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# The effects of physical activity, exercise and sports in paediatrics population with Attention-Deficit/Hyperactivity Disorder: a systematic review

Ana Francisca Oliveira Rodrigues

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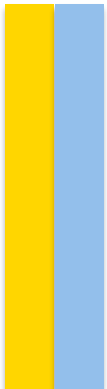

# The effects of physical activity, exercise and sports in paediatrics population with Attention-Deficit/Hyperactivity Disorder: a systematic review

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**Resumo**

Introdução: A Perturbação de Hiperatividade/Défice de Atenção (PHDA) é umas das patologias do neurodesenvolvimento mais comumente diagnosticadas na população pediátrica. Esta patologia tem um grande impacto em vários domínios da vida destas crianças, nomeadamente nas suas competências sociais (familiares e extra-familiares), no seu desempenho académico e, futuramente, na sua vida laboral. O objetivo do tratamento de PHDA é melhorar os sintomas e comportamentos associados e aumentar a funcionalidade. Atualmente, o pilar do tratamento desta patologia centra-se em opções farmacológicas (mormente psicoestimulantes) e não farmacológicas (terapia comportamental). Embora estes tratamentos sejam eficazes, a medicação pode causar efeitos adversos e algumas famílias temem os efeitos a longo prazo da terapêutica farmacológica, preferindo tratamentos não farmacológicos. Estes tratamentos geralmente necessitam de uma grande disponibilidade parental e escolar, são morosos, mais dispendiosos e de mais díficil acesso, o que pode causar o seu abondono. A atividade física influencia o desenvolvimento motor, social, emocional e cognitivo durante a infância e tem sido explorada como um tratamento não farmacológico a usar nesta patologia.

Objetivo: O principal objetivo foi realizar uma revisão sistemática da literatura dos últimos sete anos sobre os efeitos da atividade física e exercício em crianças e adolescentes com PHDA.

Métodos: Foi realizada uma pesquisa preliminar através da combinação das palavras-chave Attention-Deficit/Hyperactivity Disorder, ADHD, Exercise, Sports e Physical Activity com os MeshTerms *exercise*, *sports* and *Attention Deficit Disorder with Hyperactivity* que originou 61 artigos de interesse. Os artigos foram publicados entre julho de 2016 e janeiro de 2023. A procura manual de artigos de interesse também foi realizada.

Resultados: Um total de 23 artigos foram incluídos na revisão. Foram demonstrados benefícios na população pediátrica com PHDA tanto nos estudos a curto como a longo prazo. Estes benefícios incluem melhoria sintomática, na função cognitiva e executiva, no rendimento escolar e em parâmetros físicos e mentais. Para estudos futuros, sugerimos a avaliação dos efeitos dos diferentes tipos de atividade física, tendo em conta a sua frequência e duração e o controlo de outras variáveis como o género, idade e terapêutica farmacológica.

Conclusão: A atividade física deve ser recomendada como um tratamento adjuvante no tratamento de crianças com PHDA.

Palavras-chave: Perturbação de Hiperatividade/Défice de Atenção, atividade física, exercício, desporto, crianças.

## Abstract

Introduction: Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurodevelopment pathologies diagnosed in the paediatrics population. It impacts multiple areas of the child life, namely their social abilities and relationships, academic performance, and future careers when adults. The ultimate purpose of treating ADHD is to improve symptoms and behaviours and to enhance functionality. Nowadays, the cornerstone of the treatment of ADHD consists in pharmacologic (mainly psychostimulants) and non-pharmacologic options (behavioural therapy). Although effective, the pharmacologic treatment can have adverse effects and some families worry about the long-term effects of the medication, preferring the non-pharmacological treatments. The non-pharmacological treatments usually require a great deal of parental and school availability, are time-consuming, more expensive and less available, leading to a higher drop out of this treatment. Physical activity has a great impact on the motor, social, emotional, and cognitive development in childhood, and has been investigated as another non-pharmacological approach to treat these symptoms.

Objective: Our main objective was to conduct a systematic review of the literature in the last seven years about the various effects of physical activity and exercise in children and adolescents with ADHD.

Methods: Using a combination of keywords Attention-Deficit/Hyperactivity Disorder, ADHD, Exercise, Sports and Physical Activity and the MeshTerms *exercise*, *sports* and *Attention Deficit Disorder with Hyperactivity,* a preliminary search generated 61 articles of interest. These articles were published between July 2016 and January 2023. A manual search for articles of interest was also conducted.

Results: After examination of the articles found, a total of 23 articles were included in this review. From the analysis it was possible to conclude that both acute and long-term studies demonstrate benefits in the ADHD paediatric population. The results further indicate improvements in ADHD symptomology, cognitive and executive functions, academic performance, physical and mental parameters. For future studies, we suggest differentiating the effects of the various types of physical exercise, considering their frequency and duration, and to control for gender, age and pharmacological therapy.

Conclusion: Physical activity should be recommended as an adjuvant intervention to the current treatment of children with ADHD.

Keywords: Attention-Deficit/Hyperactivity Disorder, exercise, physical activity, sports, children.

## List of abbreviations

| | |
|---|---|
| ADHD | Attention-Deficit/Hyperactivity Disorder |
| BARAN | Balance-based Attentive Rehabilitation of Attention Networks |
| BFM | Body fat mass |
| BMI-Z-score | Body mass index-Z-score |
| DSM | Diagnostic and Statistical Manual of Mental Disorders |
| EEG | Electroencephalography |
| ERP | Event-related potentials |
| EXCIR | Exercise for cognitive improvement and rehabilitation |
| HIIT | High-intensity interval training |
| ICD | International Classification of Diseases |
| IL-13 | Interleukin-13 |
| IL-16 | Interleukin-16 |
| KiTAP | Child version of the Test of Attentional Performance |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta Analyses |
| WBVT | Whole body vibration training |
| WHO | World Health Organization |

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## Introduction

Attention-Deficit/Hyperactivity Disorder (ADHD) is one of the most common neurodevelopment pathologies diagnosed in the paediatrics population, characterized by symptoms of inattention, hyperactivity and/or impulsivity[1–3]. It is a chronic pathology and 60% of patients report the persistence of symptoms into adulthood[4]. This condition affects more male than female children in a ratio of 2M:1F in children and 1.6M:1F in adults[1,5,6]. ADHD is a clinically based diagnosis and the two main classification systems used are: Diagnostic and Statistical Manual of Mental Disorders (DSM-5-TR) and International Classification of Diseases (ICD-11)[1,3]. Both diagnostic classification systems require the presence of symptoms of inattention and/or hyperactivity-impulsivity for at least six months[1,3]. Moreover, symptoms should be inconsistent with the developmental level expected for the child, must be present in two or more settings and must have a negative impact on school, social and work functioning (for adults)[1,3]. In addition, this clinical condition cannot be explained by another mental disorder and several symptoms must be present preceding the age of twelve[1,3].

Symptoms of inattention can be failure giving attention to details, making reckless mistakes in assignments, difficulties in holding attention and not seeming to listen when spoken to directly[1,3]. Inattention can also be characterized by easily forgetting and loosing things, being easily distracted by stimulus, struggling with organization and avoiding work that require mental effort[1,3]. Hyperactivity and impulsivity can be described as difficulties in sitting and staying still when the situation requires so and difficulties in engaging in leisure activities patiently[1,3]. Talking excessively, interrupting other people, struggling to wait for his or her turn during activities and acting without thinking about the potential consequences are also examples of hyperactivity and impulsivity symptoms[1,3].

Children with ADHD face multiple challenges in their daily life. In the school setting, learning impairments specially in math, reading and spelling affect this population, leading to lower academic performance[7,8]. They also show higher rates of academic retention, school suspension and expulsion than non-ADHD children[9]. ADHD impacts the social and emotional capacities, causing difficulties in the relationships between family members, peers and colleagues[7,8,10]. This diagnosis can also be associated with anti-social, addictive, mood and anxiety disorders[11]. As adults, these patients experience more difficulties in maintaining a job and have a higher risk of being fired[7,8,12]. A greater predisposition to illicit acts is described, with higher rates of conviction and imprisonment than in the general population[13,14].

Executive functions are a set of high-level mental processes, highly complex and differentiated but interrelated, that are necessary to any type of learning. They underlie goal-oriented behaviour, problem solving and efficient knowledge acquisition and are a strong predictor of both academic and in later life success, because they enable us to interact with the environment in a fully adaptive way. Executive functions comprise several cognitive domains such as working memory, inhibition, and attention and are impaired in the ADHD population[15,16]. Executive functions are essential to inhibit undesired behaviours, to use attentional resources correctly, and for organizational purposes when coping with distractions and stressful situations[16].

Childhood is an important period for the development of motor competence, allowing children to engage in different types of physical activity[17]. Motor competence influences the weight status and health related fitness, contributing to a healthier life[17]. Contrary to popular beliefs that children with ADHD tend to move a lot and are very active, these children present poorer motor performance than their healthy peers[7].

The prevalence of childhood obesity is increasing worldwide[18]. Nowadays, children are more sedentary, spending more time watching television and using other electronic devices such as computers, tablets and smartphones[19]. Children with ADHD are at an even higher risk of obesity than the healthy population[20]. Genetic and neurobiological factors, impaired executive functions, stress and lower levels of physical activity are possible explanations for this association[20].

The ultimate purpose of treating ADHD is to improve symptoms and behaviours and to enhance functionality[21]. The treatment of ADHD consists of pharmacologic and non-pharmacologic options[22]. The first line medication used for the treatment of ADHD are psychostimulants, namely methylphenidate and amphetamines[22–25]. This medication is the most effective in controlling ADHD symptoms but only last for limited periods of time, until the drug is metabolized[22].

Of the non-pharmacological options, the most used is behavioural therapy[23,24]. Behavioural therapy is a combination of cognitive behaviour therapy for the patient associated with interventions at school and at home[26]. It aims to alter behaviour, using specific techniques to improve the child's ability to manage it by reinforcing positive behaviours and reducing problematic ones[2,26]. These techniques include giving rewards when the child shows the adequate behaviour and withdrawal of privileges when the child does not meet the designated goals[2]. It incorporates social skills training, behavioural training and self-management skills[23,26]. Another goal of this therapy is to fortify the parent-child relationship and to enhance the parents and teachers' capacities of communicating commands and establishing rules[26,27]. Older children are instructed to use behavioural strategies when navigating through their daily lives[27]. The decision between

these two alternatives is based on the patient's age, the severity of the symptoms and associated impairment, comorbidities and the patient and caregivers' preference[22,24]. Usually in younger patients (under five years old) pharmacotherapy is not recommended as first-line therapy, being the non-pharmacologic measures, more specifically parent training programmes, the first option[24,27]. For older children, medication combined with educational individualized interventions will be the most effective treatment[24,27]. In fact, through age six to twelve, behavioural therapy should be included in the treatment and in adolescents it should be encouraged, if available[27].

The use of medication has potential side effects, being the most common ones: decreased appetite, sleeping disturbances, weight changes, abdominal pain, headaches and irritability[2,28–30]. Depending on the severity of these adverse effects it can lead to changes to the prescription, to adjustments of the dose, or even to the interruption of the pharmacologic treatment[24]. In some cases, families struggle with the dilemma of starting pharmacological treatment, expressing some concerns about the short and, specially, the long-term adverse effects of the use of medication[31,32]. The non-pharmacological treatment is not associated with adverse effects, hence some caregivers prefer this option[22]. The non-pharmacological treatments, such as behavioural therapies, usually require a great deal of parental and school availability, are more expensive and less obtainable particularly in rural areas, which can lead to the abandonment of this practice[2,22].

The practice of sports, exercise or physical activity have a great impact on the motor, social, emotional and cognitive development of children and teenagers[33,34]. Physical activity improves the quality of life and sleep, cognitive function and academic performance[35–37]. It also has an important role in reducing the risk of mental illnesses (such as depression and anxiety), obesity and many other diseases (such as hypertension, type 2 diabetes, coronary heart disease, stroke, cancer and dementia)[38–40]. Practising physical activity can make people feel better and improves bone, muscular, metabolic and cardiorespiratory health[37,38].

Childhood is a crucial period for the development of movement skills, and to learn and establish a sustainable healthy lifestyle[17,38,41]. Children younger than 6 years old should be physically active during the day and older children and adolescents should do at least one hour of moderate to vigorous physical activity every day[38,42]. Parents, caregivers and peers play a key part in encouraging children to be physically active and to nurture a healthy relationship with exercise[35,38]. One important point to highlight is that children should be encouraged in experimenting different types of sports and exercises to find the one that is more enjoyable and fit for them, promoting in this way their long-term compliance[34]. Physical activity, exercise and sports also show benefits in

paediatric population with ADHD, such as improvements in executive and cognitive functions, ADHD symptomatology, emotional behavioural and motor skills development[43–51].

Physical activity is defined by the World Health Organization (WHO) as any bodily movement produced by skeletal muscles that requires energy expenditure[52]. Exercise is a planned, structured and repetitive physical activity with the purpose to improve or maintain components of physical fitness[53]. Sports are described by WHO as a set of multiple activities performed within a set of rules and undertaken as part of leisure or competition, involving physical activity performed by teams or individuals[52]. Thus, exercise and sports are part of physical activity. In this study, in order to simplify the terms used, we will use the term physical activity when also referring to exercise and sports.

In recent years, interest in the role of physical activity, exercise, and sports in the management of ADHD increased, and in 2017, Ng et al.[54] published the latest systematic review about the specific effects of physical activity in children diagnosed with ADHD. Although other reviews have been published in more recent years, they were mainly focused on specific outcomes (i.e. executive function, ADHD symptoms)[43–50]. The main objective of the present study is to expand up to our days the 2017 systematic review on the evidence of the effects of physical activity, exercise and sports in children and adolescents with ADHD.

## Methods

A systematic search was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines[55].

The keywords used in the literature search were Attention-Deficit/Hyperactivity Disorder, ADHD, exercise, sports and physical activity and the MeshTerms *exercise*, *sports* and *Attention Deficit Disorder with Hyperactivity*. A preliminary search on Pubmed generated 61 articles of interest published in the last seven years. The screening of the articles through the title and abstract was conducted. For the selected studies, full articles were acquired and examined. The articles included in this review were published between July 2016 and January 2023.

Only original articles were included in the review and the inclusion criteria were: (1) intervention study with a type of exercise, physical activity or sports, (2) study participants with a clinical diagnosis of ADHD, (3) outcome measures relating to ADHD symptoms available, (4) study participants with less than 18 years old, (5) the article was written in English or Portuguese. A manual search for other articles of interest was conducted on the references of the selected articles and other previous systematic reviews.

In the initial search a total of 61 articles of interest were identified. Through the abstracts preliminary analysis, 28 articles were excluded and 33 were sought for retrieval. One was not available and nineteen did not meet the inclusion criteria: eight had been published before July 2016, two were protocols of other included articles in this review, six did not had an exercise intervention, in two of the articles the groups had more than one diagnosis and one study was excluded due to the absence of a clinical diagnosis of ADHD. In the end, 13 articles met the inclusion criteria. A search was also conducted manually on other systematic reviews with similar themes, that added more 10 studies to this review. Figure 1 illustrates the selection process used in this review.

## Results

Twenty-three studies were included in this review. Six studies analysed the acute effect of physical activity[56–61] and 17 the long-term physical activity outcomes[62–78]. Studies of acute physical activity examine the immediate effects that follow a single bout of physical activity in the subsequent minutes to hours, while studies of chronic physical activity consider the effects that regular physical activity may have over the course of weeks, months or even years[51]. The characteristics of the articles included in this review are summarized in table 1.

The sample size of the experimental and control groups varied between 6 and 50 children. Most of the studies included mainly male subjects (80,9% versus 19,1%).

In all studies that tested the acute effect of physical activity, the control condition was watching a video. The duration of the interventions varied between 15 minutes (one study[57]), 20 minutes (three studies[58–60]), and 30 minutes (two studies[56,61]).

All the long-term intervention studies included a control and experimental group with children diagnosed with ADHD. Of these, five studies included an active control condition, namely: (1) the use of whole body vibration training (WBVT) and treadmill training compared to treadmill training alone[68]; (2) the comparison of an aerobic exercise (running) with an Exercise for Cognitive Improvement and Rehabilitation (EXCIR)[69]; the match between an aerobic exercise (running) with a Balance-based Attentive Rehabilitation of Attention Networks (BARAN)[70]; (3) the comparison between the training of tennis table with a simulated tennis table practice and a control group[71]; and (4) the effect of a taekwondo training compared to a standard physical education program[73]. In the group of studies that evaluated long-term interventions, the duration of the interventions varied between 4 weeks and 1 year and a half: two studies lasted for four to five weeks[69,70], one article had an intervention for six weeks[63], seven studies evaluated an intervention for eight weeks[62,65,67,68,72,75,77], six articles intervention duration of twelve weeks[64,66,71,74,76,78] and one study investigated an intervention with a duration of one year and a half (72 weeks)[73].

Concerning the use of medication in the ADHD children, four of the studies did not use pharmacologic treatment[62,63,68,73], five of the articles mentioned the use of medication in all of the sample[59,60,64,74,77], eight studies refer that some of the children had medication and others did not (within each group)[56,57,61,66,67,71,72,75] and five studies did not declare the use of pharmacologic treatments[65,69,70,76,78]. One article had two groups of children diagnosed with ADHD: one using medication and the other not[58].

Memarmoghaddam and colleagues[62] found significant improvements in cognitive and behavioural inhibition after an organised exercise program. Various studies identified benefits in ADHD symptomology: two articles[63,75] showed improvements after the exercise intervention (high-intensity interval training (HIIT) and tai-chi practice respectively). Durgut and colleagues[68] found benefits in ADHD symptoms in both intervention groups (aerobic exercise and aerobic exercise plus WBVT). In one study only the experimental group (EXCIR group) showed improvements in symptomology[69]. Nejati and colleagues[70] demonstrated significant improvements in the school setting in both intervention groups, but only the experimental group (BARAN group) showed benefits at home.

According to Hattabi and colleagues[78], swimming practice for twelve weeks benefited behaviour and academic performance in patients with ADHD. Concerning executive functions, three studies[69–71] demonstrated that both intervention groups improved executive functions, but these were more noteworthy in the experimental groups (EXCIR group, BARAN group and the actual tennis table training group). Also, Lee, Song and Parker found that executive functions ameliorated in both groups (exercise and inactive control)[64]. Benzing and colleagues[57,67] showed that inhibition and switching improved after an acute and a long-term exergaming activity.

There were significant improvements in complex reaction time tasks after an adapted physical activity for eight weeks[65], as well as in task switching proved by Hung and colleagues[61] after a 30-minute aerobic exercise.

Concerning attention, significant improvements were noted by Durgut and colleagues[68] after an aerobic exercise and after the combination of aerobic exercise and WBVT, and specifically in sustained attention and selective attention by Chou and colleagues[72], after a yoga intervention and by Kadri and colleagues[73], Hattabi and colleagues[76] and Silva and colleagues[77] after a taekwondo and swimming interventions, respectively.

Inhibitory control also showed significant enhancement in multiples studies: after a taekwondo intervention[73], a swimming intervention[76,78] and after an aerobic and a coordinative exercise[60].

Regarding cognitive flexibility, Silva and colleagues[77] and Ludyga and colleagues[59] demonstrated significant improvements after a swimming intervention and a 20-minute aerobic exercise. Amelioration in memory was found after eight weeks of judo training[74], after swimming practice for 12 weeks[76], and after a 30-minute aerobic exercise[61]. Also, the discrimination ability improved after eight weeks of yoga practice[72].

Only one article studied parenting stress and showed its significant diminishment after 12 weeks of exercise[66]. The quality of life of children with ADHD also improved in the intervention's groups (aerobic exercise group and aerobic exercise plus WBVT group) according to Durgut and colleagues[68].

Motor abilities and general psychopathology improved after 8 weeks of exergaming[67]. Clark and colleagues[75] demonstrated improvements in motor control and function after tai chi practice for eight weeks. Also, handwriting outcomes showed significant benefits after tennis table training and simulated tennis training, but these effects were more notorious in the actual tennis table group[71]. Motor coordination, mental health parameters and physical fitness levels improved significantly after eight weeks of swimming training[77]. Soori and colleagues[63] found benefits in body composition after 6 weeks of HIIT training as did Huang and colleagues[56] also showed in the resting electroencephalography (EEG) after 30-minute exercise.

## Discussion

Studies that researched the acute effects of physical activity found benefits in resting EEG in reaction times of inhibition and switching, in inhibitory control, in cognitive flexibility, in task switching, in working memory and in some attentional parameters, after different types of moderate intensity physical activity[56–61]. According to Villa-González et al.[47] review, intense exercise improves executive functions in the ADHD population, especially in inhibitory control, attention resources and cognitive abilities. The findings relative to short-term studies are consistent with the ones found by Villa-González et al. One should mention that in the studies reviewed in our work, improvements occurred with moderate intensity physical activity, while the previous mentioned review have only focused on the use of intense physical activity.

Studies that evaluated chronic physical activity revealed that long-term interventions showed positive effects in cognitive function, ADHD symptomology, executive functions, brain activity, reaction performance, attention, discrimination ability, memory capacity and behaviour[62–65,67–78]. In our review we also found improvements in motor abilities, handwriting function, body parameters, mental health parameters, quality of life, the levels of stress experienced by parents and academic performance[63,66,67,71,77,78].

In the previous literature it was already established that physical activity, exercise and sports demonstrated positive effects in children diagnosed with ADHD. A recent meta-analysis of randomized controlled trials concluded that after a regular moderate to vigorous physical activity program, there were improvements in ADHD symptoms and functional impairment, especially in the social context[44]. In the study by Xie et al.[46], benefits in ADHD symptomology after a physical activity intervention were observed, especially for children and adolescents, leading authors to hypothesize that physical activity could be an effective stand-alone treatment. Additionally, according to the systematic review carried by Ng et al.[54], both acute and chronic physical activity improved the cognitive, behavioural, and physical symptoms of ADHD, especially improving the neurocognitive function and inhibitory control.

The findings of our review are in line with previous reviews on the subject. This review also led to the conclusion that a regular program of physical activity affects the quality of life of the children with ADHD and the mental health of both the caregivers and children. Our results also indicate an improvement in the academic performance in this population, being this an important point for both the patients and their families.

The studies included in this review are very heterogenous in what concerns to physical activity programs, durations and frequencies, but also in the studied population, namely concerning the

age group. Swimming activities, combination of aerobic exercises, judo, running, cycling, HIIT, exergaming, tennis table, yoga, taekwondo are all examples of exercises used in the included studies. This makes it more difficult to create a valid recommendation about the type, intensity, frequency and duration of exercise. On the other side, as the studies evaluated different exercises and programs, this also means that a variety of options of physical activity are available, and they all seem in some extent to have positive effects in children with ADHD. In this way, children can choose the physical activity that they enjoy the most and fits them better, taking the greatest profit of the elected program.

This review has some limitations. Firstly, the searched literature was carried out by only one researcher, though trying to maintain the accuracy of the process. Another limitation is that the included studies are extremely diverse, with different types of physical activity and different duration and frequencies of practice, making it difficult to compare and to determine the more effective type of physical activity, duration and frequency. The third limitation present in this study is that most of the population included in this review, were boys, since ADHD is more commonly diagnosed in this group. Also, there is no categorization of the participants in the studies according to their presentations of ADHD, leaving room to speculate which presentation would benefit more from exercise. Another limitation to consider is the lack of homogeneity concerning medication use in the studies. In some studies, the sample is medicated for ADHD, in others no one in the group takes them, and, in some studies, there will be different medication status in the same group. Some of the studies try to reduce the impact of the medication in the measured outcomes, by asking the patient not to take it in the previous hours. The last limitation present in this study is the different tests used to measure the outcomes and the different outcomes evaluated. Even when the evaluated outcome is the same, some studies use different tests to assess them. This review also includes different type of outcomes measures, namely objective and subjective ones.

This review highlights that physical activity, exercise and sports impact the life of paediatric population with ADHD. As previously mentioned, the studies included addressed different types of physical activity with different intensities, duration and frequency. In this way, it is not possible to recommend the practice of a specific type of physical activity for the studied population. Furthermore, it is not possible to suggest the use of exercise as a treatment option alone. The selected studies differ about the inclusion of medicated children. Only four studies conducted the investigation free of medication. Five studies mentioned that all the children were on medication, so it cannot be guaranteed that the effects are all due to the intervention used. Eight studies had children with and without medication in the same group, and five studies did not report the use of pharmacological treatment. Consequently, the results do not demonstrate the efficacy of the use

of physical activity, exercise and sports as a stand-alone treatment. At the present time, the recommendation should be that physical activity can in fact be an important part for the emotional, social and academic development and growth during childhood and adolescence, benefiting also the ADHD population, not only in their general health, but also concerning their ADHD symptomatology. Due to the lack of adverse effects, authors consider that physical exercise should be part of the treatment of the ADHD paediatric population. Since we analysed different kinds of physical activities, families should choose the one that the children enjoy the most and that it is more feasible in the long term.

For future studies in the paediatric population with ADHD we suggest the implementation of research protocols to differentiate the effects of the various types of physical exercise, considering their frequency and duration, while controlling for the variables of gender, age and pharmacological therapy.

## Conclusion

In conclusion, children with ADHD and their caregivers should be advised to add physical activity to their current treatment. Although we cannot recommend it as a stand-alone therapy, physical activity demonstrated to have a considerable potential benefit during childhood and adolescence contributing to the normal social, emotional and motor development. Furthermore, in the specific ADHD paediatric population, physical activity also confers advantages not only in symptomatology, executive and cognitive functions and academic performance, but also in their physical health, quality of life and family ties.

## Appendix

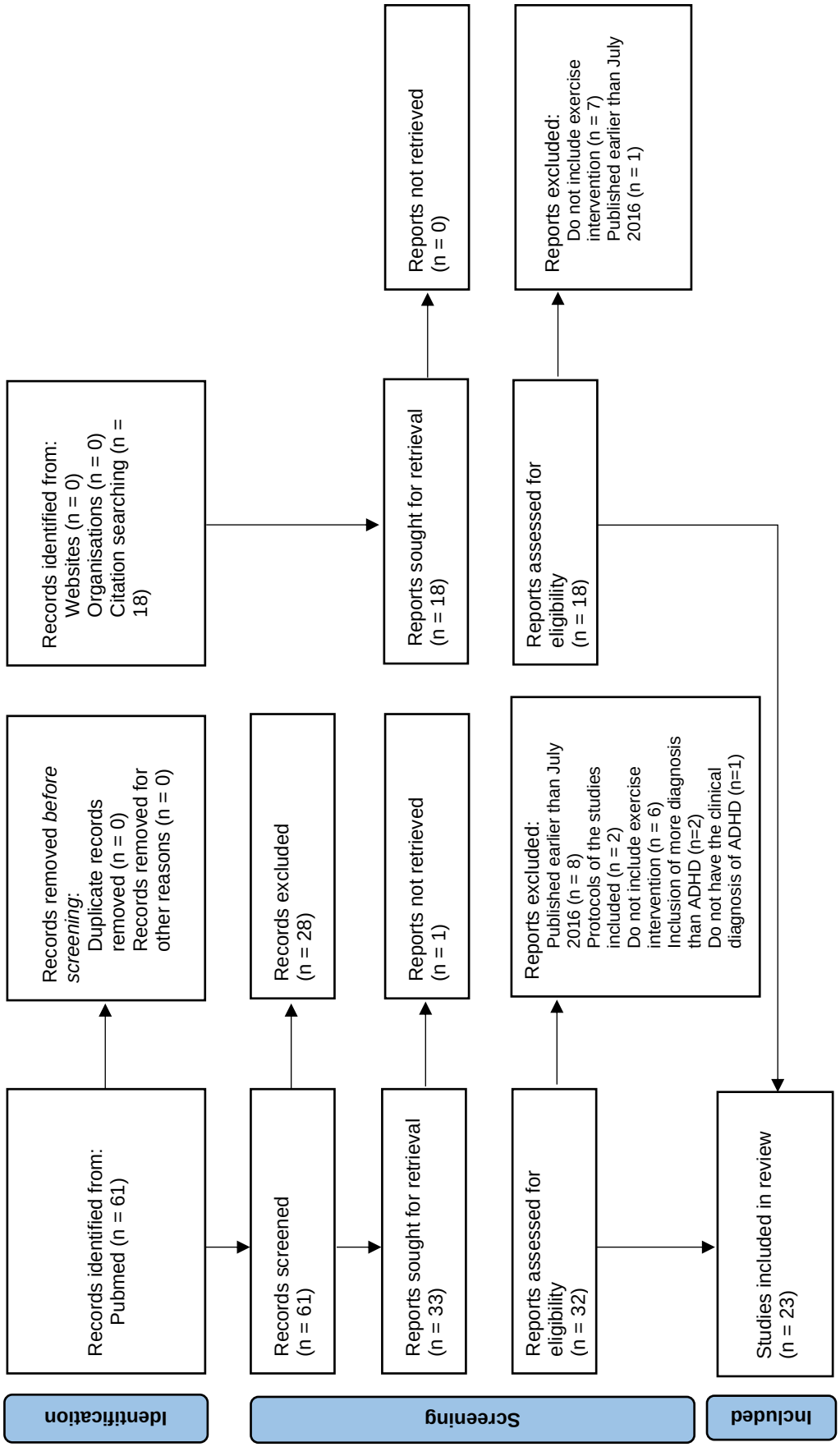


*Figure 1: PRISMA flow diagram of selection process.*

*Table I: Characteristics of the 23 studies included in this review.*

| Author | Type of study | Experimental group | Control group | Study design | Oucome measures | Evaluated outcome | Results |
|---|---|---|---|---|---|---|---|
| Memarmoghaddam [62] | Long-term study | 19 boys with ADHD, aged between 7-11 years | 17 boys with ADHD, aged between 7-11 years | Exercise program 3 sessions (90 minutes) per week, for 8 weeks | Stroop Test<br>Go-No-Go Test | Cognitive performance (cognitive inhibition and behaviour inhibition) | The experimental group showed improvements in cognitive and behavioural inhibition with an organised exercise program, with statistical significance. |
| Soori[63] | Long term study | 26 children with ADHD | 17 children with ADHD | HIIT 3 sessions a week for 6 weeks | Conners' Parent Rating Scale<br>BMI-Z-score<br>BFM<br>Lactate<br>IL-16<br>IL-13 | ADHD symptoms<br>Anthropometry and body composition<br>Biochemical parameters | Significant improvements in body composition and ADHD symptomology in the experimental group. There was also an increase of lactates and reduction in the IL-13 levels after 6 weeks of HIIT. |
| Lee[64] | Long term study | 6 boys with ADHD | 6 boys with ADHD | Exercise 3 sessions (60 minutes) a week for 12 weeks | Stroop Colour and Word Test<br>EEG | Executive functions<br>Brain activity | Significant improvements in executive functions in both groups. There were also benefits in the EEG readings, more noteworthy in the experimental group. |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Chan[65] | Long term study | 21 children with ADHD, aged between 8 and 11 years | 16 children with ADHD, aged between 8 and 11 years | Adapted exercise 2 sessions (60 minutes) a week for 8 weeks | Simple reaction time test<br>Four-choice reaction time test | Reaction performance | Improvements in complex reaction time tasks in the experimental group with statistical significance, but no significant differences in simple reaction time test. |
| Zhang[66] | Long term study | 22 children with ADHD, aged between 6 and 12 years | 21 children with ADHD, aged between 6 and 12 years | Exercise 3 sessions (60min) a week for 12 weeks | Paediatric Quality of Life Inventory<br>Parenting Stress Index-Short Form | Quality of life<br>Parenting stress | Improvements in parenting stress (specifically child domain) in the experimental group. No significant changes in the quality of life. |
| Benzing[67] | Long term study | 28 children with ADHD, aged between 8-12 years | 23 children with ADHD, aged between 8-12 years | Exergaming 3 times (at least 30 min) a week for 8 weeks | Simon Task<br>Flanker task<br>Colour span backward task<br>Conners-3 scales<br>German Motor Test | Inhibition<br>Switching<br>Updating<br>ADHD symptoms<br>Motor ability | Improvements in reaction time of inhibition and switching, motor abilities and general psychopathology, but no changes in updating and accuracy scores. |

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| Durgut[68] | Long term study | 15 children with ADHD, aged between 7-11 years | 15 children with ADHD, aged between 7-11 years | Treadmill training + WBVT (45 + 15 min) vs treadmill training (45 min), 3 days a week for 8 weeks | Stroop Test<br>TBAG<br>Conners' rating scale<br>Behaviour rating inventory of executive function<br>Paediatric quality of life inventory | Attention<br>ADHD symptoms<br>Executive functions behaviours<br>Quality of life | There were improvements in both groups in attention, executive function behaviour and quality of life. The only statistically significant difference detected was in the classroom behaviour, with the experimental group showing further improvements. |
| Nejati[69] | Long term study | 15 children with ADHD | 15 children with ADHD | EXCIR vs aerobic exercise, 3 sessions (40-50 min) a week for 4-5 weeks | One-Back Task<br>Wisconsin Card Sorting Task<br>Go/No-Go Task<br>Conner's Rating Scales | Working memory<br>Cognitive flexibility<br>Inhibitory control<br>ADHD symptoms | Improvements in working memory, cognitive flexibility and inhibitory control were present in both groups, but the effects were more notorious in the experimental group. Additionally, the ADHD symptoms only showed improvements in the EXCIR group. |

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| Nejati[70] | Long term study | 15 children with ADHD aged between 7-12 years | 14 children with ADHD aged between 7-12 years | BARAN vs aerobic exercise, 3 sessions (40-50 min) a week for 4-5 weeks | N-Back task<br>Wisconsin Card Sorting Task<br>Go/ No-Go<br>Conners' Parent and Teacher Rating Sales | Working memory<br>Cognitive flexibility<br>Inhibitory control<br>ADHD symptoms | Improvements in working memory were present in the experimental group. The inhibitory control and cognitive flexibility showed benefits in both groups, but these were more noteworthy in the experimental group. Concerning ADHD symptomology both groups presented improvements at school, but only the BARAN group at home. |
| Chang[71] | Long term study | Two groups:<br>16 children with ADHD<br>16 children with ADHD | 16 children with ADHD | Tennis table vs simulated tennis table, 3 session (60 min) a week for 12 weeks | Stroop test<br>Wisconsin Card Sorting Test<br>Grapho motor function tests (handwriting automation, movement, and performance tests) | Executive functions<br>Handwriting function | Significant improvements in executive functions and handwriting outcomes in both training groups, but these were more noteworthy in the actual tennis table group. |
| Chou[72] | Long term study | 24 children with ADHD, aged between 8 and 12 years | 25 children with ADHD, aged between 8 and 12 years | Yoga 2 sessions (40 minutes) a week, for 8 weeks | Visual pursuit test<br>Determination test | Sustained attention<br>Discrimination ability | Significant improvements in sustained attention and discrimination ability in the experimental group. |

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| Kadri[73] | Long term study | 20 children (18 boys and 2 girls) with ADHD | 20 children (18 boys and 2 girls) with ADHD | Taekwondo twice a week (50 minutes) for one year and a half vs standard physical education two sessions a week in school | Stroop Colour-Word Test<br>Ruff 2 & 7 tests | Attentional inhibitory control<br>Sustained and selective visual attention (cognitive function) | Improvements in selective attention and inhibitory control in the experimental group. |
| Ludyga[74] | Long term study | 29 children with ADHD, aged between 8 and 12 years | 28 children with ADHD, aged between 8 and 12 years | Judo 2 sessions (60 min) a week for 12 weeks | Change Detection paradigm<br>Movement Assessment Battery for children – 2<br>EEG recording | Memory capacity<br>Motor skills<br>Brain activity | The experimental group showed improvements in working memory capacity, which did not occur in motor skills. |
| Clark[75] | Long term study | 34 children with ADHD, aged between 8-12 years | ____ | Tai chi practice two sessions (60 min) a week for 8 weeks | Physical and Neurological Examination of Subtle Signs<br>Conners 3 | Motor control and function<br>Clinical symptoms and severity | Improvements in core motor function and control and ADHD symptomology (inattentive, hyperactive/impulsivity, oppositionality and executive dysfunction). |

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| Hattabi[76] | Long term study | 20 children with ADHD, aged between 8-12 years | 20 children with ADHD, aged between 8-12 years | Water exercise/ swimming program 3 sessions (90 minutes) per week for 12 weeks | Rey Osterrieth Complex Figure<br>Stroop test<br>Junior Hayling Test | Working memory<br>Selective attention<br>Inhibition | Significant improvements in memory accuracy, selective attention, and inhibition process in the experimental group. |
| Da Silva[77] | Long term study | 10 children with ADHD, aged between 11 and 14 years | 10 children with ADHD, aged between 11 and 14 years | Swimming training twice a week (45 minutes) for 8 weeks | Child Depression Inventory<br>Beck inventory<br>Perceived Stress Scale<br>Test of trails<br>TAC Cancellation Attention Test<br>Coordination tests<br>Tests of flexibility and abdominal resistance | Depression<br>Anxiety<br>Stress levels<br>Cognitive flexibility<br>Selective attention<br>Motor coordination<br>Physical fitness levels | There were improvements in stress and depression levels, cognitive flexibility, selective attention, motor coordination (lower limbs and laterality) and physical fitness (flexibility and resistance abdominal) in the experimental group. Both in the anxiety levels and in the scores concerning velocity and balance the improvements had no statistical significance. |

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| Hattabi[78] | Long term study | 20 children with ADHD, aged between 9 and 12 years | 20 children with ADHD, aged between 9 and 12 years | Swimming training 3 sessions (90 min) for 12 weeks | Junior Hayling test<br>Child Behaviour Checklist<br>Grades of reading comprehension, math and average | Inhibitory control<br>Behavioural and emotional processes<br>Academic performance | Improvements in inhibitory control, behaviour, and academic performance (in reading comprehension and math) in the experimental group. |
| Huang[56] (2nd study) | Short term study | 24 boys with ADHD aged between 8-12 years | ____ | Exercise vs video watching (30 min) | Resting EEG | Brain activity | Improvements in the resting EEG (smaller theta/beta ratio) in the experimental group. |
| Benzing[57] | Short term study | 24 children with ADHD, aged between 8-12 years | 22 children with ADHD, aged between 8-12 years | Exergaming (moderate to intense) vs watching a documentary (15 min) | Flanker Task<br>Colour Span Backwards Task | Inhibition<br>Switching<br>Visual working memory | Improvements in reaction times of inhibition and switching in the experimental group. But there were no beneficial effects in accuracy or visual working memory performance. |

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| Miklós[58] | Short term study | 100 children with ADHD aged between 6-12 years, divided in two groups: 50 medicated and 50 non-medicated | 50 healthy children aged between 6-12 years | Exercise vs video watching (20 min each session)<br><br>These groups were divided in control and exercise – 25 each group. | KiTAP | Attention<br>Executive function | Significant improvements in 2 out of 15 parameters evaluated (median reaction time in the alertness task, error rates in the divided attention task) in the medicated ADHD group and 2 out of 15 (number of total errors and errors when distractor was presented in the distractibility task) parameters evaluated in the treatment naïve group after the exercise intervention. |
| Ludyga[60] | Short term study | 16 children with ADHD aged between 11-16 years | 18 healthy children, aged between 11-16 years | Aerobic exercise vs coordinative exercise vs video watching (20 min each session) | Flanker task<br>EEG | Inhibitory control<br>Brain activity | Significantly improvements in inhibitory control (increased P300 amplitude and decreased reaction time) in both groups after an exercise condition. Aerobic exercise also seemed more efficient than the coordinative exercise in reducing the inhibitory control deficit in ADHD children. |

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| Ludyga[59] | Short term study | 16 children with ADHD, aged between 11 and 16 years | 18 healthy children, aged between 11 and 16 years | Aerobic exercise vs video watching (20 min) | Alternate Uses Task | Cognitive flexibility | Significant improvements in cognitive flexibility in both groups after an aerobic exercise. |
| Hung[61] (study 2) | Short term study | 34 children with ADHD, aged between 8 and 12 years | ____ | Aerobic exercise (treadmill) vs watching video (30 min) | Task switching paradigm<br>ERP Recording | Cognitive performance<br>Brain activity | Significantly improvements in task switching (global switch costs on RT) and working memory after the exercise intervention. |

*ADHD: Attention-Deficit/Hyperactivity Disorder, HIIT: high-intensity interval training, BMI-Z-score: body mass index-Z-score, BFM: body fat mass, IL-16: interleukin-16, IL-13: interleukin-13, EEG: electroencephalography, WBVT: whole body vibration training, EXCIR: exercise for cognitive improvement and rehabilitation, BARAN: Balance-based Attentive Rehabilitation of Attention Networks, KiTAP: child version of the Test of Attentional Performance, ERP: event-related potentials, RT: reaction time.*

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