International Journal of Innovative Technologies in Social Science

e-ISSN: 2544-9435

Scholarly Publisher
RS Global Sp. z O.O.
ISNI: 0000 0004 8495 2390

Dolna 17, Warsaw,
Poland 00-773
+48 226 0 227 03
editorial_office@rsglobal.pl

ARTICLE TITLE	PHYSICAL ACTIVITY IN ADHD PATIENTS: SIGNIFICANCE, ADVANTAGES, AND EFFECTS OF DIGITAL INTERVENTIONS PROMOTING EXERCISE
ARTICLE INFO	Patrycja Jędrzejewska-Rzezak, Monika Czekalska, Natalia Kulicka, Kinga Knutelska, Aleksandra Winsyk, Paulina Gajniak, Maciej Karwat, Tytus Tyralik, Klaudia Bilińska, Joanna Węgrzecka. (2025) Physical Activity in ADHD Patients: Significance, Advantages, and Effects of Digital Interventions Promoting Exercise. *International Journal of Innovative Technologies in Social Science*. 3(47). doi: 10.31435/ijitss.3(47).2025.3588
DOI	https://doi.org/10.31435/ijitss.3(47).2025.3588
RECEIVED	14 July 2025
ACCEPTED	19 August 2025
PUBLISHED	30 August 2025
LICENSE	The article is licensed under a **Creative Commons Attribution 4.0 International License.**

PHYSICAL ACTIVITY IN ADHD PATIENTS: SIGNIFICANCE, ADVANTAGES, AND EFFECTS OF DIGITAL INTERVENTIONS PROMOTING EXERCISE

Patrycja Jędrzejewska-Rzezak *(Corresponding Author, Email: patrycjaj@kul.lublin.pl)*
The John Paul II Catholic University of Lublin, Al. Racławickie 14, 20-950 Lublin, Poland
ORCID ID: 0000-0003-2144-5810

Monika Czekalska
Norbert Barlicki Memorial Teaching Hospital No. 1 of the Medical University of Lodz, Kopcińskiego 22, 90-153 Łódź, Poland
ORCID ID: 0009-0004-7091-5369

Natalia Kulicka
Lower Silesian Specialist Hospital, Kamieńskiego 73a, 51-124 Wrocław, Poland
ORCID ID: 0009-0002-9321-1693

Kinga Knutelska
The University Hospital in Cracow, ul. Jakubowskiego 2, 30-688 Kraków, Poland
ORCID ID: 0009-0003-0795-0228

Aleksandra Winsyk
University Clinical Hospital No. 4 in Lublin, 8 Jaczewskiego St., 20-964 Lublin, Poland
ORCID ID: 0009-0003-9780-3829

Paulina Gajniak
Poznań University of Medical Sciences, ul. Fredry 10, 61-701 Poznań, Poland
ORCID ID: 0000-0003-0402-6737

Maciej Karwat
Independent Public Health Care Center of the Ministry of the Interior and Administration in Krakow, Kronikarza Galla 25, 30-053 Kraków, Poland
ORCID ID: 0009-0007-5917-977X

Tytus Tyralik
Stefan Żeromski Specialist Hospital – Independent Public Healthcare Institution in Kraków, Osiedle Na Skarpie 66, 31-913 Kraków, Poland
ORCID ID: 0009-0001-7370-4610

Klaudia Bilińska
District Railway Hospital in Katowice, Panewnicka 65, 40-760 Katowice, Poland
ORCID ID: 0009-0003-4137-6135

Joanna Węgrzecka
Fedmed, ul Widna 45, 06-400 Ciechanów, Poland
ORCID ID: 0009-0007-5714-3431

ABSTRACT

Attention deficit hyperactivity disorder (ADHD) is among the most commonly diagnosed neurodevelopmental disorders in children, frequently continuing into adulthood. Recent years have witnessed an increasing interest in the importance of physical activity as an adjunctive therapy for controlling ADHD symptoms, including impulsivity, focus difficulties, and hyperactivity. This article aims to review the existing evidence about the effects of physical activity on individuals with ADHD, focusing specifically on contemporary digital methods, including mobile applications, exergaming, virtual reality (VR) technologies, wearable fitness trackers and artificial intelligence (AI) programs. Studies confirm that physical activity improves executive functions, attention, inhibitory control and cognitive flexibility. The article presents the neurobiological mechanisms that elucidate the advantageous effects of exercise on executive functions, together with a review of empirical data validating the efficacy of these interventions. The essay additionally explores the possibility for customizing digital physical activity programs. The findings suggest that physical activity, augmented by digital technologies, can serve as a significant component of a comprehensive ADHD treatment framework, particularly in terms of personalizing therapy and enhancing patient involvement.

Materials and methods: A review of the literature available in the PubMed and Google Scholar database was performed, using the key words: “Attention Deficit Hyperactivity Disorder”, “ADHD”, “physical activity”, “digital interventions”, “exergaming”, “virtual reality”, “VR”.

KEYWORDS

Attention Deficit Hyperactivity Disorder, ADHD, Physical Activity, Digital Interventions, Exergaming, Virtual Reality, VR

CITATION

Patrycja Jędrzejewska-Rzezak, Monika Czekalska, Natalia Kulicka, Kinga Knutelska, Aleksandra Winsyk, Paulina Gajniak, Maciej Karwat, Tytus Tyralik, Klaudia Bilińska, Joanna Węgrzecka. (2025) Physical Activity in ADHD Patients: Significance, Advantages, and Effects of Digital Interventions Promoting Exercise. *International Journal of Innovative Technologies in Social Science*. 3(47). doi: 10.31435/ijitss.3(47).2025.3588

1. Introduction

Attention Deficit Hyperactivity Disorder (ADHD) is one of the most commonly diagnosed neurodevelopmental diseases in children and adolescents. It is estimated to impact 5% to 7% of the school-age population (Salari et al., 2023). The primary symptoms encompass difficulty concentrating, impulsivity, and excessive motor activity. These features significantly impede the child's functioning both in the school and home environment, affecting cognitive, emotional, and social functioning. Furthermore, the enumerated symptoms often persist throughout adulthood (Edinoff et al., 2022).

Conventional intervention options have generally encompassed the combination of medication, psychotherapy, and modifications to the environment in educational and occupational contexts. Although their efficacy, they frequently necessitate augmentation through techniques that support the enhancement of executive functioning and emotional regulation.

In recent years, there has been increasing focus on the function of physical activity as an adjunct to traditional therapy for children with ADHD. Studies demonstrate that consistent physical exercise positively influences cognitive skills such as attention, working memory, and impulse control, in addition to enhancing general arousal and mood levels. Furthermore, physical activity can elevate neurotransmitter levels, such as dopamine and norepinephrine, which are lacking in individuals with ADHD. Exercises can enhance cerebral blood circulation and cognitive performance (Feng et al., 2024).

It is important to acknowledge that individuals diagnosed with ADHD frequently have significant challenges in participating in physical activity. Effective engagement in exercise is frequently constrained by compromised motor coordination or deficient sensory integration in this patient population. Moreover, deficits in executive functions, encompassing skills such as planning, organization, and behavioral regulation, may exacerbate their capacity to engage in activities necessitating structured effort.

The advancement of new technologies creates novel opportunities in the design of movement-based therapies, particularly appealing and engaging for youngsters. Movement games, known as exergaming,

activity monitoring applications, virtual reality technology, and wearable gadgets enhance children's motivation for physical activity while simultaneously offering instruments for continuous evaluation of treatment advancement.

The study aims to examine the possibility of technology-assisted physical activity as a support mechanism for children with ADHD. This presentation will outline the mechanisms by which physical activity influences symptoms in children with ADHD, highlighting its potential as an adjunct to pharmaceutical and behavioral therapies, based on a review of contemporary scientific studies. The effectiveness of interventions using technologies will also be discussed. The article also aims to indicate directions for further research on the use of modern technological solutions in the treatment of neurodevelopmental disorders, which include ADHD.

2. ADHD - characteristics of the disorder

Attention deficit hyperactivity disorder (ADHD) is a group of neurodevelopmental mental disorders characterized by attention deficiency, impulsivity and hyperactivity (Chaulagain et al., 2023). Attention deficiency is characterized by challenges in concentration, susceptibility to distractions, and insufficient attention to detail. Impulsivity refers to the interruption of others during conversation and the challenge of waiting one's turn. Excessive motor activity manifests itself as fidgeting and difficulty staying in one place. These symptoms must persist for a minimum of 6 months and substantially impair the child's functioning across multiple domains: educational, social, and familial.

The etiology of ADHD is complex and includes both genetic and environmental factors. Between 74% and 88% of ADHD cases are estimated to be associated with genetic variables, suggesting a significant degree of heritability for the illness. ADHD is a polygenic condition, indicating that numerous gene variants, each exerting a minor influence, contribute to the likelihood of acquiring the disorder (Faraone & Larsson, 2019). Environmental variables, including prenatal exposure to toxins (e.g., alcohol, nicotine), low birth weight, preterm, and detrimental psychosocial situations, may elevate the risk of developing ADHD (Cioffredi et al., 2024).

ADHD is associated with alterations in brain structure and function, especially in areas responsible for executive functions, including the prefrontal cortex and basal ganglia. Neuroimaging research has demonstrated diminished volume in these areas and decreased activity in brain networks associated with attention and impulse regulation. ADHD is linked with dysfunction of neurotransmitter systems, particularly dopaminergic and noradrenergic. Dopamine regulates functions like motivation, attention, and reward modulation. ADHD is characterized by diminished dopaminergic activity, particularly in the prefrontal cortex and basal ganglia (da Silva et al., 2023). Norepinephrine is responsible for alertness, focus, and executive functions. Dysfunction of the noradrenergic system may exacerbate ADHD symptoms, including challenges in maintaining attention and regulating impulses (da Silva et al., 2023).

ADHD is linked to a wide array of comorbid conditions, including anxiety, depression, oppositional defiant disorder, conduct disorder, and tic disorder (Arrondo et al., 2022). The existence of comorbidities can markedly complicate diagnosis, treatment, and prognosis; thus, their identification is essential for optimal therapy. Individuals with ADHD face heightened risks for severe adverse consequences, including suboptimal educational achievements, injuries and accidents, adolescent pregnancies, familial discord, and criminal conduct leading to incarceration. Moreover, those with ADHD exhibit a twofold heightened risk of early mortality relative to those without the disorder, primarily attributable to unnatural causes (Catalá-López et al., 2022).

Treatment for ADHD is individualized and usually includes a combination of pharmacotherapy and non-pharmacological interventions. Stimulants, such as methylphenidate and amphetamine, increase dopamine and norepinephrine levels in the brain, which improves attention and reduces impulsivity. Nonstimulants, primarily atomoxetine, act primarily on the noradrenergic system, while guanfacine and clonidine affect α2-adrenergic receptors, which can improve impulse control and hyperactive behavior. It is important to acknowledge that certain patients and their caregivers have negative attitudes about pharmacotherapy, and some patients either cannot endure side effects or fail to derive adequate benefits from drugs. Consequently, non-pharmacological interventions hold significant potential in the management of ADHD. Behavioral therapy focuses on modifying behaviors through the use of techniques such as reinforcing positive behaviors, reward and punishment systems, and social skills training. Behavioral therapy is particularly effective when combined with pharmacotherapy. Cognitive-behavioral treatment (CBT) emphasizes the development of techniques to manage ADHD symptoms, enhance organization, planning, and impulse regulation. Educational and environmental support, together with the personalization of the educational process, implementation of mobility breaks, minimization of distracting stimuli, and the utilization of technology that facilitate learning are important. Non-pharmacological approaches that augment the treatment of ADHD encompass also cognitive training, neurofeedback, somatic therapy, dietary modifications, and supplements (Sibley et al., 2023). Increasing evidence confirms also that regular physical activity positively influences ADHD symptoms and serves as an effective and safe adjunct to pharmacotherapy.

3. Advantages of Physical Activity for Patients with ADHD

Physical activity has been cited as one of the most promising non-pharmacological interventions in the management of patients diagnosed with ADHD. Executive functions are a set of advanced cognitive abilities that enable the regulation and management of thought and behavior to attain objectives. In people with ADHD, executive functions are often impaired, which manifests itself in difficulties with maintaining attention, impulsivity and difficulties in inhibition, deficits in impulse control, disorders of planning and organizing, and difficulties in monitoring the progress of activities. Individuals with ADHD frequently encounter comorbid emotional challenges, behavioral issues, and sleep problems. Research indicates that consistent physical activity markedly enhances executive processes and emotional regulation in children with ADHD, as well as aids in behavioral control and sleep quality.

Investigations into the cerebral function have demonstrated that symptoms of ADHD results from physiological, anatomical, and functional anomalies in the central nervous system (Chan et al., 2022)(Christiansen et al., 2019). Current research indicates that consistent physical activity helps improve cognitive processes, including attention, working memory, inhibitory control, cognitive flexibility, and emotional regulation in individuals with ADHD (Xie et al., 2021)(Sun et al., 2022).

Initially, ADHD is posited to be linked to malfunction in neurotransmitter systems, particularly the dopaminergic and noradrenergic systems, as well as diminished activity in the prefrontal regions of the brain. Physical activity has been demonstrated to elevate neurotransmitter levels in the prefrontal cortex, leading to enhanced attention and executive function (Christiansen et al., 2019). A single session of exercise has been demonstrated to enhance cognitive function via immediate neurochemical responses, including elevated brain-derived neurotrophic factor (BDNF) secretion and increased levels of synaptic proteins, glutamate receptors, and insulin-like growth factor availability, which seem to promote cell proliferation and neuroplasticity, increasing blood flow and circulation in the brain (Müller et al., 2020). Moreover, individuals with ADHD exhibit diminished overall brain volume and a reduction in the size of the basal ganglia (namely the globus pallidus and putamen) and neuroimaging research indicates that consistent physical activity can enhance grey matter volume (Hoogman et al., 2017). Physical activity therefore induces neurofunctional and neurostructural alterations in the brain, particularly in regions associated with executive functions, such as the frontal lobe and hippocampus, thereby enhancing neuroplasticity and optimizing the efficiency of neural circuits responsible for cognitive and behavioral regulation(Azazy et al., 2018). Moreover, regular physical activity influences the modulation of the function of the anterior cingulate cortex, which manifests itself in better control of attention and impulses. Furthermore, studies indicate that physical activity may enhance cerebellar function, perhaps leading to improved executive control or task automation (Mastrangelo et al., 2024).

During the investigation of the impact of physical activity on cerebral function in individuals with ADHD, alterations in EEG tests were also noted. Initially, people with ADHD exhibited elevated theta/beta ratios compared to control group (Kiiski et al., 2020). Secondly, those with ADHD who engaged in exercise exhibited reduced theta/beta ratios compared to those who did not, indicating that exercise can modulate arousal and alertness in this population (Su et al., 2022).

Meijer et al. (Meijer et al., 2020) in their research indicates that including regular physical activity into children's daily routines can enhance neurophysiological brain development, especially for those with ADHD. Nonetheless, there is no definitive data indicating that physical activity positively influences children's brain structure. In 2021, Welsch et al. (Welsch et al., 2021) found that physical activity interventions positively influenced executive functioning, such as working memory and cognitive flexibility. Physical activities that demand a higher level of cognitive involvement (e.g., workouts necessitating coordination and planning) yielded more significant advantages for impulse control. Research indicated that children administered methylphenidate exhibited diminished advantages from physical activity interventions relative to those not receiving the medication; thus, it was underscored that exercise regimens should be customized to meet the specific requirements of each child, considering both the nature of the activity and the involvement of pharmacotherapy.

A systematic review and meta-analysis by Xie et al. in 2021 (Xie et al., 2021) demonstrated that physical activity markedly alleviated ADHD symptoms in children, especially regarding inattention, hyperactivity/impulsivity, and emotional and behavioral issues, indicating that physical interventions could serve as an effective alternative or adjunct to conventional ADHD treatments. The authors underscore the necessity for more research with bigger samples to ascertain the ideal frequency and intensity of these interventions. It was also found that physical activity can significantly reduce symptoms of depression and anxiety across the lifespan of people with ADHD. Liang et al.'s 2021 (Liang et al., 2021) review encompassed 15 randomized controlled trials evaluating the impact of physical exercise treatments on executive function in children diagnosed with ADHD. The findings demonstrated moderate to large positive impacts of physical activity on executive function, particularly in inhibitory control and cognitive flexibility. Moderate-intensity

therapies and long-term (chronic) sessions were more efficacious in enhancing executive function than high-intensity interventions or short-term sessions.

A more recent study, published in 2024 by Booth et al. (Booth et al., 2024), confirmed these conclusions from the studies discussed above, indicating that physical activity programs produce significant benefits in patients with ADHD. The study participants consisted of youngsters exhibiting indications of ADHD and experiencing reading difficulties. They spent an average of 46% of their class time to moderate to vigorous level physical activity, equating to around 27 minutes daily. Following the 12-week physical exercise program, notable enhancements were noted in inhibition and visuospatial working memory, irrespective of diagnostic category (ADHD, reading difficulties, comorbidity of both disorders, and control group). The findings indicate that a physical activity program could serve as a beneficial intervention for children with ADHD and reading difficulties, enhancing their executive skills and alleviating the symptoms of both diseases.

The 2025 study conducted by Song et al. (Song et al., 2024) is a systematic review and meta-analysis evaluating the impact of physical activity on depression, anxiety, and emotional control in children diagnosed with ADHD. The analysis encompassed 18 randomized controlled trials including 830 people. The findings demonstrate considerable advantages of physical activity concerning ADHD. Initially, physical exercises demonstrated a moderate impact in alleviating symptoms of anxiety and despair in children with ADHD, indicating its potential to enhance the mental health of this population. Moreover, physical activity significantly enhanced emotion regulation, underscoring their importance in augmenting emotional management capabilities in children with ADHD. Programs characterized by short duration, high frequency, and moderate intensity were most efficacious in alleviating anxiety. Short-duration, low-frequency, moderate-intensity mixed programs were the most beneficial for depression. To enhance emotion control, mixed programs characterized by extended duration, moderate to high frequency, and low intensity yielded optimal outcomes. The efficacy of physical interventions is contingent upon the type, duration, intensity, frequency, and total length of the exercise.

Sleep disorders are one of the most common co-occurring difficulties in people with ADHD. Regular physical activity has a beneficial effect on the regulation of circadian rhythm by modulating the hypothalamic-pituitary-adrenal axis and regulating the secretion of serotonin and melatonin — neurotransmitters that play a key role in the initiation and maintenance of sleep. In people with ADHD, disorders in the secretion of melatonin and dysregulation of circadian rhythms are often observed, which may explain the partial effectiveness of moderate physical activity as a tool for normalizing sleep. It enhances the release of serotonin and melatonin (Chennaoui et al., 2015) and, in addition consistent physical activity reduces cortisol levels, hence lowering psychophysical arousal. The third mechanism pertains to the modulation of the circadian rhythm, particularly during outdoor exercise, influenced by daylight.

A number of interventional studies confirm the positive effect of physical exercise on sleep parameters in children and adults with ADHD. A 2023 study conducted by Liu et al. (Liu et al., 2023) evaluated the impact of physical activity on sleep quality in children diagnosed with ADHD. They recruited 33 children diagnosed with ADHD and randomly allocated them to either an intervention group or a control group. The intervention comprised a structured workout regimen. Statistically substantial enhancements were noted in the intervention group regarding sleep efficiency, sleep latency, and alertness after sleep start. A systematic review by Alnawwar et al. in 2023 (Alnawwar et al., 2023) demonstrates the health advantages of physical activity for people with ADHD, namely in enhancing sleep quality and mitigating symptoms of sleep problems. Consistent physical training, including walking, jogging, swimming, or yoga, is advised to enhance sleep quality. The authors underscore the significance of physical activity as a non-pharmacological approach to enhance the management of sleep problems and promote overall mental and physical well-being. A systematic study by Wang et al. (T. Wang et al., 2024) concluded that exercise interventions enhance sleep efficiency and diminish arousal after sleep onset in children and adolescents with neurodevelopmental disorders, including ADHD. Mind-body methods, such as yoga and tai chi, demonstrated notable efficacy in enhancing sleep quality according to a meta-analysis.

In summary, physical activity appears as a therapeutic tool that not only helps to cope with the core symptoms of ADHD but also has a positive effect on concomitant comorbidities such as anxiety, depression, and sleep disorders. Therefore, the inclusion of physical exercise programs should be considered as a necessary complementary intervention in the treatment of ADHD.

4. The impact of different types of physical activity on ADHD symptoms

To optimize the advantages of exercise for individuals with ADHD, it is crucial to select the appropriate type of activity, as research indicates that not all physical activities exert the same influence on ADHD symptoms.

Aerobic exercise, including running, swimming, and cycling, has demonstrated beneficial effects on executive skills in children with ADHD. The meta-analysis by Yang et al. (Yang et al., 2024) demonstrates that regular aerobic exercise enhances inhibitory control, cognitive flexibility, and working memory. Optimal benefits were noted in programs lasting 6 to 12 weeks and conducted at moderate intensity. Aerobic exercise has been linked to decreased reliance on stimulant drugs for ADHD. Research conducted by Smith et al. (Smith et al., 2013) revealed that children with ADHD who consistently participated in aerobic exercise necessitated reduced doses of methylphenidate for effective symptom management in contrast to their inactive counterparts. This indicates that integrating structured aerobic exercise into ADHD treatment regimens may diminish the necessity for high-dose pharmaceutical interventions and alleviate potential side effects linked to stimulant drugs.

High-intensity exercise is a type of physical activity when heart rate and energy expenditure attain 70–90% of the maximum heart rate. High-intensity interval training is increasingly being utilized in the treatment of ADHD. Studies indicate it can rapidly elevate dopamine and norepinephrine levels, enhancing attention and self-regulation. It should be noted here that high-intensity activities, owing to their stimulating effects, should be avoided immediately prior to bedtime, as they may exacerbate difficulties in initiating sleep.

Tasks necessitating exact motor coordination, including balancing, movement games, or intricate exercises, positively influence sensory-motor integration and cognitive abilities. Kim et al. (Kim et al., 2021) shown that sensorimotor activities enhance executive functioning and postural control in children with ADHD. These activities may be especially advantageous for children with concurrent mobility impairments.

Organized physical activities, especially martial arts, have garnered interest as potential nonpharmacological treatments for ADHD. These disciplines integrate physical activity with cognitive concentration, discipline, and self-control, effectively targeting fundamental ADHD symptoms including inattention, impulsivity, and hyperactivity (Kadri et al., 2019). Mindfulness-based physical activities, such as yoga, are receiving growing acknowledgment for their capacity to enhance behavioral and cognitive functions in individuals with ADHD. These activities integrate regulated movement, respiratory exercises, and mindfulness techniques that can enhance self-regulation and attention management (Cohen et al., 2018).

The kind of physical activity is significant in the context of ADHD treatment. Aerobic and coordination exercises exhibit the highest potential for enhancing executive processes, whilst practices like yoga or martial arts may further facilitate emotional management and social functioning. The selection of the activity type must be customized to the patient's specific demands, the intensity of symptoms, and the available environmental conditions. Table 1 is a summary of the impact of various types of physical activity on ADHD symptoms.

Table 1. The impact of various types of physical activity on ADHD symptoms

Type of physical activity	Effects
Aerobic exercise	Improves attention Enhances working memory Increases cognitive flexibility
High-Intensity Interval Training	Short-term attention boost Boosts dopamine levels
Coordination Exercises	Improves coordination and balance Enhances sensory-motor integration Supports executive function development
Martial Arts (e.g. taekwondo)	Increases self-discipline Reduces impulsivity Improves social interaction
Yoga and Mindfulness Exercises	Reduces hyperactivity Improves emotional regulation Promotes calm and focus

5. Physical activity supported by digital interventions

The advancement of digital technologies has generated novel opportunities for integrating physical activity with interactive therapeutic instruments. Digital therapies centered on movement, including active video games (termed "exergaming"), mobile applications, and systems that monitor physical activity, are gaining popularity as an engaging therapeutic approach for children with ADHD.

5.1. Mobile applications and wearables

Mobile applications and wearable technologies are effective instruments for facilitating ADHD therapy. Innovative training programs and wearable devices (such as watches and fitness bands) provide real-time surveillance of physical activity patterns and their possible influence on ADHD symptoms, offering objective data that enhances conventional diagnostic approaches (Zhang et al., 2024).

In their 2025 paper, Thompson et al. (Thompson et al., 2025) present the results of a systematic review of the use of smartwatches and activity trackers in health interventions for children aged 5–11. Most of these studies focused on improving children's physical activity. Interventions included elements such as step goals, gamification (e.g., earning points, digital rewards), cooperation or competition with other participants, and reminders to move. Many studies showed short-term increases in physical activity, such as more steps per day, during the intervention. However, the long-term effects were unclear—activity levels often returned to previous levels after the intervention ended. Trackers helped to increase children's motivation by visualizing goals and progress. Gamification elements were particularly effective for younger users, increasing engagement.

Nonetheless, it appears that for individuals with ADHD, the utilization of technological tools can pose difficulties. Denyer et al. (Denyer et al., 2023) investigated the barriers and facilitators associated with the utilization of remote measurement technology (RMT) for the long-term monitoring of individuals with ADHD. Individuals with ADHD indicated increased challenges in engaging in the study due to signs of ADHD, including concentration difficulties and impulsivity. Furthermore, they regarded cognitive tasks as more time-consuming and cognitively taxing, thereby impacting their involvement. Additionally, individuals with ADHD encountered increased technological difficulties, such as challenges in operating devices or applications, which may hinder frequent utilization of RMT. This suggests the necessity to tailor RMT to the particular requirements of this population, particularly as participants with ADHD demonstrated favorable views towards prolonged usage of RMT (1–2 years), contingent upon the technology being customized to their needs and adequate assistance being offered.

5.2. Exergaming and movement games

Exergaming (from exercise + gaming) is a form of physical activity combined with video games that require body movement to control the game. This combination encourages physical activity, particularly in children and teenagers, and can enhance physical fitness, coordination, reflexes, and cognitive abilities. Innovative approaches utilizing exercise-based simulators and virtual reality (VR) are increasingly being investigated and implemented across diverse healthcare industries.

Studies indicate that children with ADHD exhibit increased engagement and heightened motivation to partake in this form of game compared to conventional activities. Exergaming enhances selective attention, impulse regulation, and elevates mood. Utilizing games facilitates the modification of difficulty according to the child's capabilities, so enhancing the personalization of therapy. Gao et al. (Gao et al., 2020) examined the application of exercise games utilizing motion-sensing controllers, such Xbox Kinect and Wii systems, in preschool children. Preschool children engaged in these exercise games, which markedly elevated their level of moderate-to-vigorous physical training. This study highlights the ability of exercise games to increase physical activity engagement in young children. Benzing and Schmidt [39] studied children with ADHD participating in exercise game sessions aimed at improving executive functions and motor skills. The intervention resulted in accelerated reaction times and enhanced motor skills, illustrating the prospective advantages of exercise games in augmenting cognitive and motor functions in children with ADHD.

Virtual reality (VR) is a technology that enables users to be immersed in an artificially constructed, computer-generated environment that can either replicate reality or be entirely imaginative. Shema-Shiratzky et al. (Shema-Shiratzky et al., 2019) integrated a treadmill with a virtual reality environment to enhance cognitive and behavioral functions in children diagnosed with ADHD. The training consisted of walking on a treadmill with virtual obstacles. Before and after training and after 6 weeks, behavior (reported by parents), cognitive functions (memory, executive functions, attention) and gait regularity during walking while performing a task (dual-tasking) were assessed. Notable enhancements were noted in executive function,

memory, and gait regularity, alongside decreases in social issues and psychosomatic behaviors. This study indicates substantial advantages of integrating physical and cognitive training using VR-based therapies. Ko et al. (Ko et al., 2020) examined the efficacy of a ski simulator for both VR and non-VR exercises discovering that VR exercise enhanced exercise capacity and attention levels, with the VR cohort exhibiting superior engagement and focus relative to the non-VR cohort. Virtual reality exercises in exploitation games can significantly enhance users' motor skills and focus, providing an appealing alternative to conventional physical activities. Ji et al. (Ji et al., 2023) conducted a study evaluating the impact of exergaming on attention in children with ADHD, comparing it to conventional aerobic exercise. Exergaming yielded effects on enhancing attention in children with ADHD that were comparable to those of conventional aerobic exercise. Furthermore, exergaming may provide supplementary advantages for control functions, indicating its potential as an alternate therapy for youngsters with ADHD.

Although exergaming and VR offer children with ADHD new, attractive ways of learning and physical activity, they also carry certain risks. Children with ADHD exhibit heightened sensitivity to environmental stimuli. Virtual reality and high-intensity games can result in overstimulation (due to light, music, and quick scene transitions), and excessive stimulation in the evening may hinder the ability to fall asleep and disturb circadian cycles, which are frequently irregular in children with ADHD. Consequently, sensory breaks must to be implemented, and virtual reality should be avoided just prior to bedtime. Children with ADHD may struggle to distinguish between the game and reality, transferring unsuitable behavior from the game to the real world, particularly in the context of virtual reality. T hese patients are more susceptible to behavioral addictions, potentially leading to excessive engagement in exergaming or virtual reality, which can detrimentally affect sleep, learning, and relationships, hence heightening the likelihood of developing an addiction to games or screens. A cross-sectional study in Canada investigated video game usage among children with ADHD, demonstrating elevated addiction scores and prolonged play durations relative to peers without ADHD, with a strong correlation between ADHD severity and excessive gaming (Masi et al., 2021).

Utilizing movement-based strategies, including movement games and virtual reality-assisted physical exercises, offers a dynamic and engaging approach to boosting self-regulation and improving executive function (P. Wang et al., 2024). While these tools can be helpful in skill development and behavior reinforcement, additional study is required to enhance these interventions, maximize their long-term efficacy, and guarantee their accessibility to varied populations. It is particularly important to assess the risk of their overuse.

5.3. Artificial Intelligence-enhanced physical activity

Artificial intelligence (AI) can markedly enhance the facilitation of physical activity for those with ADHD by means of personalization and automation of assistance. AI-driven systems evaluate biometric data (e.g., from activity trackers, smartwatches, cellphones) and tailor physical activity recommendations to the specific requirements of the user. For those with ADHD, this may entail brief, intensive sessions customized to concentration levels, activity reminders aligned with circadian rhythms and attention patterns, and the gamification of tasks to enhance participation. AI systems can analyze activity patterns and anticipate declines in motivation or exacerbation of ADHD symptoms, facilitating real-time modifications to intervention efforts. This may encompass the early identification of a decline in activity, recommending modifications to the daily itinerary, and synthesizing data with mood and cognitive journaling. Chatbots and virtual assistants can function as coaches or therapists, providing reminders, motivational messages, and recommending breathing or relaxation techniques to facilitate self-regulation.

An et al. (An et al., 2024) reviewed that AI-driven virtual coaching platforms employ machine learning to assess behavioral patterns and recommend tailored physical activity therapies that enhance cognitive and emotional advantages. Yu and Fang (Yu & Fang, 2024) propose a novel methodology to evaluate the efficacy of physical activity on ADHD patients through AI-techniques. The research examines an integrated AI model that combines Random Forest, Temporal Convolutional Network (TCN), and Adaptive Control of Thought-Rational (ACT-R) algorithms to analyze behavioral and EEG data, as well as the impact of physical activity on ADHD patients. The researchers employed machine learning techniques to evaluate extensive data sets and identify patterns that may be undetectable by conventional statistical methods. The combined AI model attained an accuracy of 98.21% and a sensitivity of 93.86% in the analysis of ADHD data. Exceptional results were achieved in the analysis of EEG data, with an accuracy of 96.62% and a sensitivity of 95.21%. These findings indicate that AI can aid in the formulation of personalized therapy strategies centered on physical exercise, customized to the specific requirements of ADHD patients. This methodology opens new directions

in ADHD research, facilitating a more profound comprehension of the neurological mechanisms underlying this condition and the possibilities for treatment interventions.

A novel method to ADHD therapy is the integration of physical activity with technologies like neurofeedback or brain-computer interfaces (BCI). The amalgamation of these methodologies facilitates real-time surveillance of neural activity and concurrent modification of workouts, perhaps resulting in enhanced treatment efficacy and superior therapeutic results. These technologies provide significant ethical dilemmas about identity and autonomy, necessitating additional interdisciplinary investigation and ethical assessment (Gordon & Seth, 2024).

In conclusion, AI serves as a potent instrument for comprehending and enhancing the efficacy of physical activity as a therapeutic intervention for ADHD, providing a tailored approach to care and recommendations for the sustained management of this disorder. Comprehensive and longitudinal investigations are necessary to validate these findings and enhance the application of AI-based therapies in ADHD therapy.

6. Conclusions

ADHD is a neurodevelopmental disorder affecting 5% to 7% of children and adolescents, causing difficulties in concentration, impulsivity, and excessive motor activity. It affects cognitive, emotional, and social functioning and often persists into adulthood. Traditional interventions include medication, psychotherapy, and modifications to the environment in educational and occupational contexts. However, physical activity has been increasingly studied as an adjunct to traditional therapy for children with ADHD.

Physical activity is a promising non-pharmacological intervention in managing ADHD symptoms. Consistent physical activity enhances executive processes, emotional regulation, behavioral control, and sleep quality in children with ADHD. It induces neurofunctional and neurostructural alterations in the brain, particularly in regions associated with executive functions. Regular physical exercises also modulate the function of the anterior cingulate cortex, resulting in better control of attention and impulses. Physical activity programs can also significantly reduce symptoms of depression and anxiety across the lifespan of people with ADHD. Further research is needed to determine the optimal frequency and intensity of these interventions.

Advancements in technology, such as exergaming, activity monitoring applications, virtual reality technology, and wearable gadgets, can enhance children's motivation for physical activity and provide continuous evaluation of treatment advancement. Mobile applications and wearable devices, such as smartwatches and activity trackers, provide real-time surveillance of physical activity patterns, enhancing therapeutic approaches. A primary avenue for future study is the creation of AI-driven algorithms capable of analyzing data from wearable devices (e.g., activity trackers, EEGs, sleep monitors) to customize therapeutic interventions according to particular patient requirements. Research should concentrate on confirming the efficacy of these treatments and their integration with conventional treatment modalities, including medication and behavioral therapy.

Exergaming, a combination of exercise and video games and virtual reality, has been shown to enhance physical fitness, coordination, reflexes, and cognitive abilities. Further investigation is required about the influence of immersive settings on the cognitive and emotional development of children with neurodevelopmental problems. Assessing the long-term effects of utilizing these technologies and the risks associated with their abuse is particularly crucial.

The rapidly evolving industry of educational and therapeutic games provide an opportunity to build interesting modalities of movement therapy. Games incorporating physical activity aspects can enhance the development of executive functions, motor skills, and self-discipline. Nevertheless, comparative analyses are essential to ascertain which gaming mechanisms (e.g., degree of interactivity, reward systems, session duration) influence the amelioration of ADHD symptoms.

AI-supported systems can enhance physical activity facilitation for ADHD patients by analyzing biometric data and tailoring recommendations. AI-driven virtual coaching platforms can also provide motivational messages and relaxation techniques.

Overall, physical activity, both traditional and digital, is a valuable adjunct to ADHD treatment. Integrating behavioral, pharmacological, and physical activity therapies, including digital interventions, can yield synergistic effects in ADHD management. Research should aim to create technological ecosystems that allow ongoing monitoring of therapy effects and rapid modification of treatment strategies. The challenge remains to ensure data protection and social acceptance of such solutions.

The successful deployment of contemporary technology necessitates collaboration among experts from diverse disciplines, including neuropsychology, biomedical engineering, computer science, and education. Future research ought to be translational, integrating experimental findings with actual clinical requirements. Conducting long-term cohort studies will be essential to evaluate the sustainability of therapeutic benefits and the influence of new technologies on the quality of life for patients and their families.

Disclosure

Author's contribution
Conceptualization: Patrycja Jędrzejewska-Rzezak
Metoholody: Joanna Węgrzecka, Kinga Knutelska,
Formal analysis: Paulina Gajniak, Tytus Tyralik,
Investigation: Klaudia Bilińska, Maciej Karwat, Patrycja Jędrzejewska-Rzezak
Writing - Rough Preparation: Aleksandra Winsyk, Natalia Kulicka
Writing-Review and Editing: Monika Czekalska, , Tytus Tyralik
Data curation: Joanna Węgrzecka, Kinga Knutelska, Paulina Gajniak, Aleksandra Winsyk
Visualisation: Maciej Karwat, Monika Czekalska
Project administration: Natalia Kulicka, Klaudia Bilińska

All authors have read and agreed with the published version of the manuscript.

Funding Statement: The authors didnot receive special funding.
Institutional Review Board Statement: Not applicable.
Informed Consent Statement: Not applicable.
Data Availability Statement: Not applicable.
Conflict of Interest Statement: The authors declare no conflict of interest

REFERENCES

1. Alnawwar, M. A., Alraddadi, M. I., Algethmi, R. A., Salem, G. A., Salem, M. A., & Alharbi, A. A. (2023). The Effect of Physical Activity on Sleep Quality and Sleep Disorder: A Systematic Review. *Cureus*. https://doi.org/10.7759/cureus.43595
2. An, R., Shen, J., Wang, J., & Yang, Y. (2024). A scoping review of methodologies for applying artificial intelligence to physical activity interventions. In *Journal of Sport and Health Science* (Vol. 13, Issue 3, pp. 428–441). Elsevier B.V. https://doi.org/10.1016/j.jshs.2023.09.010
3. Arrondo, G., Solmi, M., Dragioti, E., Eudave, L., Ruiz-Goikoetxea, M., Ciaurriz-Larraz, A. M., Magallon, S., Carvalho, A. F., Cipriani, A., Fusar-Poli, P., Larsson, H., Correll, C., & Cortese, S. (2022). Associations between mental and physical conditions in children and adolescents: An umbrella review. In *Neuroscience and Biobehavioral Reviews* (Vol. 137). Elsevier Ltd. https://doi.org/10.1016/j.neubiorev.2022.104662
4. Azazy, S., Nour-Eldein, H., Salama, H., & Ismail, M. (2018). Quality of life and family function of parents of children with attention deficit hyperactivity disorder. *Eastern Mediterranean Health Journal*, *24*(6), 579–587. https://doi.org/10.26719/2018.24.6.579
5. Booth, J. N., Mitchell, I. A., Tomporowski, P. D., McCullick, B. A., Boyle, J. M. E., & Reilly, J. J. (2024). Evaluation of a pilot physical activity intervention for children with ADHD symptoms and reading difficulties. *Journal of Research in Special Educational Needs*, *24*(2), 254–268. https://doi.org/10.1111/1471-3802.12628
6. Catalá-López, F., Hutton, B., Page, M. J., Driver, J. A., Ridao, M., Alonso-Arroyo, A., Valencia, A., Macías Saint-Gerons, D., & Tabarés-Seisdedos, R. (2022). Mortality in Persons with Autism Spectrum Disorder or Attention-Deficit/Hyperactivity Disorder: A Systematic Review and Meta-analysis. In *JAMA Pediatrics* (Vol. 176, Issue 4, p. E216401). American Medical Association. https://doi.org/10.1001/jamapediatrics.2021.6401
7. Chan, Y. S., Jang, J. T., & Ho, C. S. (2022). Effects of physical exercise on children with attention deficit hyperactivity disorder. In *Biomedical Journal* (Vol. 45, Issue 2, pp. 265–270). Elsevier B.V. https://doi.org/10.1016/j.bj.2021.11.011
8. Chaulagain, A., Lyhmann, I., Halmøy, A., Widding-Havneraas, T., Nyttingnes, O., Bjelland, I., & Mykletun, A. (2023). A systematic meta-review of systematic reviews on attention deficit hyperactivity disorder. *European Psychiatry*, *66*(1). https://doi.org/10.1192/j.eurpsy.2023.2451
9. Chennaoui, M., Arnal, P. J., Sauvet, F., & Léger, D. (2015). Sleep and exercise: A reciprocal issue? In *Sleep Medicine Reviews* (Vol. 20, pp. 59–72). W.B. Saunders Ltd. https://doi.org/10.1016/j.smrv.2014.06.008

10. Christiansen, L., Beck, M. M., Bilenberg, N., Wienecke, J., Astrup, A., & Lundbye-Jensen, J. (2019). Effects of exercise on cognitive performance in children and adolescents with adhd: Potential mechanisms and evidence-based recommendations. In *Journal of Clinical Medicine* (Vol. 8, Issue 6). MDPI. https://doi.org/10.3390/jcm8060841
11. Cioffredi, L. A., Yerby, L. G., Burris, H. H., Cole, K. M., Engel, S. M., Murray, T. M., Slopen, N., Volk, H. E., & Acheson, A. (2024). Assessing prenatal and early childhood social and environmental determinants of health in the HEALthy Brain and Child Development Study (HBCD). *Developmental Cognitive Neuroscience*, *69*. https://doi.org/10.1016/j.dcn.2024.101429
12. Cohen, S. C. L., Harvey, D. J., Shields, R. H., Shields, G. S., Rashedi, R. N., Tancredi, D. J., Angkustsiri, K., Hansen, R. L., & Schweitzer, J. B. (2018). Effects of Yoga on Attention, Impulsivity, and Hyperactivity in Preschool-Aged Children with Attention-Deficit Hyperactivity Disorder Symptoms. *Journal of Developmental and Behavioral Pediatrics*, *39*(3), 200–209. https://doi.org/10.1097/DBP.0000000000000552
13. da Silva, B. S., Grevet, E. H., Silva, L. C. F., Ramos, J. K. N., Rovaris, D. L., & Bau, C. H. D. (2023). An overview on neurobiology and therapeutics of attention-deficit/hyperactivity disorder. In *Discover Mental Health* (Vol. 3, Issue 1). Springer Nature. https://doi.org/10.1007/s44192-022-00030-1
14. Denyer, H., Deng, Q., Adanijo, A., Asherson, P., Bilbow, A., Folarin, A., Groom, M. J., Hollis, C., Wykes, T., Dobson, R. J. B., Kuntsi, J., & Simblett, S. (2023). Barriers to and Facilitators of Using Remote Measurement Technology in the Long-Term Monitoring of Individuals With ADHD: Interview Study. *JMIR Formative Research*, *7*. https://doi.org/10.2196/44126
15. Edinoff, A. N., Apgar, T. L., Rogers, J. J., Harper, J. D., Cornett, E. M., Kaye, A. M., & Kaye, A. D. (2022). Attention Deficit Hyperactivity Disorder and Bipolar Disorder: Diagnosis, Treatments, and Clinical Considerations: A Narrative Review. In *Psychiatry International* (Vol. 3, Issue 1, pp. 17–28). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/psychiatryint3010002
16. Faraone, S. V., & Larsson, H. (2019). Genetics of attention deficit hyperactivity disorder. In *Molecular Psychiatry* (Vol. 24, Issue 4, pp. 562–575). Nature Publishing Group. https://doi.org/10.1038/s41380-018-0070-0
17. Feng, L., Li, B., Yong, S. S., & Tian, Z. (2024). Effects of Exercise Intervention on Physical and Mental Health of Children and Adolescents with Attention-Deficit/Hyperactivity Disorder: A Systematic Review and Meta-analysis Based on ICF-CY. *Journal of Science in Sport and Exercise*. https://doi.org/10.1007/s42978-024-00295-8
18. Gao, Z., Zeng, N., McDonough, D. J., & Su, X. (2020). A Systematic Review of Active Video Games on Youth's Body Composition and Physical Activity. *International Journal of Sports Medicine*, *41*(09), 561–573. https://doi.org/10.1055/a-1152-4959
19. Gordon, E. C., & Seth, A. K. (2024). Ethical considerations for the use of brain–computer interfaces for cognitive enhancement. *PLoS Biology*, *22*(10). https://doi.org/10.1371/journal.pbio.3002899
20. Hoogman, M., Bralten, J., Hibar, D. P., Mennes, M., Zwiers, M. P., Schweren, L. S. J., van Hulzen, K. J. E., Medland, S. E., Shumskaya, E., Jahanshad, N., Zeeuw, P. de, Szekely, E., Sudre, G., Wolfers, T., Onnink, A. M. H., Dammers, J. T., Mostert, J. C., Vives-Gilabert, Y., Kohls, G., … Franke, B. (2017). Subcortical brain volume differences in participants with attention deficit hyperactivity disorder in children and adults: a cross-sectional mega-analysis. *The Lancet Psychiatry*, *4*(4), 310–319. https://doi.org/10.1016/S2215-0366(17)30049-4
21. Ji, H., Wu, S., Won, J., Weng, S., Lee, S., Seo, S., & Park, J. J. (2023). The Effects of Exergaming on Attention in Children With Attention Deficit/Hyperactivity Disorder: Randomized Controlled Trial. *JMIR Serious Games*, *11*. https://doi.org/10.2196/40438
22. Kadri, A., Slimani, M., Bragazzi, N. L., Tod, D., & Azaiez, F. (2019). Effect of taekwondo practice on cognitive function in adolescents with attention deficit hyperactivity disorder. *International Journal of Environmental Research and Public Health*, *16*(2). https://doi.org/10.3390/ijerph16020204
23. Kiiski, H., Rueda-Delgado, L. M., Bennett, M., Knight, R., Rai, L., Roddy, D., Grogan, K., Bramham, J., Kelly, C., & Whelan, R. (2020). Functional EEG connectivity is a neuromarker for adult attention deficit hyperactivity disorder symptoms. *Clinical Neurophysiology*, *131*(1), 330–342. https://doi.org/10.1016/j.clinph.2019.08.010
24. Kim, Y. J., Baek, S. H., Park, J. B., Choi, S. H., Lee, J. D., & Nam, S. S. (2021). The psychosocial effects of taekwondo training: A meta-analysis. In *International Journal of Environmental Research and Public Health* (Vol. 18, Issue 21). MDPI. https://doi.org/10.3390/ijerph182111427
25. Ko, J., Jang, S. W., Lee, H. T., Yun, H. K., & Kim, Y. S. (2020). Effects of virtual reality and non–Virtual reality exercises on the exercise capacity and concentration of users in a ski exergame: Comparative study. *JMIR Serious Games*, *8*(4). https://doi.org/10.2196/16693
26. Liang, X., Li, R., Wong, S. H. S., Sum, R. K. W., & Sit, C. H. P. (2021). The impact of exercise interventions concerning executive functions of children and adolescents with attention-deficit/hyperactive disorder: a systematic review and meta-analysis. In *International Journal of Behavioral Nutrition and Physical Activity* (Vol. 18, Issue 1). BioMed Central Ltd. https://doi.org/10.1186/s12966-021-01135-6
27. Liu, H. L. V., Sun, F., & Tse, C. Y. A. (2023). Examining the Impact of Physical Activity on Sleep Quality in Children With ADHD. *Journal of Attention Disorders*, *27*(10), 1099–1106. https://doi.org/10.1177/10870547231171723

28. Masi, L., Abadie, P., Herba, C., Emond, M., Gingras, M. P., & Amor, L. Ben. (2021). Video Games in ADHD and Non-ADHD Children: Modalities of Use and Association With ADHD Symptoms. *Frontiers in Pediatrics*, *9*. https://doi.org/10.3389/fped.2021.632272
29. Mastrangelo, S., Peruzzi, L., Guido, A., Iuvone, L., Attinà, G., Romano, A., Maurizi, P., Chieffo, D. P. R., & Ruggiero, A. (2024). The Role of the Cerebellum in Advanced Cognitive Processes in Children. *Biomedicines*, *12*(8), 1707. https://doi.org/10.3390/biomedicines12081707
30. Meijer, A., Königs, M., Vermeulen, G. T., Visscher, C., Bosker, R. J., Hartman, E., & Oosterlaan, J. (2020). The effects of physical activity on brain structure and neurophysiological functioning in children: A systematic review and meta-analysis. In *Developmental Cognitive Neuroscience* (Vol. 45). Elsevier Ltd. https://doi.org/10.1016/j.dcn.2020.100828
31. Müller, P., Duderstadt, Y., Lessmann, V., & Müller, N. G. (2020). Lactate and BDNF: Key mediators of exercise induced neuroplasticity? In *Journal of Clinical Medicine* (Vol. 9, Issue 4). MDPI. https://doi.org/10.3390/jcm9041136
32. Salari, N., Ghasemi, H., Abdoli, N., Rahmani, A., Shiri, M. H., Hashemian, A. H., Akbari, H., & Mohammadi, M. (2023). The global prevalence of ADHD in children and adolescents: a systematic review and meta-analysis. *Italian Journal of Pediatrics*, *49*(1). https://doi.org/10.1186/s13052-023-01456-1
33. Shema-Shiratzky, S., Brozgol, M., Cornejo-Thumm, P., Geva-Dayan, K., Rotstein, M., Leitner, Y., Hausdorff, J. M., & Mirelman, A. (2019). Virtual reality training to enhance behavior and cognitive function among children with attention-deficit/hyperactivity disorder: brief report. *Developmental Neurorehabilitation*, *22*(6), 431–436. https://doi.org/10.1080/17518423.2018.1476602
34. Sibley, M. H., Bruton, A. M., Zhao, X., Johnstone, J. M., Mitchell, J., Hatsu, I., Arnold, L. E., Basu, H. H., Levy, L., Vyas, P., Macphee, F., Gonzalez, E. S., Kelley, M., Jusko, M. L., Bolden, C. R., Zulauf-McCurdy, C., Manzano, M., & Torres, G. (2023). Non-pharmacological interventions for attention-deficit hyperactivity disorder in children and adolescents. In *The Lancet Child and Adolescent Health* (Vol. 7, Issue 6, pp. 415–428). Elsevier B.V. https://doi.org/10.1016/S2352-4642(22)00381-9
35. Smith, A. L., Hoza, B., Linnea, K., McQuade, J. D., Tomb, M., Vaughn, A. J., Shoulberg, E. K., & Hook, H. (2013). Pilot Physical Activity Intervention Reduces Severity of ADHD Symptoms in Young Children. *Journal of Attention Disorders*, *17*(1), 70–82. https://doi.org/10.1177/1087054711417395
36. Song, Y., Jia, S., Wang, X., Wang, A., Ma, T., Li, S., Chen, J., Guo, Z., Ding, F., Ren, Y., & Qin, M. (2024). Effects of physical exercise on anxiety depression and emotion regulation in children with attention deficit hyperactivity disorder: a systematic review and meta-analysis. In *Frontiers in Pediatrics* (Vol. 12). Frontiers Media SA. https://doi.org/10.3389/fped.2024.1479615
37. Su, W. C., Amonkar, N., Cleffi, C., Srinivasan, S., & Bhat, A. (2022). Neural Effects of Physical Activity and Movement Interventions in Individuals With Developmental Disabilities–A Systematic Review. In *Frontiers in Psychiatry* (Vol. 13). Frontiers Media S.A. https://doi.org/10.3389/fpsyt.2022.794652
38. Sun, W., Yu, M., & Zhou, X. (2022). Effects of physical exercise on attention deficit and other major symptoms in children with ADHD: A meta-analysis. In *Psychiatry Research* (Vol. 311). Elsevier Ireland Ltd. https://doi.org/10.1016/j.psychres.2022.114509
39. Thompson, L., Charitos, S., Bird, J., Marshall, P., & Brigden, A. (2025). Exploring the Use of Smartwatches and Activity Trackers for Health-Related Purposes for Children Aged 5 to 11 years: Systematic Review. *Journal of Medical Internet Research*, *27*. https://doi.org/10.2196/62944
40. Wang, P., Ai, X., Zhang, X., Ma, F., Zhuang, Y., & Wang, S. (2024). Evaluating virtual reality technology in psychotherapy: impacts on anxiety, depression, and ADHD. In *Frontiers in Psychiatry* (Vol. 15). Frontiers Media SA. https://doi.org/10.3389/fpsyt.2024.1480788
41. Wang, T., Li, W., Deng, J., Zhang, Q., Liu, Y., & Zheng, H. (2024). The impact of the physical activity intervention on sleep in children and adolescents with neurodevelopmental disorders: a systematic review and meta-analysis. In *Frontiers in Neurology* (Vol. 15). Frontiers Media SA. https://doi.org/10.3389/fneur.2024.1438786
42. Welsch, L., Alliott, O., Kelly, P., Fawkner, S., Booth, J., & Niven, A. (2021). The effect of physical activity interventions on executive functions in children with ADHD: A systematic review and meta-analysis. *Mental Health and Physical Activity*, *20*. https://doi.org/10.1016/j.mhpa.2020.100379
43. Xie, Y., Gao, X., Song, Y., Zhu, X., Chen, M., Yang, L., & Ren, Y. (2021). Effectiveness of Physical Activity Intervention on ADHD Symptoms: A Systematic Review and Meta-Analysis. In *Frontiers in Psychiatry* (Vol. 12). Frontiers Media S.A. https://doi.org/10.3389/fpsyt.2021.706625
44. Yang, G., Liu, Q., Wang, W., Liu, W., & Li, J. (2024). Effect of aerobic exercise on the improvement of executive function in children with attention deficit hyperactivity disorder: a systematic review and meta-analysis. In *Frontiers in Psychology* (Vol. 15). Frontiers Media SA. https://doi.org/10.3389/fpsyg.2024.1376354
45. Yu, D., & Fang, J. hui. (2024). Using artificial intelligence methods to study the effectiveness of exercise in patients with ADHD. *Frontiers in Neuroscience*, *18*. https://doi.org/10.3389/fnins.2024.1380886
46. Zhang, W., Xiong, K., Zhu, C., Evans, R., Zhou, L., & Podrini, C. (2024). Promoting child and adolescent health through wearable technology: A systematic review. In *Digital Health* (Vol. 10). SAGE Publications Inc. https://doi.org/10.1177/20552076241260507