term aerobic

training. Baseline cognitive ability is one such factor. Individuals with higher baseline cognitive performance may show smaller cognitive gains from aerobic exercise compared to those starting with lower cognitive function. This is particularly relevant in populations at risk of cognitive decline, such as older adults or individuals with mild cognitive impairment, where aerobic exercise may serve as a critical intervention to preserve brain health. Lifestyle factors like diet, sleep quality, and overall physical activity levels also play a significant role. For example, individuals who pair aerobic exercise with a healthy diet and adequate sleep are likely to experience more pronounced cognitive and emotional benefits compared to those who neglect these other aspects of wellness.

Genetic predispositions further modulate the effects of aerobic exercise. Variations in genes that regulate the production of brain-derived neurotrophic factor (BDNF), for instance, can influence how much a person benefits from exercise in terms of cognitive improvement. Individuals with certain genetic profiles may produce more BDNF in response to aerobic activity, leading to greater neuroplasticity and cognitive gains. Conversely, those with less favorable genetic variants may require more intense or longer periods of exercise to achieve similar outcomes. Overall, the cognitive and emotional outcomes of long-term aerobic training are shaped by a complex interplay of demographic characteristics, baseline abilities, lifestyle choices, and genetic factors, which underscores the need for personalized exercise programs to optimize results.

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