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The Impact of Chronic Exercise on Cognitive Function: An Overview of Reviews

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Abstract

Objective: Understanding the associations between cognitive function and chronic exercise has gained significant attention in the last decade. This overview aims to consolidate current knowledge and shed light on potential benefits of long-term exercise on cognitive abilities.
Method: Relevant databases, including Scopus, PubMed, and Web of Science, were searched through predefined keywords related to chronic exercise and cognitive function. We included all relevant systematic-reviews and meta-analysis in our data-synthesizing.
Results: We identified 74 references across PubMed (33), Scopus (35), and Web of Sciences (6). After deduplication, 52 unique references remained. Screening by title and abstract yielded 28 relevant studies. Full-text review based on inclusion criteria resulted in nine eligible articles. Most were meta-analyses, examining 10 to 71 randomized controlled trials on executive functions across various age groups and health statuses. Both acute and chronic exercises demonstrated small to moderate positive effects on cognitive functions, with chronic exercise outcomes influenced by type, duration, frequency, session length, age, and cognitive status.
Conclusion: Extensive research underscores a robust and compelling link between involving in regular, long-term physical exercise and enhancement of cognitive functioning. This connection emphasizes the critical role that consistent physical activity plays in safeguarding mental well-being and maintaining sharp cognitive abilities throughout various life stages. Positive effect of sustained physical exercise on cognitive functioning serves as a compelling reason to integrate exercise as a fundamental component of a holistic approach to mental wellness and cognitive longevity.

Key words: *Cognitive Function; Exercise; Mental Health; Physical Activity; Psychiatric Disorders*

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It has been shown that chronic exercise, which is defined as planned and purposeful physical activities for a relatively long time (1, 2), has many physiological and psychological (3) benefits across different age groups. It includes, but is not limited to, improving cardiovascular health, enhancing blood circulation and respiratory function (4), increasing muscle strength and endurance (5), helping to regulate metabolism, contributing to weight management and reducing risk of chronic illnesses like diabetes and hypertension. On psychological front, chronic exercise has been shown to alleviate stress (6), anxiety (7), and depression (8) through releasing endorphin, the body's natural mood elevator. Additionally, it can help reduce levels of the stress hormone cortisol, leading to improved mood and reduced anxiety (9). In terms of symptoms, chronic exercise has been shown to reduce feelings of sadness, hopelessness, and excessive worry commonly associated with depression and anxiety (10). Moreover, it plays critical roles in improving mood and decreasing the frequency and intensity of panic attacks (11). For individuals with ADHD, chronic exercise has been associated with improvements in attention span, impulse control, and reduction in hyperactivity symptoms. Additionally, it can boost self-esteem and mood in individuals with ADHD. In fact, it can serve as a complementary treatment to traditional ADHD therapies (12). When it comes to sleep, chronic exercise has been found to help manage sleep paradigms and enhance the sleep quality. This is essential for managing mood disorders and maintaining overall mental well-being (13). Although the research is less extensive, chronic exercise has shown promise in improving symptoms and general well-being for individuals with schizophrenia, substance use disorder, and bipolar disorder (14, 15). It may help in managing symptoms and improving overall quality of life (16). Regular physical activity also promotes better sleep patterns, enhances cognitive function, and fosters a sense of well-being and self-confidence. Additionally, engaging in group activities through chronic exercise may provide social support and strengthen interpersonal relationships, further improving mental health (17).

In the contemporary landscape of health research, there has been a notable surge in interest surrounding the exploration of how chronic exercise may influence and elevate brain function and cognitive abilities. This heightened interest stems from a growing recognition of the interconnectedness between physical fitness and cognitive well-being. As advancements in neuroscience continue to shed light on the complex mechanisms underlying brain function (18), there is a growing realization that regular engagement in exercise might hold significant promise for optimizing cognitive processes. With mounting evidence suggesting that physical activity can exert profound effects on neural plasticity, synaptic connectivity, and neurochemical signaling (19), researchers are eager to delve deeper into the potential therapeutic implications of chronic exercise for bolstering cognitive functions. Moreover, as societies grapple with the rising prevalence of age-related neurologic impairments and cognitive declines, like dementia, there is a pressing need to identify effective strategies for promoting brain health and resilience across the lifespan. Chronic exercise emerges as a compelling avenue for intervention, offering a holistic approach to enhancing cognitive vitality and mitigating the risk of cognitive impairment (20, 21).

Against this backdrop, health researchers are embarking on multidisciplinary investigations that span neuroscience, exercise physiology, and behavioral psychology. Through rigorous experimentation and longitudinal studies, they seek to elaborate precise processes by which chronic activity exerts its cognitive benefits, identify optimal exercise modalities and intensities, and elucidate the underlying neurobiological pathways involved (22). In doing so, they aim to not only expand our understanding of intricate interplay between physical activities and cognitive function but also to pave the way to develop targeted interventions and personalized exercise prescriptions that can optimize brain health and cognitive resilience across diverse populations.

Emerging evidence suggests that chronic exercises may exert useful influences on cognitive functioning through multiple mechanisms. Physical activity has been linked to increased levels of neurotrophic factors, like brain-derived neurotrophic factor (BDNF) (19), which promote neuroplasticity and cognitive function (23). Moreover, exercises have been proven to decrease inflammation (19) and enhance cardiovascular health (24), both of which are important factors in cognitive health (25).

Despite these potential benefits, associations between cognitive functioning and chronic exercise is not yet fully understood. Previous reviews have reported conflicting findings, with some indicating a positive relationship between cognitive function and exercise, while others have found limited or inconsistent effects. These discrepancies may be attributed to differences in research designs, exercise interventions, outcome measure, and participant characteristics. This umbrella review wants to synthesize and critically evaluate existing evidence on association between chronic exercises and cognitive functioning. Through examining a wide range of reviews, we seek to present a complete review of current state of knowledge in this field. Particularly, we would explore influences of chronic exercises on different aspects of cognitive functioning, such as memory, executive functions, and processing speed. Furthermore, we will investigate potential moderators of this relationship, such as intensity, type, and duration of exercise, and also age and health status of participants. Understanding these factors is essential

for elucidating the underlying mechanisms and optimizing the cognitive benefits of exercise.

Materials and Methods

In our study as an umbrella review, our quest for relevant literature spanned three eminent scientific databases: PubMed, Scopus, and Web of Sciences. Our objective was to identify systematic reviews and meta-analyses exploring impacts of chronic exercises on cognitive functioning. Employing carefully selected search terms, we fine-tuned our search parameters and utilized the databases' filters to isolate systematic reviews and meta-analyses exclusively. Subsequently, we meticulously purged duplicate references from our findings before embarking on a meticulous screening process based on the titles and abstracts of the remaining papers. Each eligible article underwent thorough scrutiny by our research team, ensuring adherence to predefined criteria. Relevant data pertaining to impacts of chronic exercises on cognitive functioning were systematically extracted and organized using a predefined form, facilitating comprehensive analysis and synthesis of the reviewed literature.

Table 1. Summary of Findings of Included Systematic Reviews and Meta-Analyses on the Impact of Chronic Exercise on Cognitive Function

Author (Year), Type of Study	Aim	Primary Studies	Relevant Findings	Potential Risk of Bias
Zhang *et al*. (2023), Meta-analysis (28)	To investigate the impact of exercise intervention on cognitive functions in normal populations.	54 RCTs	Exercise intervention led to large, significant enhancement in overall cognition, moderate, significant improvements in EF and memory, and positive but not statistically significant impacts on information processing and attention. Among the different age groups, older adults (over 60 years) experienced the most substantial cognitive benefits from exercises, particularly in EFs, overall cognition, and memory, relative to younger individuals (aged 6–60 years).	Low
Liu *et al.* (2020), Meta-analysis (29)	To assess the impact of chronic and acute exercise on EFs in youths	36 RCTs	Both acute and chronic exercise can significantly enhance EF in youths. The impact on cognitive flexibility and inhibitory control is seen as having small effect size, whereas impact on working memory is viewed as having a moderate effect size.	Low
Haverkamp *et al*. (2020), Meta-analysis (30)	To assess the impact of PA intervention on cognition and pedagogical outcomes in youths.	71 RCTs	Results indicated that acute interventions significantly enhanced attention, processing speed, and inhibition. A meta-regression analysis revealed that shorter intervention durations were linked to larger enhancement in cognitive flexibility and attention, while factors such as gender, age, dose and intensity did not show significant associations. Long-term intervention notably enhanced cognitive flexibility, attention, processing speed, working memory, and language skills. In the meta-regression, a larger percentage of males was related to higher improvement in working memory and attention, whereas other variables were not significantly associated.	Low
Chen *et al*. (2020), Meta-analysis (31)	To assess the impact of PA on EFs in elderly people and investigate potential moderators underpinning the impacts of PA on EFs.	33 RCTs	Exercise training was found to significantly improve EF overall. The improvement was consistent across the sub-domains of inhibition, updating, and shifting. Frequency of exercise notably influenced the outcomes, with moderate frequency yielding better results than low frequency. The type of exercise also mattered, with other exercises, yoga and Tai Chi, and resistance exercise showing larger effects than aerobic and combined exercise. Shorter training lengths were more effective than longer ones. The intensity and session time of exercise did not significantly impact the outcomes. Age was a significant factor, with younger participants (55-65 years old) and middle-aged participants (66-75 years old) benefiting more than older participants (over 75 years old). Sedentary individuals experienced greater improvements	Low

			compared to those who were already physically fit. Additionally, cognitively normal individuals showed more significant benefits than people with mild cognitive impairments. No notable difference was found based on sex.	
Loprinzi *et al*. (2018), Systematic review (32)	To assess the impact of PA on memory among young to middle-aged people.	17 RCTs	Both chronic and acute PA seem to have a significant impact on memory in young to middle-aged people.	High
Lin *et al*. (2024), Meta-analysis (35)	To investigate the effect of chronic exercise on EFs in overweight children.	10 RCTs	Chronic exercise interventions consistently improved EF, regardless of intervention duration, the weekly frequency, or the length of each session. However, due to the limitation in quantity and design of the trials, more high-quality trial is necessary to reinforce the findings.	Low
Sun *et al*. (2021), Meta-analysis (36)	To assess the impact of PA training on cognitive functioning of obese youths	17 RCTs	The meta-analysis found that PA training enhanced main EFs (core-EFs) and non-EFs, but not pedagogical outcome or metacognition. Core-EFs saw the most benefit from enriched PA and combined enriched and enhanced PA intervention, whereas non-EFs improved more with enhanced PA. Additionally, interventions that positively affected adiposity measures led to greater improvements in core-EFs compared to those that did not impact adiposity.	Low
Huang *et al*. (2023), Meta-analysis (33)	To assess the impact of of CEIs on EFs and main signs in youths with ADHD.	22 RCTs	CEIs had a small positive effect on overall main signs and inattention in youths with ADHD. Closed-skill exercises led to significant improvements in core symptoms, while open-skill exercises did not. CEIs also showed a moderate useful effect on global EF and a moderate-to-large impact on certain EFs. These effects were consistent regardless of age group (children or adolescents), exercise session duration, or the total number of exercise sessions.	Low
Liang *et al*. (2022), Meta-analysis (34)	To assess the impact of of PA intervention on EF in youths with ASD.	14 RCTs	CEIs showed a small to moderate positive impact on global EF in youths with ASD. Specifically, these interventions had small to moderate enhancement in cognitive flexibility and inhibitory control. Nonetheless, the impact on working memory was not significant.	Low

Inclusion/Exclusion Criteria

Our study encompassed systematic reviews and meta-analytic studies exploring impacts of chronic exercises on cognitive functioning among healthy and patient populations. We excluded studies that included unplanned physical activities, just acute exercise (review studies that contained both chronic and acute exercise were included), and animal subjects.

Assesing Risk of Bias

We employed the Risk of Bias in Systematic reviews (ROBIS) checklist to thoroughly evaluate quality of evidence gathered from studies analyzed (26, 27). The ROBIS tool helps researchers and reviewers evaluate the methodological rigor of systematic reviews by identifying potential sources of bias that could affect the validity and reliability of their findings. The ROBIS tool contains a structured approach for evaluating risk of bias across four domains: study eligibility criteria, identification and selection of studies, data collection and study appraisal, and synthesis and findings. Within every domain, specific signaling items help reviewers investigate the risk of bias.

Results

The goal of this research was to explore the state of current evidence regarding potential impacts of chronic exercises on cognitive functioning. Totally, we found 74 refrences from three databases (33, 35, and 6 articles from PubMed, Scopus and Web of Sciences, respectively). After removing duplicates, 52 unique references remained. In the next step, by reviewing the 52 references based on their title and abstract, we found 28 relevant studies. After that, we carefully explored the full text of the remaining papers according to the

predefined exclusion and inclusion criteria. In the final step, nine eligible articles remained for data synthesizing (Figure 1).

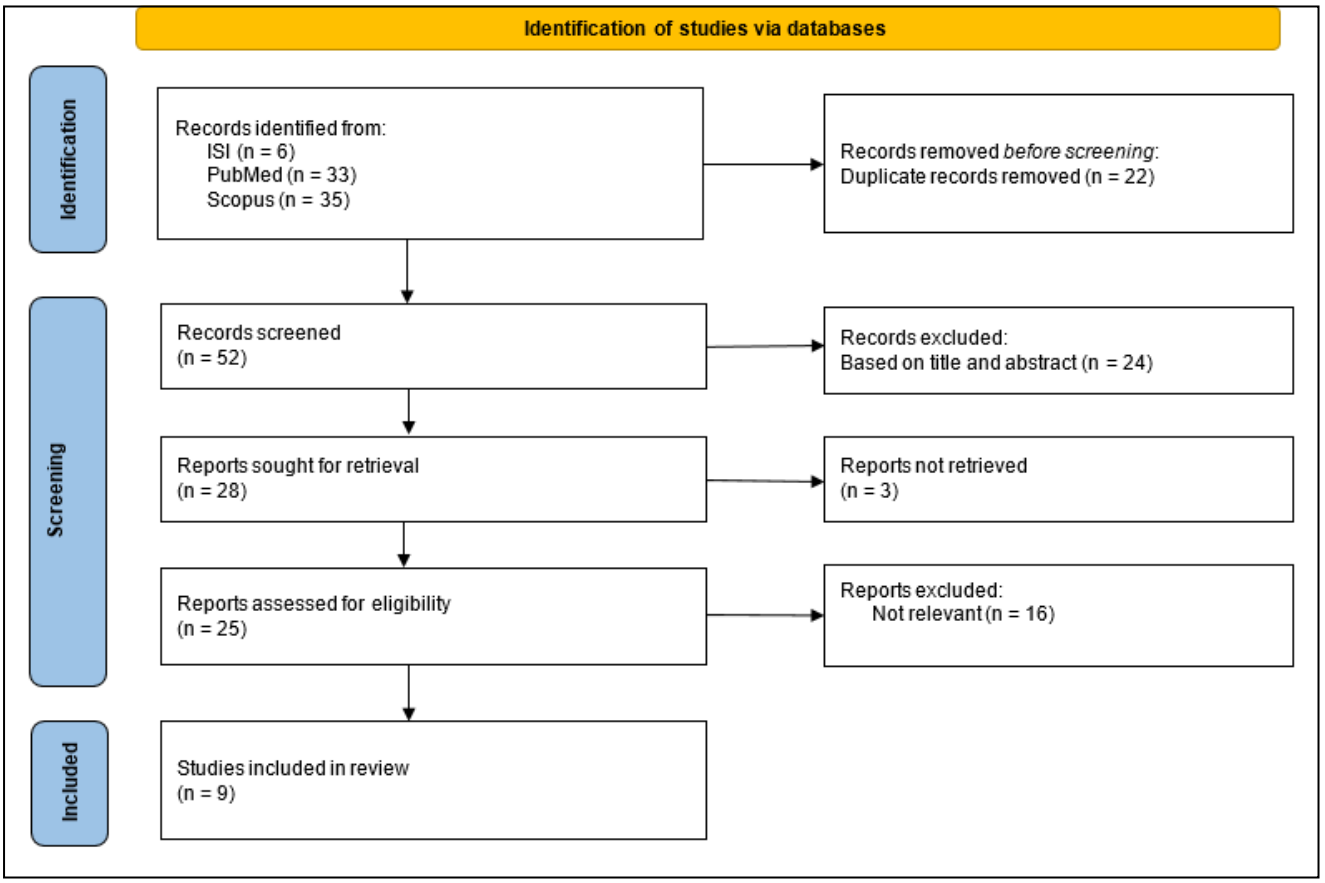

Figure 1. PRISMA Diagram of Different Phases of Our Study To Include Relevant Studies on the Impact of Chronic Exercise on Cognitive Function.

All studies, except one, were meta-analyses and included 10 to 71 randomized controlled trials, and executive functions were the most studied cognitive function. Regarding the study population, different age groups (adolescents, children, adults, and older adults), as well as healthy and patient (ASD, ADHD, overweight and obese) subjects were studied. Five trials have assessed the impact of exercise intervention on different cognitive functions in healthy volunteers (28-32). One study in children and adolescents with ADHD (33), one study in children and adolescents with ASD (34), and two studies have investigated the effect of chronic exetcise-based intervention on cognitive function of obese youths (35, 36). Overall, cognition, working memory, executive function, inhibitory control, cognitive flexibility, memory, attention, language skills, information processing, and academic performance have been studied as cognitive outcomes. Based on the five studies among the general population, regular physical activity significantly improves global cognition (large effect size), executive function and memory (moderate effect size) in different age groups (28), working memory (moderate effect size), cognitive flexibility and inhibitory control (small effect sizes) in youths (29), processing speed, cognitive flexibility, language skills (small effect size), working memory and attention (moderate effect size) in adolescents or young adults (30), executive function (small effect size) in older adults (31), and memory functioning in young to middle-aged adults (32). Two meta-analytic studies that assessed the impact of physical activity intervention on the cognitive functioning of obese youths have suggested that chronic exercise has small positive effect on executive functions in this group of children and adolescents (35, 36). ADHD and ASD are most common neurodevelopmental disorders. Huang *et al*. (33) found that chronic exercise interventions have small to moderate useful influences on EFs and main symptoms in youths with ADHD. Similarly, a meta-analysis conducted through Liang *et al*. (34) revealed that long-term exercise intervention had a small to moderate positive impact on overall executive functions in youths with ASD, especially in terms of cognitive flexibility and inhibitory control.

Although all included studies indicate that regular exercise can have small to moderate positive effects on different cognitive functions across various populations, this effect is affected by several factors, such as exercise type, intervention duration, weekly frequency, session length, and the participants' age and cognitive status.

Discussion

To gain a better understanding of chronic exercise impacts on cognitive functions, we comprehensively reviewed the literature and found nine meta-analyses and systematic reviews. Five studies focused on healthy population, involving children, adolescents, and adults. Zhang and colleagues (28) discovered that engaging in exercise had beneficial impacts on general cognition and specific cognitive areas; aerobic exercises were particularly effective in enhancing overall cognition, while resistance exercises showed notable improvements in executive function. Additionally, mind-body exercises were found to enhance memory. Across different age groups, older adults experienced the most significant cognitive benefits from exercise, particularly in terms of global cognition, executive function, and memory when compared to those who did not engage in exercise. In another meta-analytic study, Liu *et al*. (29) reviewed 36 RCTs and revealed that chronic and acute exercise regimes have been demonstrated to enhance executive functions of youths. The impact on cognitive flexibility and inhibitory control is considered minor, while the effect on working memory is deemed moderate. Haverkamp and colleagues (30) performed a meta-analysis to examine the influence of excercise intervention on cognitive functioning and pedagogical outcomes among youths. Their findings indicated that acute interventions enhanced attention, processing speed, and inhibition. A meta-regression revealed that short-term interventions were significantly linked with higher enhancement in cognitive flexibility and attention, while factors such as gender, age, dose, and intensity did not have a significant impact. Chronic interventions markedly enhanced cognitive flexibility, attention, processing speed, working memory, and language abilities. In the meta-regression, a larger percentage of males correlated with better improvements in working memory and attention, whereas other variables were not significant factors. As adults and older adults are vulnerable groups to cognitive decline, investigating any effective interventions for cognitive enhancement is necessary for them. In relation to this issue, Chen *et al*. (31) reviewed how exercise trainings affect EFs in elderly volunteers and investigated potential factors that may affect the outcomes of exercise training on EFs. Based on their findings, there was a small yet significant enhancement in EF associated with exercise training. No substantial differences were observed among the EF domains of updating, inhibition, and shifting, indicating uniform improvements across these areas. The effects varied according to the frequency of exercise, with moderate frequency showing greater effect sizes (ESs) compared to low frequency. Different types of exercise also influenced the ESs, with the largest improvements seen in alternative exercises, followed in order by Tai Chi and yoga, resistance training, aerobic workouts, and combined exercises. The duration of the exercise programs also affected the outcomes, with shorter programs showing the largest ESs, followed by medium and longer durations. There were no significant changes based on the intensity of exercises or the duration of sessions. Participant characteristics also moderated the outcomes; age was a significant factor, with pronounced benefits observed in individuals aged 55-65 years and 66-75 years, but not in those over 75. The physical fitness level of participants further influenced the results, with larger ESs seen in sedentary individuals compared to their fitter counterparts. Cognitive status was another moderator; those with normal cognitive functions experienced greater benefits relative to those with mild cognitive impairments. No notable difference in outcomes was related to the sex of the participants. In an older review study, Loprinzi *et al*. (32) also found similar results.

Chronic exercises have been demonstrated to show several positive influences on cognitive functioning at multiple levels, including cellular, brain systems-level, and behavioral levels. At the cellular level, chronic exercise can lead to increased neurogenesis, which is the process of generating new neurons within the brain, especially in the hippocampus (37). This can enhance brain plasticity and improve cognitive function (38). Exercise is also shown to elevate the level of BDNF, a protein to support growth, survival, and differentiation of neurons. This protein has been associated with improvement in learning, memory, and overall cognitive function (39). Moreover, the HPA-axis is involved in the body's reaction to stress. Chronic exercise can modulate HPA-axis activity, leading to reduced levels of stress hormones such as cortisol (40). Furthremore, chronic exercise affects various neurotransmitter systems, including dopamine, serotonin, and norepinephrine, which play crucial roles in mood regulation, stress response, and cognitive function. Exercises have been proven to elevate the release and availability of these neurotransmitters, contributing to improved mood, attention, and cognitive performance (41). At the brain systems-level, chronic exercise has been linked to changes in brain morphology, including increased gray matter volumes in certain brain areas such as the prefrontal lobe and hippocampus. These structural alterations are linked to improved cognitive functioning, like EFs and memory (42). Chronic exercise has also been associated with alterations in neuroelectric potentials, including changes in brainwave patterns that are linked to attention, memory, and cognitive processing speed (43). Chronic exercise has been found to enhance brain connectivity, particularly within neural networks associated with cognition and memory.

Improved brain connectivity is thought to support efficient information processing and optimal cognitive function (44). In terms of behavioral effects, chronic exercise has been related to enhanced cognitive function, like improved attention, memory, and executive functions. It also has the capability to decrease the risk of cognitive impairments and neurodegenerative diseases in later life (45). These outcomes are believed to be mediated via various processes, including improved cerebral blood flow, increased synaptogenesis, and reduced inflammation in the brain (46). Figure 2 provides a conceptual model of mechanisms of action of chronic exercise on cognitive functioning at different levels.

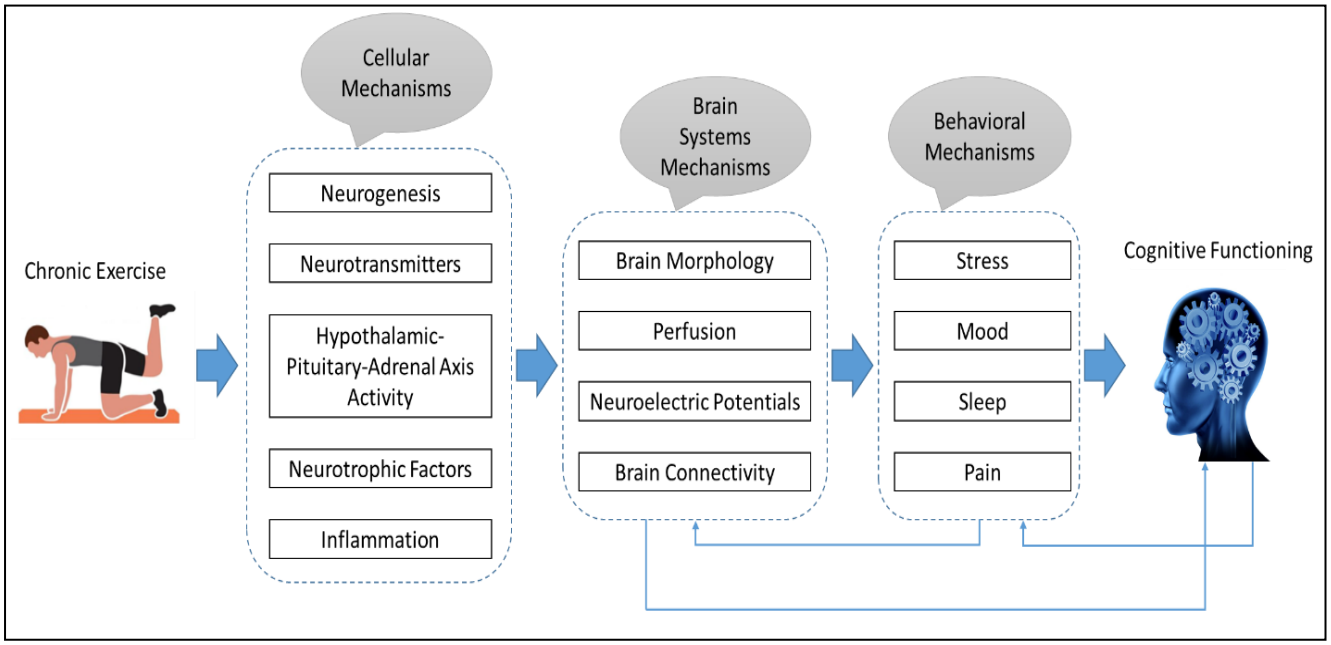

Figure 2. Conceptual Model of Mechanisms of Action of Chronic Exercise on Cognitive Functioning at Different Levels

Two meta-analytic studies explored the impacts of long-term exercises on cognitive functioning among obese children and adolescents (35). Both studies demonstrated that participants experienced enhancements in their executive functions following a period of chronic exercise intervention. The research from Lin and colleagues (35) showed that this positive impact has not been correlated with intervention duration, frequency, and length. To clarify the impact of task characteristics on the level of cognitive enhancement among obese youths, Sun and colleagues (36) divided interventions into 3 types: 1) Enhanced: raising time; 2) Enriched: raising cognitive demand of experiments; 3) Both (enriched and enhanced). They found that main EFs anhanced after type 2 and type 3 interventions, whereas the non-EF domains enhanced after type 1 intervention. Neurodevelopmental disorders constituted another group of populations under investigation (33, 34). In a meta-analytic study, impact of chronic exercise interventions on EFs and main signs in youths with ADHD was assessed (33). Their results revealed that exercise interventions had a slight positive impact on core symptoms overall, particularly addressing inattention in youths diagnosed with ADHD. Notably, closed-skill exercises displayed a substantial enhancement in main signs, while open-skill exercise did not yield the same effect. Moreover, exercise interventions exhibited a moderate benefit on overall EFs and a moderate to large effect on certain EFs. Interestingly, combined effects on EFs and main signs were not notably influenced by factors such as the age group of the study population (children or adolescents), duration of exercise sessions, or total number of exercise sessions. In the context of autism spectrum disorders (ASD) (34), the research indicated that sustained exercise interventions resulted in a modest to moderate improvement in overall EFs among youths with ASD. When considering EF domains specifically, sustained exercise interventions yielded a slight to moderate enhancement in cognitive flexibility and inhibitory control.

Limitation

To better comprehend the association between chronic exercise and cognitive functions it could be helpful to combine and reanalyze the results of the included meta-analysis, which was not considered in our research. The lack of access to all scientific databases, which may cause the loss of some valuable studies, is another limitation of the current research.

Conclusion

Taken together, the available evidence underscores a strong and enduring association between persistent

physical exercises and cognitive functioning, underscoring the significance of consistent physical activity in sustaining brain health and cognitive acuity across all stages of life. It is imperative that future investigations delve deeper into uncovering the most effective exercise routines, their ideal duration, and intensity levels necessary to optimize cognitive advantages. Furthermore, there is an urgent need to deepen our understanding of the intricate neurobiological mechanisms that underlie this relationship, which will be vital in informing strategies aimed at improving cognitive well-being by physical activity. As cognitive dysfunctions are underlying factors for different psychiatric disorders, recommending regular physical activity can be an accessible and affordable way to prevent and decrease psychological problems among the general population. Nonetheless, it is important to note that while exercise can have numerous positive effects, it is not a panacea. It should be thought of as a part of a holistic approach to managing these disorders, which may include therapy, medication, and other lifestyle changes.

Conflict of Interest

None.

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