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Does Exercise Make You Smarter?

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Abstract

Physical exercise has been applauded for its beneficial cardiovascular and mental effects for decades. Recently, researchers have begun to study exercise from a different perspective, focusing on the positive relationship between exercise and cognition. One area of cognition highlighted in association with exercise is its positive impact on executive function. Executive function refers to the collection of neurocognitive processes involved in goal-directed problem-solving. Improved levels of cognitive function have been found to impact significant achievements throughout life. Because of this, the development, improvement, and preservation of these functions are essential. While research has proven a correlation between exercise and improved cognition, the different aspects that might influence its effectiveness are currently unclear. This research paper comprehensively analyzes various factors such as type, intensity, and age groups that may modulate exercise's effect on cognitive and executive functions. Aerobic exercise was found to improve blood flow and increased transportation of nutrients and oxygen to areas in the central nervous system. While anaerobic exercise has also been shown to raise insulin-like growth factor-1(IGF-1) concentrations, which enhances general cognitive function, lactic acid accumulation was found to have a negative effect on cognitive improvement. Exercises that include specific cognitive brain stimulation were found to directly improve that cognitive function. In terms of intensity, moderate exercise was shown to be the most effective overall. In some areas, High intensity interval training (HIIT) exercise matched moderate exercise's effect on cognitive function and outperformed it in others. These findings were shown to be true for all age groups, particularly among children, adolescents, and older adults. However, because the number of studies were limited, further research is needed to understand the exact influence exercise has on young to middle-aged adults. Furthermore, while the study did find that exercise can increase general cognition, it was unable to assess the exact impact of different types of exercise on specific cognitive processes.

Introduction

Hippocrates once said, "All parts of the body, if used in moderation and exercised in labors to which each is accustomed, become thereby healthy and well developed and age slowly; but if they are unused and left idle, they become liable to disease, defective in growth and age quickly." Physical exercise has long been associated with increased physical health and prevention of disease. Studies have associated exercise with preventing physical illnesses such as cardiovascular disease, (Agarwal, 2012) colon cancer, hypertension, and diabetes while improving mental health such as reduced anxiety, stress, and depression (Vina et al., 2012). Additionally, new research found that exercise may reduce the risk of acute respiratory distress syndrome (ARDS), a major cause of death in patients with the novel coronavirus (COVID-19) (COVID-19: Exercise May Help Prevent Deadly Complication, 2020). While the World Health Organization (WHO) recommends that adults should have at least 150–300 minutes of exercise per week, it estimates that 1 in every 4 adults and 4 out every 5 adolescents are insufficiently active (World Health Organization, 2020). Recently, researchers have begun studying the positive association between exercise and cognition. Cognition is broadly defined as the mental process of gaining information and understanding through intellect, observation, and sensation (Merriam-Webster, 2018). One area of cognition highlighted in association to exercise is executive function. Executive function refers to the collection of neurocognitive processes involved in goal-directed problem solving, which includes inhibitory control, cognitive flexibility, and working memory. These are basic skills that are used daily such as self-awareness, self-control, understanding different perspectives, organization, and completing tasks effectively (Carlson et al., 2013).

The development, enhancement, and preservation of cognitive processes is significant for all ages as they can play a major role in a variety of areas. For instance, studies have found that cognitive abilities are key factors of academic success (Rohde & Thompson, 2007) and school readiness (Welsh et al., 2010) among children. Furthermore, higher cognitive function is found to positively impact career success (Judge et al., 2010) and performance at work (Lang et al., 2010). Additionally, as life expectancy increases there's a rise of neurodegenerative diseases that cause cognitive decline in the elderly, which severely diminishes the quality of life (Batista & Pereira, 2016). Therefore, it is important to analyze how exercise can beneficially affect cognition. Besides for its well-established health benefits, exercise is cost-effective, non-pharmaceutical, and readily accessible. While the research linking exercise to improved cognition has been established, the various factors that can impact its effectiveness is still unclear. This review will first analyze several characteristics of exercise and discuss their underlying biological mechanisms in order to determine how to maximize exercise's benefits. Then, it will examine the pertinence of findings on various age groups and discuss recommended exercise regimens.

Method

Articles and studies for this paper were gathered using the EBSCO, PubMed, Google Scholar, and ProQuest databases, with access granted by the Touro College Library. The articles found discuss several elements that modulate exercise's effect on cognition and executive function. This paper's analysis was formed after a thorough assessment of review articles, meta-analysis, case studies, and experimental investigations.

Results and Discussion:
Aerobic, Anaerobic, and Different Types of Exercise
Exercise can be differentiated into two general categories, aerobic and anaerobic. These differ in intensity and physical exertion and involve different muscle groups. Research has proven that both types of exercises benefit a variety of health issues, such as preventing cardiovascular disease and improving mental health. However, it remains to be seen if one specific type of workout is more effective in improving cognition than another.

Aerobic
Aerobic exercise is defined by the American College of Sports Medicine as any activity that engages large muscle groups, can be sustained continuously, and is rhythmic in character (Pescatello & American College Of Sports Medicine, 2014). Aerobic means "with oxygen". As the name implies, aerobic exercise relies on the body's ability to perform aerobic respiration to fuel these muscle groups. Biologically, this energy is produced when pyruvate can enter the citric acid cycle and undergo oxidative phosphorylation. However, this can only occur when there's oxygen present as the final electron acceptor of the cycle (Melkonian & Schury, 2019). Exercises that fall into this category include swimming, cycling, jogging, dancing, and hiking. All of these exercises are continuous exercises that require large muscle groups and rhythm to move. Research on aerobic exercise primarily revolves around its impact on the cardiovascular system as it is proven to help prevent heart attacks and coronary vascular diseases (Patel et al., 2017).

Recent studies have begun researching aerobic exercise's effect on cognition. A study analyzed aerobic exercise's effects on cognitive performance. Over a 10-week period, they studied 91 healthy adults split into 2 experimental groups and a control group. The control group exercised aerobically 0-2 times a week, while the experimental groups exercised aerobically 3-4 times a week, and 5-7 times a week, respectively. Many areas of cognitive function were tested using the Stroop test and various other tests. The study found considerable improvement in attention (rise of 33.7%) and cognitive flexibility (18.1%) in the experimental group compared to the control group (rise of 6.2% and 0.2%, respectively). The researchers also determined that as the frequency of exercises increased throughout the week, executive function increased. Since cognitive flexibility and attention are measures of executive functions, this indicates that aerobic exercise positively affects the prefrontal cortex which is associated largely with executive function (Masley et al., 2009). Similar results were found in a study that compared a control group to 66 subjects who exercised aerobically and found significant improvements in executive functions. Interestingly, they also found that exercise's effect on cognition increased as age increased. The best results were among 50-65-year-old group (Stern et al., 2019).

Researchers have proposed underlying mechanisms on how aerobic exercise affects cognition. One study has shown that aerobic exercise lowers blood viscosity which, in turn improves blood flow in the brain. This is due to hemodynamic changes, which consequently facilitates the transfer of nutrients and oxygen to essential central nervous system structures involved in learning and memory, thereby boosting cognitive performance (Cassilhas et al., 2007). They also set out to uncover a mechanism by analyzing aerobic exercise's positive effect on learning and spatial memory in rats. They found that aerobic exercise releases increased synapsin and synaptophysin in the hippocampus that are proven to improve spatial and learning memory (Cassilhas et al., 2012).

After researching various forms of aerobic workouts, specific cognitive benefits can be attributed to the specific forms of exercise. Dancing, for example was studied to determine its specific cognitive effects. The study was done over a 6-month period and compared a dancing experimental group to a non-dancing control group. The study found that in the dancing group there was significant improvement of cognition and attention compared to the control group, which found no change. They also noted that learning new and advanced dance-related motions has been shown to modify both functional and effective connections in the brain. This may suggest that if there's a cognitive aspect to the exercise it may provide an additional benefit, besides for the regular benefits generally associated with aerobic exercise (Kattenstroth et al., 2013). A review done by Yael Netz (2019) came to a similar conclusion. She found that motor-related exercises, such as ones that require coordination and balance, affect cognition directly. She hypothesized that how complex the motor-related task is determines the increase in neuroplasticity (Netz, 2019). Researchers suggested that this may be due to the increase in neurotrophic factors in the areas associated with those cognitive functions. They hypothesized a specific threshold may be required to facilitate lasting neural changes, and more cognitively challenging activities may help you get there more efficiently (Carey et al., 2005). It seems that overall aerobic exercise has a significant positive effect on cognitive functions, and it may be especially beneficial if there's a cognitive aspect to it.

Anaerobic

Anaerobic exercise is characterized by exercise that does not use oxygen and is often intense in a short duration of time (Patel et al., 2017). Without the presence of oxygen, our cells resort to glycolysis and fermentation to fuel the workout. This occurs when oxygen demand exceeds oxygen supply, and the muscles rely on anaerobic glycolysis for ATP synthesis. Under these circumstances, pyruvate is transformed into lactate, allowing glycolysis to occur (by regenerating NAD+) to create ATP as the energy source. A product of this process is the buildup of lactic acid (Melkonian & Schury, 2019). These exercises include sprinting, pushups, and powerlifting. Besides for building muscle mass, many positive effects are associated with resistance training as it is found to reduce fear of falling, depression, and anxiety. The elevation in mood and confidence causes an improved performance of day-to-day tasks that may indirectly help cognition.

A study conducted by Cassilhas et al., (2007) analyzed resistance training's effect on cognition. They followed 39 subjects who performed resistance training over a 6-week period compared to 23 non-exercisers. The volunteers were given various cognitive tests before and after the study to assess the outcome. It was discovered that following the period of the experiment, the subjects performed better in short and long-term memory tests as well as a considerable improvement in attention. This study suggests that anaerobic exercise seems to positively affect many executive functions. A meta-analysis conducted by Landrigan et al. (2019) found similar results. The analysis included 868 subjects from 24 studies on lifting and its effect on cognitive and executive functions. It was found that lifting has a beneficial influence on overall cognition and executive function. Interestingly, the study did not find much effect on working memory. However, it is unclear if this is due to the anaerobic aspect of the exercise or the cognitive aspect of resistance exercises. For instance, one must always pay attention to what they are doing during lifting so that they do not injure themselves or anyone around them. These periods of attentiveness may serve as a sort of attention training, explaining why there was a higher performance on executive function tests, since many of these tests assess an individual's capacity to focus on specific stimuli. In contrast, lifting doesn't activate memory performance, which may explain why memory wasn't so affected in the analysis. These findings are consistent with the aforementioned studies that found that task-specific exercises may affect the cognitive processes used in the exercise. (Landrigan et al., 2019)

Different theories were proposed in regard to the biological effect of anaerobic exercise on cognition. One proposed neurophysiological mechanism is the increase in IGF-1 concentrations. The IGF-1 hormone binds to receptors in the central nervous system, stimulating glial cell development, myelination, and neuron proliferation; an increase in its concentration is associated with greater cognitive and executive functions (Tsai et al., 2015). Multiple studies have found significantly higher levels of IGF-1 in people who performed resistance exercises compared to control groups (Cassilhas et al., 2007; Tsai et al., 2015).

While these studies imply that anaerobic exercise has a favorable effect on cognition, the impact of lactic acid production from these exercises' merits further examination. It remains to be determined whether these exercises are comparable or favored to aerobic exercise. Multiple studies were conducted to investigate the impact of the accumulation of lactic acid on cognitive functions compared to the lower levels of aerobic exercises. They found that levels of exercise that are high in lactic acid (in the anaerobic threshold) decrease the benefits of affected cognitive performances and executive functions such as attention skills. It has been suggested that this happens because high lactic acid conditions are associated with reduced pH levels and exhaustion of alkaline reserves. These states are known to affect voltage-gated channels that regulate neuronal excitability even with slight changes in pH levels (Córdova et al., 2009; Coco et al., 2019). While anaerobic exercises seem to beneficially impact cognitive functions, the proliferation of lactic acid seems to suggest aerobic exercises are more beneficial.

Intensity

One important factor that many studies research is which level of exercise intensity has the most beneficial effect on cognition. Understanding how different levels of exercise intensity affect various cognitive functions allows us to maximize the effects of our exercise regimen. While there are various ways to measure intensity, many studies categorize the three levels of intensity by percentages of maximum heart rate (% HR) a person reaches during the workout. Any exercise that causes between 40 and 50 % HR increase is referred to as low intensity, between 50 and 70 % is referred to as moderate, and above 70% is considered high (Mayo Clinic Staff, 2018). One of the early proposals hypothesized that the levels of intensity benefits are correlated as an inverted 'U.' They suggest that as the level of intensity increases, the greater the improvement of task performance is until a certain point, where then the task performance begins deteriorating (McMorris & Hale, 2012). The negative consequences of exhaustion may cancel out the beneficial effects of exercise. According to this proposition, moderate exercise is perceived as the optimal intensity of exercise. However, as recent studies begin to analyze the effects of various intensities, a review of the results is required in order to compare the findings and ascertain the beneficial levels of intensity.

Researchers have used the inverted U theory as the baseline hypothesis for their studies. A study was done to measure the response rate of individuals after low, moderate, and high-intensity exercises. They proposed that the differences in intensity may affect different executive functions. Light and moderate intensity may benefit more response inhibition in executive function which requires less effort and demand, while more intense exercises may benefit more complex tasks. The study used the P3 component of an event-related brain potential to measure the interactions between the brain and exercise. The P3 component is believed to show how the brain distributes attentional resources and processes memory and is widely used as a measure for cognitive gains. Overall, it was measured that the P3 amplitude increases during the light and moderate exercise but not during intense exercise. According to this study, moderate exercise has a positive effect on executive functions, specifically allocating attention resources and memory processing. This seems to support the inverted U theory that the benefits may be diminished by the exhaustion associated with higher levels of intensity. However, the study did find a shortened response time amongst all intensities, which displays that intense exercise does have some positive effects (Kamijo et al., 2007)

In a different study, low and high-intensity exercise's cognitive effects were measured using an MRI to compare different cognitive effects on the brain. The MRI showed that low-intensity exercises increased resting-state functional connectivity (rs-FC) in the left and right frontoparietal networks. The frontal lobe in general is known to control executive function, and specifically the frontoparietal network areas are associated with cognitive functions and attentional control. In contrast, these areas were not highlighted during high-intensity exercises. The study aligns with the inverted U theory that proclaims that high-intensity exercise may deteriorate the positive effects of exercise. It supports that the greatest benefits of exercise are found between low and moderate intensities and decrease with further intensification. The study proposed that the post-exhaustive state after high-intensity exercises is what limits the positive cognitive aspects of exercise (Schmitt et al., 2019).

An interesting study was conducted to highlight the benefits of moderate exercise. The study began by researching whether a bout of moderate or high-intensity exercise increased cognitive function. They then proceeded to evaluate whether there was an effect on inhibitory control with food consumption. They found that there was a considerable improvement on the Stroop test following the moderate exercise, while there was negligible improvement following the high-intensity exercise. Similarly, while there was no correlation between the amount of food consumed and the intensity of exercise, the moderate exercisers selected the healthier choice. They exhibited an inhibitory response by selecting the healthier option rather than the unhealthy option. Again, this supports the previous theory that moderate exercise affects executive function, specifically response inhibition. Additionally, these benefits seem to deteriorate as the intensity increases (Lowe et al., 2014).

While the aforementioned studies seem to support the inverted U theory that higher levels of intensity may be detrimental, recently researchers have been studying how to utilize high-intensity exercise beneficially. Jiang et al. studied an MRI of the brain after extreme fatigue of the motor neurons. It was discovered that functional connectivity in subcortical nuclei, which are essential components of the motor control system, had increased significantly. These findings seem to indicate a stronger connection between the motor and interneurons after high-intensity exercise. This may suggest a bio-feedback system is regulating the motor neurons after fatigue to adjust optimally to accommodate the intense vigorous exercise. It may seem that high-intensity exercise helps the body adjust to accommodate higher motor performance and may build a tolerance to evade the detrimental effects (Jiang et al., 2016).

Furthermore, researchers may have devised a method to circumvent the possible cognitive deterioration caused by the exhaustion of high-intensity exercises. In a study, Alves et al., (2014) analyzed the use of HIIT as an alternative to traditional exercises. HIIT consists of a series of brief, intermittent bursts of intense exercise separated by intervals of rest or low-intensity exercise. HIIT can be extremely beneficial as studies have found people to enjoy it more than moderate exercise (Bartlett et al., 2011) and is considered to be time-efficient (this takes between 10-20 minutes). Alves et al. (2014) compared moderate exercise with HIIT by studying 22 subjects (9 men and 13 women). The results concluded that compared to moderate exercise, HIIT did indeed increase the cognitive function of selective attention tests, however, did not show improvement on short-term memory (Alves et al., 2014). According to this study, HIIT exercise enhances executive function just as much as moderate exercise and even exceeds it in terms of selective attention.

A similar study was conducted to analyze the effects of HIIT on executive function. They studied 12 male subjects using the Stroop test. They discovered that both moderate and high-intensity exercise had an equivalent impact on executive function immediately following exercise. However, as opposed to the moderate workouts, the HIIT had a positive effect on executive function for a full 30 minutes post-workout. These findings show that HIIT may be a more effective technique for sustained improvement of executive function over time than moderate exercise (Tsukamoto et al., 2016).

Research seems to indicate that while all levels of intensities have some beneficial effect on cognition, there are preferred levels. Moderate exercise seems to be the optimal level while anything more intense seems to be detrimental, in line with the inverted U theory. However, researchers have identified a method to maximize higher intensity workouts, by incorporating breaks throughout the routine. These HIIT exercises were seen to match moderate exercise benefits in some executive functions while outperforming it in other ones.

Age Groups and Dose

One interesting component of exercise's effect on cognition is how the discussion varies between age groups. In children and adolescents, the studies analyze how exercise affects cognitive development and whether it should be implemented in the school curriculum. In adults, the discussion revolves around whether it improves cognitive function significantly enough to affect career development and job success. In the elderly, researchers investigate whether it can prevent cognitive decline and possibly even improve cognitive function. While exercise has been proven to help cognition overall, a review of the studies will help determine whether these findings hold true throughout different age groups, whether any group is favored, and the recommended exercise regimen.

Children and Adolescents

The primary goal of children and adolescents during their childhood years (ages 4-18) involve succeeding in school, creating social experiences, and progression of skills. Therefore, the development of cognitive and executive functions is crucial during this period. Memory, recall, concentration, and learning allows for better test-taking skills and higher academic achievements. Self-awareness and understanding other people's perspectives help foster social connections. A meta-analysis done by Alvarez-Bueno et al., (2017) on exercise's relationship with cognitive and executive functions in children and adolescents. They concluded that exercise has substantial beneficial effects on these functions including working memory, inhibition, and cognitive flexibility. In a cross-sectional study, Chaddock et al., (2010) discovered that active children have bigger hippocampus volumes than less active children. An increase in these areas has been associated with improved memory, which lends itself to the possibility that exercise throughout childhood may result in long-term changes in brain structure and function (Chaddock et al., 2010). Additionally, multiple studies have found that an increase in exercise has led to higher grades and academic success among children and adolescents (Brock et al., 2009; Ardoy et al., 2014; Donnelly & Lambourne, 2011). These findings seem to support that the findings of this paper pertain to children and adolescents. These positive associations strongly suggest that resources should be allocated on physical education in schools and be incorporated into the grade school curriculum (Álvarez-Bueno et al., 2017).

Young To Middle-Aged Adults

The application of the findings of this paper on young to middle-aged individuals (ages 18-50) is significant for a number of reasons. Besides for the fact that the bulk of the world's population is in this age group, adults are beginning, building, and establishing their careers and relationships during this stage. Cognitive improvement has been found to affect work accomplishment and career success (Judge et al., 2010; Lang et al., 2010) while providing a sense of fulfillment that creates an overall wellness to the individual. A systematic review looked at the relationship between physical activity and cognitive performance of adults in that age bracket (Cox et al., 2016). The review confirmed that exercise is positively associated with executive function. As for the frequency of exercise, researchers have not identified a specific amount that is beneficial, rather the magnitude of the effect rose as the intervention length increased (Ludyga et al., 2020). Interestingly, the review only discovered a limited collection of relevant literature (14 studies) exploring this association because the majority of the research focused on children and the elderly. Although a positive association was found, the small sample size disallows for any unequivocal conclusions. This age group represents a significant period of people's lives and it is imperative that more research is done to ascertain whether the findings of this paper are fully pertinent to them (Cox et al., 2016).

Elderly

In the elderly the focus hones in on whether exercise can prevent dementia, preserve cognition, and even improve cognitive processes. At the same time, the exercise has to be not too physically demanding in that the older adult can still be capable of executing the exercise without risking injury. Researchers have found that exercise benefits healthy elderly adults in significantly improving both memory and executive functions. Additionally, exercise has been positively associated with helping elderly adults with cognitive impairments prevent decline and improve cognition in neurodegenerative diseases such as dementia and Alzheimer's (Blondell et al., 2014). To maximize the effects, the findings of this paper suggest a combination of aerobic and resistance exercises, as both have been linked to positive changes in neurobiological pathways, and they are likely to complement one another. Being that IGF-1 deficiency has been associated with cognitive decline, resistance exercise has been found to combat this by increasing IGF-1 concentrations (Tsai et al., 2015). Therefore, older adults should engage in a combination of aerobic and anaerobic workouts at least three times per week (45 min per session), on as many days of the week as possible (Sanders et al., 2019; Northey et al., 2017).

Summary and Further Research

In conclusion, while exercise has been found to overall benefit and improve cognitive and executive functions, several factors modulate how effective it is. Various elements of exercise stimulate different mechanisms which modifies their impact. Aerobic exercise has been found to significantly improve cognition by improving blood flow and increasing transportation of nutrients and oxygen to areas in the central nervous system. While anaerobic exercise has also been proven to increase IGF-1 which improves overall cognitive function, the buildup of lactic acid has a detrimental effect on cognition. Older adults though are still recommended to include anaerobic exercise as part of their regimen because it is the direct result of a lack of IGF-1 that causes their decline in cognitive function. Furthermore, exercises that include specific cognitive brain stimulation were found to directly improve that cognitive function. The greater the complexity of the task, the greater the impact on cognition. Following the inverted U hypothesis, moderate exercise was determined to be the overall optimal level of intensity. However, HIIT exercise matched moderate exercise's effect on cognitive function in some areas and even performed better in other areas. Therefore, it may be seen as an alternative as some people found HIIT more enjoyable and more time efficient. In regard to age, these findings are applicable to all age groups, particularly among children, adolescents, and older adults.

Further research is necessary to determine the exact magnitude of impact exercise had on young to middle-aged adults as the number of studies was limited. In addition, while overall cognition was found to be improved by exercise, the research was unable to determine the exact benefit of different modalities of exercise on specific cognitive functions. Therefore, in practice, it may be difficult to target a specific cognition function, such as attention or memory, with specific types of exercises in regard to intensity, type, and duration. Furthermore, as exercises' effect on cognition is a relativity new area of study, long-term studies are required to determine whether these effects are permanent or transient.

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