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Physical Exercise as a Therapeutic Strategy for ADHD in Children and Adolescents

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Abstract

Background: ADHD (Attention Deficit Hyperactivity Disorder) is one of the most commonly diagnosed neurobiological disorders in children and adolescents. It is characterized by difficulties in maintaining attention, impulsivity, and excessive physical activity, which affect daily functioning at school, at home, and in social interactions. Traditional approaches to ADHD treatment are primarily based on pharmacotherapy and behavioral therapy. However,

there is a growing interest in the role of physical activity as a natural and complementary method for managing the disorder.

Aim: This article aims to analyze the impact of different forms of physical activity on alleviating ADHD symptoms amongst young patients and to explore the mechanisms through which sports can serve as an effective therapeutic tool.

Materials and methods: A review was conducted incorporating data from PubMed and Google Scholar using keywords such as "ADHD", "sports", "physical activity","mental health", "adolescents" and "children".

Results: Scientific studies indicate that regular physical activity, particularly aerobic exercises and team sports, can improve executive functions, emotional regulation, and concentration levels in children with ADHD. Moreover, physical activity influences neurotransmitters such as dopamine and norepinephrine, which play a key role in ADHD symptoms.

Conclusion: A literature review suggests that incorporating physical activity into the daily lives of children with ADHD can help alleviate symptoms such as inattention, impulsivity, impaired executive function, emotional dysregulation, and poor concentration. However, study outcomes remain inconsistent and call for further investigation. Gaining a clearer understanding of the mechanisms through which physical activity exerts its effects, as well as determining the most effective approaches, could support the development of new therapeutic strategies for managing ADHD in young individuals.

KEYWORDS: ADHD, attention, cognitive functions, adolescent, sports, physical activity, mental health, children

ADHD

Attention deficit hyperactivity disorder (ADHD) is one of the most commonly diagnosed neurodevelopmental disorder in children, with a global prevalence ranging from 5.2% to 7.2% (Thomas et al., 2015), with diagnoses being more common in boys than in girls, at a ratio of approximately three boys for every one girl. (Witthen et al., 2011) Although ADHD has long been viewed as a disorder of childhood, it is now well recognized that significant symptoms often persist into adulthood in a substantial proportion of cases (approximately 65%). (Cortese et al., 2018) The disorder can lead to difficulties in education, challenges in securing and maintaining employment, marital problems, and an increased risk of engaging in criminal activities. Additionally, ADHD is frequently comorbid with other mental health disorders,

including personality disorders, self-harm, mood disorders, and substance abuse. (Willoughby, 2003, Shaw et al., 2012, Choudhry et al., 2013)
The core symptoms of ADHD include inattention, hyperactivity and impulsivity. (Polanczyk et al., 2014) Children with ADHD often struggle with tasks that involve response inhibition, working memory, planning, and adapting their actions and thoughts flexibly. This is commonly linked to a core deficit in executive functions, though it may also stem from more fundamental impairments, such as difficulties in allocating attentional or cognitive resources. (Hilger et al., 2020)
ADHD treatment includes both pharmacological and non-pharmacological approaches, each playing a crucial role in symptom management. Stimulant medications such as methylphenidate and amphetamines are widely used and have been shown to be effective, though their long-term benefits remain uncertain, and some patients experience side effects or develop tolerance. Non-stimulant alternatives like atomoxetine and guanfacine provide additional options but tend to have a slower onset of action. (Posner et al., 2020) Medication has been proven effective in reducing ADHD symptoms and related motor difficulties. (Kaiser et al., 2015, O'Connor et al., 2023) Behavioral and psychological interventions, including cognitive-behavioral therapy (CBT), parent training, and social skills training, play a crucial role in improving self-regulation, emotional control, and executive functioning. These approaches are particularly beneficial for individuals who do not respond well to medication or experience adverse effects. A multimodal treatment strategy that combines medication with behavioral interventions is often the most effective, as personalized treatment plans tailored to symptom severity and individual needs yield better outcomes. (Posner et al., 2020)
Physical activity (PA) has recently gained recognition as a potential non-pharmacological intervention for improving inhibitory function in patients with ADHD. In children with ADHD, physical exercise has been shown to improve problems of inattention, hyperactivity and impulsivity (Ashdown-Franks et al., 2020, Villa-González et al., 2020), but in adults with ADHD there is still a lack of knowledge. (Lindvall et al., 2023) However, the optimal duration of PA remains unclear, as studies present mixed findings. Some suggest that long-term engagement leads to improvements, while others indicate that even short-term interventions can produce significant benefits. (Wang et al., 2023) This article investigates how different types of physical activity contribute to reducing ADHD symptoms.

Neurological aspects of ADHD

Although the exact etiology of ADHD is still unknown, one of the most widely accepted neurobiological models of ADHD implicates dysregulation in catecholamic systems, particularly those involving dopamine [DA] and norepinephrine [NE], and their effects on brain regions responsible for executive control. Those include the prefrontal cortex (PFC), basal ganglia (especially the caudate nucleus) and cerebellum, which form a distributed network critical for attention, inhibition and working memory - core deficits in ADHD. (Cortese et al., 2012, Rubia et al., 2014) More recent studies highlight how structural and functional impairments in these areas affect how differently individuals with ADHD process cognitive load and task complexity. (Hukherjee et al., 2021) Functional and structural imaging studies have also consistently shown reduced gray matter volume and altered connectivity in these areas in individuals with ADHD. (Castellanos and Proal, 2012, Hoogman et al., 2017) The activity within this network is extremely sensitive to the neurochemical environment,

particularly to the balance and interaction of dopamine and norepinephrine acting through multiple presynaptic and postsynaptic receptors (Arnsten, 2009, Robbins and Arnstern 2009). Dopamine regulates signal-to-noise ratio in the PFC, enhancing goal-directed behavior, while norepinephrine strengthens network connectivity by increasing the salience of relevant signals. (Berridge and Waterhouse, 2003) Both neurotransmitters work synergistically to optimize prefrontal cortical function, and disruptions in their availability or receptor activity may lead to impaired attention regulation and behavioral inhibition. (Del Campo et al., 2011) Executive function deficits are now considered a hallmark of ADHD, and include problems with inhibition, working memory, cognitive flexibility, and planning. (Barkley, 1997) These cognitive domains are mediated by the very fronto-striatal and fronto-cerebellar circuits disrupted in ADHD, supporting the idea that neurochemical abnormalities in catecholaminergic transmission are closely tied to both structural brain differences and observable behavioral symptoms. (Arnsten and Pliszka, 2011) Taken together, this evidence highlights ADHD as a neurodevelopmental disorder rooted in the dysfunctional integration of brain systems that are tightly regulated by dopamine and norepinephrine.

Mechanisms discussed earlier are the basis of most medications for ADHD, which are thought to act primarily on catecholamine pathways. At the synaptic level, they act as catecholamine agonists by increasing the availability of dopamine or norepinephrine, often by inhibiting their reuptake. Each drug works slightly differently. Psychostimulants like methylphenidate (MPH) and amphetamines (AMP) block dopamine and norepinephrine transporters, enhancing neurotransmission mainly in the striatum and prefrontal cortex. Atomoxetine (ATX) selectively blocks the norepinephrine transporter (NET1), boosting norepinephrine levels throughout the brain and dopamine specifically in the prefrontal cortex, where dopamine transporters are scarce. Alpha-2 agonists such as clonidine (CLO) and guanfacine (GFC) activate alpha-2 adrenergic receptors in the brain, increasing norepinephrine activity in the prefrontal cortex, partly through indirect stimulation from the locus coeruleus. Bupropion is metabolized into compounds that strongly increase norepinephrine activity by blocking its transporter. Tricyclic antidepressants (TCAs) primarily block serotonin and norepinephrine reuptake, enhancing their signaling, but have minimal impact on dopamine. Modafinil causes a unique change in the dopamine transporter that differs from standard stimulants. Despite these different mechanisms, all these drugs tend to raise dopamine and/or norepinephrine levels, which affects broader brain circuits—mainly GABAergic and glutamatergic—linked to cognitive functions like executive control, reward processing, memory, and timing. (Caye et al., 2019) All of this information will be considered in exploring which pharmacological mechanisms might be imitated by physical activity and how this can be used in advantage for patients with ADHD.

How exercise affects brain chemistry?

To determine how sport can impact young patients with ADHD it is crucial to understand how sport affects our brain chemistry in general. Physical activity has been associated with a plethora of functional, cellular, and molecular alterations within the brain. It is widely known that exercise improves mood and cognition, accelerating hippocampal neurogenesis in humans and in animal models. Although the exact mechanisms are still not fully discovered, we will look at several studies, both on animals and humans, that link physical activity with brain functions on a molecular level.

Moderate to high-intensity physical exercise elicits neurophysiological responses that promote neurotransmitter synthesis, elevate levels of brain-derived neurotrophic factor (BDNF), and enhance cerebral blood flow. These mechanisms contribute to improved neuroplasticity and cognitive processing. Consequently, such exercise may alleviate core symptoms and comorbidities of attention-deficit/hyperactivity disorder (ADHD) and support neural development and regulation in affected children. (Chan et al., 2023)

Studies have demonstrated that exercise enhances both movement and cognitive function in humans and rodents. In Guendalina Bastioli study, scientists found that 30 days of voluntary exercise increases DA release across the striatum and raises levels of BDNF in the dorsal (motor) part of the striatum. Additionally, stimulating BDNF receptors with a drug also led to increased DA release. These findings suggest that BDNF plays a crucial role in mediating the exercise-induced increase in DA release, offering a potential explanation for how exercise benefits people with dopamine-related neurological and psychiatric conditions. (Bastioli et al., 2022)

Another study demonstrated similar results in patients with Parkinsons Disease. They concluded that aerobic exercise changes how the ventral striatum responds, likely due to modifications in the mesolimbic DA pathway, and it also boosts DA release in the caudate nucleus. These effects suggest that exercise's therapeutic benefits may be partly due to increased DA release and improved adaptability (plasticity) in the corticostriatal brain circuits. (Sacheli et al., 2019) Furthermore, in peripheral inflammation-induced PD animal model, four weeks of treadmill exercise before inflammation has been shown to prevent the inflammation-induced dopaminergic neuron loss. (Wu et al., 2011)

Another noteworthy study on rats found that just one session of physical exercise can enhance memory retention through activation of D1 dopamine receptors and the protein kinase A (PKA) signaling pathway in the hippocampus. The same research group had previously shown that a single exercise session could improve recognition memory via D1/D5 receptor activation. In this new study, they set out to determine whether both receptors are required for this effect or just one. Their findings support the idea that D1-like dopamine receptors, acting through the PKA pathway, play a key role in the memory-enhancing effects of acute exercise. This shows that not only regular aerobic activity might affect the dopamine system, but just one session also may have a positive effect on individuals. (Ramires et al., 2021) Tantillo et al. also investigated the effects of a single session of exercise on children with ADHD. By assessing spontaneous eye blink rates, acoustic startle reflexes, and motor inhibition, they provided indirect evidence that a single exercise session performed at 65%–75% of peak oxygen consumption (VO_2 peak) may lead to increased dopamine levels in the brain. (Tantillo et al., 2002)

Regular physical activity appears to have even more impact on brain chemistry, especially in the long term.

A 2016 meta-analysis of 29 studies found that regular exercise training significantly increases resting BDNF levels in the blood. Overall, chronic aerobic exercise led to higher baseline BDNF (moderate effect size), whereas resistance training showed no significant change. (Dinoff et al., 2016) This suggests that sustained aerobic activity elevates this neurotrophin, which is thought to support brain plasticity and neuron health. Numerous rodent studies report upregulation of BDNF in the brain after long-term voluntary exercise. For example, voluntary wheel running for days to weeks consistently increased BDNF protein in hippocampal regions (dentate gyrus, CA1-CA4) and parts of the cortex. (Vecchio et al., 2018) These biochemical changes in BDNF signaling cascades are robust across different protocols, indicating exercise reliably boosts neurotrophic support in the brain. Converging evidence also shows that regular physical activity enhances dopaminergic function. A 2021 systematic review of 15 studies concluded there are *"*robust effects*"* of long-term exercise on the dopamine system across young and older adults. (Marques et al., 2021) Animal and human studies have found chronic

aerobic exercise can increase dopamine synthesis, upregulate dopamine receptors, and enhance dopamine neurotransmission in various brain regions. (Robertson et al., 2016) These neurochemical adaptations were observed under diverse conditions, suggesting a general pro-dopamine effect of sustained exercise. PET imaging also confirms the impact of PA on the dopamine system. A controlled trial in 2016 using PET scans demonstrated that 8 weeks of structured aerobic training can reverse dopamine deficits in the human striatum. In methamphetamine-dependent adults (who typically have low dopamine D2/D3 receptor availability), those who underwent exercise showed a significant increase in striatal D2/D3 receptor binding compared to non-exercising controls. (Pietrelli et al., 2018) This finding indicates that regular exercise can restore dopamine receptor levels in the brain's reward/motor circuitry even in adults with impaired dopaminergic function.

Long-term exercise also induces changes in the serotonin (5-HT) system. In an animal study of lifelong moderate exercise, trained rats showed *elevated serotonin levels* in the brain (including the raphe nuclei) along with an increase in serotonin transporter (SERT) and 5-HT_{1a} receptor expression in the hippocampus and cortex. (Saskia et al., 2015) In other rodent experiments, sustained exercise has been shown to increase serotonin synthesis and metabolism in regions like the cortex and brainstem. (Erickson et al., 2011) These adaptations suggest that regular physical activity boosts monoamine neurotransmitters (like 5-HT and dopamine), which could underpin its mood-elevating and stress-buffering effects.

Biochemical Changes Linked to Cognitive or Behavioral Outcomes

Exercise seems to not only affect our brain chemistry, but also structure of the brain. It also causes changes in cognition and behaviour. An example of this can be the randomized controlled trial, which studied 120 older adults who exercised aerobically for one year. The exercise group showed a ~2% increase in hippocampal volume, effectively reversing 1–2 years of age-related loss, whereas a sedentary control group had a ~1.4% volume decline. Notably, the gains in hippocampal size correlated with improvements in spatial memory performance. (Donnelly et al., 2016) This landmark study indicates that long-term exercise can induce neurochemical and structural changes (e.g. BDNF-driven neurogenesis) that translate into tangible cognitive benefits in humans.

There are a few systematic reviews that deal with this topic. Donnelly's study tried to answer two questions: "Among children age 5-13 yr, do PA and physical fitness influence cognition, learning, brain structure, and brain function?" and "Among children age 5-13 yr, do PA, physical education (PE), and sports programs influence standardized achievement test performance and concentration/attention?". They analysed 137 studies and concluded that most studies support the hypothesis that physical fitness, individual sessions of physical activity (PA), and structured PA interventions positively influence children's cognitive functioning. However, they found limited evidence regarding the impact of PA on learning outcomes, with only a single cross-sectional study meeting the inclusion criteria. Existing research suggests that PA is associated with brain regions involved in higher-order cognitive functions during controlled tasks. While cross-sectional and longitudinal studies have generally shown positive associations between PA and academic achievement, findings from controlled experimental studies remain inconsistent, highlighting the need for further rigorous research. (Robbins and Arnsten, 2009) Another systematic review found out that lack of physical activity in childhood can cause limited perception and developmental disorders and that children who devote at least an hour each day to intensive physical activity show much better cognitive functioning and concluded that it is important to encourage children do engage in sports, especially in the late childhood,

because it positively influences cognitive and emotional functions. (Bidzan-Bluma and Lipowska, 2018)
Another core symptom of ADHD is attention deficits. Emerging evidence suggests that physical activity (PA) may play a beneficial role in mitigating attentional impairments associated with the disorder. Vanhelst's meta-analysis after adjusting for confounding factors such as age, sex, BMI, parental education, fat mass, aerobic fitness, and study center, adolescents who engaged in more moderate or moderate-to-vigorous physical activity (MVPA) showed significantly better performance on attention tasks. Analysis identified threshold values linked to better attention: at least 41 minutes per day of moderate activity, 12 minutes of vigorous activity, or 58 minutes of MVPA. These results indicate that regular engagement in MVPA may positively influence attention capacity—a key aspect of cognitive function—in adolescents. (Vanhelst et al., 2016)
Similar conclusions were drawn from a 2018 meta analysis which found that a single session of physical activity had a moderate positive effect on attention ($g = 0.43$), while long-term physical activity programs led to small but significant improvements in executive functions ($g = 0.24$), attention ($g = 0.90$ in one study), and academic performance ($g = 0.26$). This suggests that physical activity has beneficial effects on executive function, attention, and academic achievement in preadolescent children. The strongest outcomes are associated with consistent, sustained physical activity interventions implemented over several weeks. (de Greef et al., 2018)

There are also a lot of studies that analyse the impact of PA on cognition in older adults, especially those with Alzheimer's disease (AD). The 2019 meta-analysis of 13 randomized controlled trials with 673 participants diagnosed with AD also found that physical activity significantly improves cognitive function, as measured by MMSE scores. While different amounts of exercise produced varying effects, higher frequency did not necessarily lead to greater benefits. The study highlights the potential of exercise as a cognitive intervention for AD, but emphasizes the need for more rigorously designed trials to confirm these findings and determine optimal exercise parameters. (Jia et al., 2019)
After we examined mechanisms underlying the positive effects of physical activity we will now investigate how different types of sports can impact the young people with ADHD.

Exergaming

The study published in the Scandinavian Journal of Medicine & Science in Sports (Benzing and Schmidt, 2019) aimed to assess the impact of exergaming on executive functions, ADHD symptoms, and motor skills in children with ADHD. Exergaming involves digital games that require physical movement, creating an interactive gaming experience that also serves as a form of physical activity. (Benzing and Schmidt, 2018) By blending physical activity with cognitive exercises in a gamified format, exergaming enhances motivation, variety, and adaptability. (Primack et al., 2012) In a randomized clinical trial, 51 children aged 8–12 years were divided into an intervention group, which participated in an 8-week exergaming program (three 30-minute sessions per week), and a control group on a waitlist.
The results showed that children in the exergaming group demonstrated improvements in reaction time for inhibition and switching tasks, overall psychopathology, and motor skills compared to the control group. However, no improvements were found in updating abilities or core ADHD symptoms, indicating that while exergaming supports some aspects of executive function, its impact on ADHD symptoms remains limited. Additionally, the study noted a high dropout rate in the exergaming group, suggesting that while the intervention has potential

benefits, engagement may be a challenge. These findings suggest that exergaming may have a positive effect on executive functions and motor abilities in children with ADHD, potentially contributing to the reduction of psychopathological symptoms. However, to maximize its benefits and establish exergaming as a valuable complement to ADHD treatment, tailored game designs should be developed. (Benzing and Schmidt, 2019)

Aquatic exercise

The study conducted by Soukaina Hattabi et al. (Hattabi et al. 2022), published in the International Journal of Environmental Research and Public Health investigated the effects of a structured swimming program on the cognitive functions, behavior, and academic performance of Tunisian children with ADHD. The findings indicate that after 12 weeks, children in the experimental group demonstrated significant improvements in inhibitory control, selective attention, and self-regulation, as well as better academic performance. They completed cognitive tasks faster and made fewer errors, reflecting enhanced executive functions. Additionally, improvements in emotional control and classroom behavior were observed, suggesting that structured physical activity can positively impact both cognitive and socio-emotional aspects.

These results support the idea that swimming could serve as an effective non-pharmacological intervention for ADHD, complementing traditional treatments. Engaging and structured exercise programs may help improve self-regulation and academic success in children with ADHD. (Hattabi et al. 2022)

Another study published in Archives of Clinical Neuropsychology in 2014 (Chang et al., 2014) examined whether a water-based exercise intervention, combining aerobic and coordination exercises, could improve response inhibition in children with ADHD. The study involved 30 children aged 5 to 10 years who had been diagnosed with ADHD. Participants were randomly assigned to either an aquatic exercise group or a waitlist control group. The intervention lasted for eight weeks, with participants in the exercise group attending two 90-minute sessions per week. To assess the effects, all children underwent pre- and post-intervention evaluations using the Go/No-Go task and motor coordination tests. The results showed that children in the aquatic exercise group demonstrated significant improvements in accuracy when responding to No-Go stimuli, indicating enhanced inhibitory control. Additionally, improvements in motor coordination were observed in the intervention group. However, no significant differences were found between groups in reaction time or accuracy for Go stimuli. These findings suggest that a structured water-based exercise program incorporating aerobic and coordination activities may enhance behavioral inhibition in children with ADHD. This indicates that such interventions could be effective in supporting executive functions in this population. (Chang et al., 2014)

The case report by Skalidou et al. (Skalidou et al. 2023) presents the effects of a swimming exercise program on ADHD symptoms in an adult diagnosed in childhood. The eight-week training intervention in a 31-year-old woman showed that participating in the swimming program significantly reduced inattention and hyperactivity symptoms, as assessed by the psychometric measures used in the study. (Skalidou et al. 2023)

In another study (Silva et al., 2020), researchers examined the effects of a swimming-learning program on mental health, cognition, and motor coordination in children with ADHD. The results indicated that the aquatic exercise program led to significant improvements in depression, stress levels, cognitive flexibility, and selective attention. Regarding motor coordination and physical fitness, there were notable improvements in lower limb laterality coordination, flexibility, and abdominal endurance. Overall, these findings suggest that a swimming-learning

program can significantly enhance mental health, cognitive function, and motor coordination in children with ADHD. (Silva et al., 2020)

Aerobic exercise

The study, "Measurement of the Effect of Physical Exercise on the Concentration of Individuals with ADHD" by Silva et al. (Silva et al, 2015) examines how short, intense physical exercise affects concentration in children with ADHD. The researchers recruited 28 children, both with and without ADHD, and had them complete a computerized attention task. Before the task, half of the children engaged in five minutes of intense running, while the others remained at rest. The goal was to determine whether brief physical activity could have an immediate positive impact on focus and cognitive performance. The results showed a significant improvement in attention among children with ADHD who participated in the exercise. Their performance on the task improved by 30.52% compared to those who did not exercise, and they performed almost as well as children without ADHD. This suggests that even a short burst of physical activity can temporarily enhance cognitive function in children with ADHD, making it a potential strategy for improving academic performance and daily focus. (Silva et al, 2015)

Another study by Hoza et al. (Hoza et al., 2015) compared the effects of before-school physical activity (PA) versus sedentary classroom-based (SC) interventions on children at risk for ADHD and typically developing children. The PA intervention involved sustained physical activity at an intensity that made children breathe harder, aligning with the moderate-to-vigorous energy expenditure range commonly used in physical activity research. (Marshall et al., 2008) The PA group showed greater improvements in reducing inattention and moodiness, particularly at home. The findings also suggest the potential benefit of SC interventions for managing ADHD symptoms. (Hoza et al., 2015)

The study by Ahmed & Mohamed (Ahmed and Mohamed 2011) examined the impact of aerobic exercise on ADHD symptoms in 84 students aged 11 to 16. The participants were divided into two groups, with the exercise group engaging in a 10-week program that included upper and lower limb, trunk, neck exercises, and running. Significant improvements were observed in attention, motor skills, and classroom behavior in the exercise group, while no improvements were found in the control group. The study concluded that regular aerobic exercise can help alleviate ADHD symptoms. (Ahmed and Mohamed 2011)

The study by Choi et al. (Choi et al., 2015) explored the combined effects of methylphenidate and aerobic exercise on adolescents with ADHD. After six weeks, the exercise group showed improvements in ADHD symptoms, cognitive function, and brain activity, particularly in the right frontal lobe. The exercise group had reduced perseverative errors and better brain responses during cognitive tasks compared to the education group. These results suggest that aerobic exercise enhances the effects of methylphenidate in managing ADHD symptoms and improving brain function. (Choi et al., 2015)

The study “Correlates of physical activity with intrusive thoughts, worry and impulsivity in adults with attention deficit/hyperactivity disorder: a cross-sectional pilot study” (Abramovitch et al., 2013) focused on adults with ADHD, examining the relationship between physical activity and symptoms like impulsivity, intrusive thoughts, and worry. The results showed that adults engaging in frequent aerobic exercise experienced significantly fewer impulsivity symptoms and less intrusive and worrisome thoughts compared to those with low physical activity. These findings suggest a potential link between exercise and reduced ADHD symptoms in adults, warranting further investigation into the causal relationship. (Abramovitch et al., 2013)

It remains unclear whether a single session of exercise can impact ADHD symptoms in adults. Researchers in “Acute Exercise Improves Mood and Motivation in Young Men with ADHD

Symptoms" (Fritz et al., 2016) study examined the effects of a 20-minute cycling session on attention, hyperactivity, mood, and motivation in young men with elevated ADHD symptoms. The results showed that exercise significantly improved mood by increasing energy and reducing fatigue, depression, and confusion. It also enhanced motivation for cognitive tasks. However, there were no observed effects on attention or hyperactivity. These findings suggest that while acute exercise may not directly address core ADHD symptoms, it can provide short-term emotional and motivational benefits. (Fritz et al., 2016)

Mind-body exercises

Tai chi

Most scientific studies conducted so far have concentrated on physical outcomes of Tai Chi like gait, posture, and cardiovascular health, primarily in middle-aged and older adults. (Yang et al., 2015), decrease anger and confusion, enhance positive emotions, and improve mood. (Brown et al., 1995, Jin 1992) Although few studies have examined the effects of Tai Chi in youth populations, these practices are known to provide physical health benefits in both general and disease-specific groups. (Riskowski and Almeheyawi 2019) A small number of preliminary studies have started to explore the effects of Tai Chi in younger adults, suggesting that it may lead to improvements in physical and mental health, mindfulness, mood, perceived stress, and sleep quality. (Webster et al., 2015, Wang et al., 2004, Zheng et al., 2015, Caldwell et al., 2016, Caldwell et al.,2011) However, further research is needed to better understand their impact on psychological well-being, behavior, and adolescent development. (Riskowski and Almeheyawi 2019) The study conducted by Hernandez-Reif et al. (Hernandez-Reif et al., 2001) explored the impact of Tai Chi on anxiety, mood, hyperactivity, and behavior in children with ADHD. Thirteen adolescents diagnosed with ADHD took part in Tai Chi classes twice a week for a period of 5 weeks. Teachers evaluated the children's behavior using the Conners Scale at the start, after the 5-week Tai Chi sessions, and once more 2 weeks later. After the intervention, the adolescents exhibited lower levels of anxiety, improved behavior, reduced daydreaming, fewer inappropriate emotions, and the greatest improvement in hyperactivity. These positive changes were maintained during the 2-week follow-up, even without any additional Tai Chi sessions. (Hernandez-Reif et al., 2001) In a biomarker development study, 34 children participated in an 8-week Tai Chi-based mindful movement program and showed improvements in ADHD symptoms of inattention, hyperactivity/impulsivity, oppositionality and executive dysfunction following treatment, which were linked to better motor performance. (Clark et al., 2020)

Yoga

Yoga practice includes various poses, deep breathing, focus, and both mental and physical relaxation, all of which help regulate emotional states. (Zipkin 1985) Additionally, it supports self-control, enhances attention and concentration, boosts self-confidence, increases body awareness, and reduces stress. (Peck et al., 2005) The systematic review by Gonzalez et al. (Gonzalez et al., 2023) evaluated the effectiveness of yoga and meditation as potential alternatives or supplements to medical treatment for children with ADHD. Researchers analyzed 10 studies selected from an initial pool of 51,675 articles using PubMed and Google Scholar. The findings suggest that yoga can improve ADHD symptoms and serve as an additional therapy. Both interventions positively influenced family dynamics, with meditation

helping parents feel calmer and more mindful when caring for their children. Additionally, yoga and meditation had beneficial effects on mental health, reducing anxiety, stress, and insecurity. Meditation specifically improved executive function, inhibitory control, hyperactivity, impulsivity, attention, and emotional regulation. While these interventions show promise, the small sample sizes in the reviewed studies prevent a definitive conclusion about replacing medication. Instead, yoga and meditation should be considered as complementary treatments to enhance the quality of life for children with ADHD. Further research with larger participant groups and longer study durations is needed to fully assess their long-term benefits. (Gonzalez et al., 2023)

Pilates

Another study, by Kouhbanani et al. (Kouhbanani et al., 2023) aimed to evaluate the effect of Pilates training on attention switching and sustained attention in a sample of adults with ADHD. A total of 52 adults with ADHD, aged 20 to 50 years, were randomly assigned to either a 24-week Pilates training group or a control group, with follow-up assessments conducted six months later. The Pilates group demonstrated significant improvements in sustained attention, as evidenced by reductions in omission errors, commission errors, and reaction time. Additionally, attention switching showed notable enhancement in the post-test, with fewer perseverative errors, non-perseverative errors, and total errors. These findings provide support for the beneficial effects of Pilates training in addressing attention difficulties in adults with ADHD. (Kouhbanani et al., 2023)

Marital arts

Taekwondo (TKD) is a traditional Korean martial art that has evolved over generations, incorporating physical, mental, emotional, social, and educational elements to support overall personal development. (Lim 2009, Ahn et al., 2009, Fong et al., 2012, Lakes et al., 2013, Kim 2015, Cho et al., 2017, Petrovic 2017, Cho et al., 2018) The study by Kadri et al. (Kadri et al., 2019) examined the effects of a 1.5-year Taekwondo (TKD) intervention on cognitive function in adolescents with ADHD. The results showed significant improvements in selective attention and inhibitory control, as measured by the Stroop and Ruff 2 and 7 tests (Frazier et al., 2004). TKD practice led to enhanced attentional control, reduced errors, and faster reaction times. The findings suggest that martial arts training can positively impact cognitive functions in adolescents with ADHD, supporting its inclusion in intervention programs. (Kadri et al., 2019) Another studies investigated the effects of judo in children. (Toh et al., 2018, Ludyga et al., 2022) Judo is a sport that involves performing intricate movements and demands a high degree of strategic planning. Neuroimaging studies have shown that children who practice judo exhibit increased gray matter volume and enhanced white matter connectivity in various functional regions, such as the fronto-parietal network and the corpus callosum. (Jacini et al., 2009, Toh et al., 2018) These structures are associated with working memory capacity. (Darki and Klingberg, 2015, Bathelt et al., 2018) This study investigated the effects of judo training on working memory capacity in children with ADHD. A randomized controlled trial with 57 children (aged 8-12) assigned participants to either a judo training group or a waitlist control group. The judo program consisted of 120 minutes per week for three months. Results showed that judo training improved visuospatial working memory capacity and increased contralateral delay activity, indicating enhanced attentional control. However, motor skill improvements

were not observed. The findings suggest that judo could be a beneficial complement to pharmacological treatments for ADHD. (Frazier et al., 2004)

Discussion

The collective evidence reviewed here strongly supports the inclusion of physical exercise as a valuable non-pharmacological intervention for managing ADHD. Across a diverse range of modalities—from aerobic and aquatic exercise to cognitively demanding practices like martial arts and yoga—structured physical activity consistently demonstrates the capacity to improve core symptoms of inattention and hyperactivity, as well as associated deficits in executive function and emotional regulation.

The therapeutic benefits appear to be rooted in robust neurobiological mechanisms. Exercise-induced modulation of the dopamine and norepinephrine systems mirrors the action of first-line pharmacological treatments. Concurrently, the upregulation of BDNF promotes neuroplasticity, potentially leading to lasting structural and functional changes in brain networks critical for attention and self-control. Cognitively demanding activities like martial arts or exergaming may offer a "dual benefit" by simultaneously engaging the body and training the executive functions that are impaired in ADHD.

Despite these promising findings, several limitations in the current body of research must be acknowledged. Many studies are constrained by small sample sizes, short intervention durations, and a lack of long-term follow-up, making it difficult to draw definitive conclusions about the sustainability of the benefits. Furthermore, the heterogeneity of exercise protocols—varying in type, intensity, frequency, and duration—prevents the establishment of a standardized "prescription" for PA in ADHD treatment. Future research should prioritize large-scale, randomized controlled trials with standardized interventions and long-term follow-up to clarify the most effective approaches and to distinguish the unique contributions of different exercise modalities.

Conclusion

Physical activity represents a promising, accessible, and non-pharmacological intervention that can play a valuable role in the management of ADHD symptoms in children and adolescents. A growing body of research highlights the neurobiological mechanisms by which sports influence key brain regions implicated in ADHD, including the prefrontal cortex, caudate nucleus, and cerebellum. Regular exercise has been shown to enhance dopamine and norepinephrine transmission, neurotransmitters crucial for attention, emotional regulation, and executive functioning. Furthermore, physical activity stimulates the release of brain-derived neurotrophic factor (BDNF), supporting neuroplasticity and cognitive development.

Empirical studies demonstrate that both acute and chronic physical activity—ranging from aerobic training to structured sports and even martial arts—can lead to measurable improvements in attention span, impulse control, emotional self-regulation, and social behavior in youth with ADHD. While physical activity should not be viewed as a stand-alone treatment, it can serve as a highly effective adjunct to traditional therapies, particularly when implemented in structured environments such as schools, families, or clinical programs.

As our understanding of the interaction between physical activity and brain function deepens, it becomes increasingly evident that sports not only promote physical health but also support cognitive and emotional well-being. Future research should continue to explore optimal exercise types, intensities, and frequencies for ADHD populations. Nonetheless, current findings support the integration of regular, developmentally appropriate physical activity as part of a holistic approach to ADHD treatment in young individuals.

Disclosure

Author's contribution

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