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## 4. The role of diet and physical activity in children and adolescents with ADHD

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**Abstract.** ADHD (Attention Deficit and Hyperactive Disorder) is the most common neurobehavioral disorder of childhood, presenting with pervasive and impairing symptoms of inattention, hyperactivity, impulsivity, or a combination. There is scientific evidence that some dietary and physical activity strategies may be useful to improve the symptoms of ADHD and benefit the social, cognitive and academic performance of children and adolescents with ADHD. The purpose of our study was to review the scientific literature on the role of diet and physical activity in ADHD symptomatology up to date.

### Introduction

Attention deficit and hyperactivity disorder (ADHD) is one of the most common psychiatric disorders in early childhood and adolescence with a prevalence rate exceeding 5% [1]. Some of the most common symptoms

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associated with ADHD are hyperactivity, attention deficit, cognitive deficit and poor impulse control [2]. The etiology of ADHD is still unknown, although there are several factors which may have a certain influence in the symptomatology, including diet and physical activity [2].

The research aimed to study the association between diet and ADHD has been growing in the last decades. Thus, children and adolescents with ADHD seem to have lower levels of certain nutrients such as: iron [3], zinc [4,5], and omega 3 [6,7], among others. In some cases, the supplementation with these nutrients, especially with omega 3 [6], has showed to improve the ADHD symptomatology. The most significant research done in this field is summarized in Table 1.

**Table 1.** Relevant scientific evidence of deficiency or supplementation in essential nutrients observed in ADHD children and adolescents.

Study	Nutrients	Study design	Main Findings
Colter <i>et al.</i> [8]	Omega 3- Omega 6	Case-control	Children with ADHD have lower omega 3 and 6 plasma levels than healthy children.
Tranler <i>et al.</i> [9]		Placebo-controlled studies	A daily supplementation (for 4 months) with a mixture of omega-3 and 6 decreased frequency and severity of symptoms.
Bloch and Qawasmi [6]		Systematic review and meta-analysis	Supplementation was statistically significant beneficial for children with ADHD. EPA's effect was bigger than DHA' effect.
Gillies <i>et al.</i> [7]		Systematic review	A combination of omega-3 and -6 is not statistically significant in the treatment of ADHD.
Widenhorm-Müller <i>et al.</i> [10]		Randomized placebo-controlled intervention trial	Supplementation improves working memory function in ADHD children.
Konofal <i>et al.</i> [11]	Iron	Case-control	Serum ferritin levels were lower in children with ADHD than controls. Lower ferritin levels were correlated with more severe ADHD symptoms.
Konofal <i>et al.</i> [3]		Double-blind, placebo-controlled, randomized trial	Supplementation (80 mg/day) appeared to improve ADHD symptoms in children with low serum ferritin levels.
Oner <i>et al.</i> [12]		Cross-sectional	Hyperactivity was significantly associated with ferritin levels but not with cognitive measures.
Donfrancesco <i>et al.</i> [13]		Case-control	No significant relationship between serum ferritin levels and ADHD.
Bilici <i>et al.</i> [4]	Zinc	Placebo-controlled double-blind study	Supplementation was significantly better to placebo in reducing symptoms of hyperactivity, impulsivity and impaired socialization in patients with ADHD.
Akhondzadeh <i>et al.</i> [5]		Double blind and randomized trial	Supplementation might be beneficial in the treatment of children with ADHD.
Arnold <i>et al.</i> <sup>14</sup>		Placebo-controlled double-blind	Zinc supplementation alone (8 weeks) did not improve inattention, but when combined with pharmacological treatment, the optimal dose of the drug was reduced by 37%.
Kozielec and Starobrat-Hermelin <sup>15</sup>		Case-control	95% of ADHD children showed deficiency in magnesium comparing to controls. After 6 months of Mg supplementation (200 mg/day) hyperactivity was reduced.
Mousain-Bosc <i>et al.</i> <sup>16</sup>	Magnesium	Placebo-controlled double-blind	Mg supplementation (100 mg/day) combined with vitamin B6 for 6 months improved symptomatology
Huss <i>et al.</i> <sup>17</sup>		Observational study	Hyperactivity and inattention of most of patients was reduced after supplementation for 12 weeks with a combination of omega-3 and 6, magnesium and zinc.

Other studies suggest that diets rich in sugars and artificial colorings increase the hyperactivity of children [18–22]; however, those findings are still inconsistent and more data are needed. Research about the associations of different dietary patterns and ADHD has also been conducted [22–25]. This approach is really interesting since it assesses the influence of the whole diet.

Besides the potential benefits that a healthy dietary pattern may have on neurocognitive, behavioral and physical growth, it has also been suggested that physical activity might have a positive impact in behavior, neurocognitive function, motor skills, and school performance of children and adolescents with ADHD [26–29], as it will be discussed further.

Although the pathophysiology of ADHD has been not fully demonstrated, there is an important hypothesized mechanism of deregulated dopamine in the prefrontal cortex (PFC). The PFC has the function to regulate behavior, inhibit inappropriate emotions, impulses and habits [30]. Several studies indicate that patients with ADHD present anatomic abnormalities or neurochemical brain dysfunction [31]. Stimulant medications (such as methylphenidate and amphetamines) are used to treat the majority of the symptoms of children with ADHD, but not all the patients have a good response to them and some parents have the concern about the side effects of these drugs in the growth, nervous and cardiovascular system of their children [32]. There is an important need to develop other interventions that do not have repercussion in the health and wellness of the children. Thus, it has been proposed that the combination of diet and physical activity could help children and adolescents with ADHD to improve the symptomatology and their whole quality of life. The aim of this chapter is to review the scientific literature regarding the possible benefits of different dietary approaches and physical activity for symptom management for children and adolescents with ADHD.

## **1. Role of the whole diet on ADHD: healthy patterns *versus* restrictive elimination diets?**

### **1.1. Dietary patterns and ADHD**

As mentioned above, several studies have analyzed the beneficial or detrimental effects of specific single nutrients on ADHD symptomatology [33]. Moreover, associations between dietary patterns and ADHD have been recently examined in several cross-sectional studies (Table 2). This new approach is of great interest since nutrients are nearly always consumed together, and they are highly interrelated in the food matrix. Therefore, the

study of dietary patterns is really useful for understanding much better the role of diet in ADHD. Assessing the whole diet instead of the effects of a single nutrient on the relation between diet and ADHD may contribute even more to understand this complex relationship.

The majority of studies on diet and ADHD conclude that ADHD patients have a tendency to have a poor quality diet, which could cause certain nutrient deficiencies. Those deficiencies might affect the neurocognitive, behavioral and physical development at this important stage of life. Indeed, Park *et al.* [35] found that higher intakes of sweetened desserts, fried food, and salt were associated with more learning, attention, and behavioral problems. On the other side, a balanced diet, regular meals, and a high intake of dairy products and vegetables were associated with less learning, attention, and behavioral problems.

**Table 2.** Summary of the main studies on the influence of the diet on children and adolescents with attention-deficit and hyperactive disorder (ADHD).

Reference	Design	N; age	Country	Main Findings
Howard <i>et al.</i> [24]	Cross-sectional study	115; 14y follow-up	Australia	A Western-style diet <sup>a</sup> may be associated with ADHD.
Azadbakht & Esmailzadeh [23]	Cross-sectional study	375; 6-11y	Iran	Significant independent associations between the sweet <sup>b</sup> and fast food <sup>c</sup> dietary patterns and the prevalence of ADHD.
van Egmond-Fröhlich <i>et al.</i> [34]	Cross-sectional study	9,428; 6-17y	Germany	Poor nutrition quality and high-energy intake appear to be independently associated with ADHD symptoms.
Park <i>et al.</i> [35]	Cross-sectional study	986; 8-11y	Korea	High intake of sweetened desserts, fried food, and salt is associated with more learning, attention, and behavioral problems, whereas a balanced diet, regular meals, high intake of dairy products and vegetables is associated with fewer problems.
Woo <i>et al.</i> [25]	Case-Control study	192; 7-12y	Korea	The traditional-healthy Korean <sup>d</sup> dietary pattern was associated with lower odds having ADHD
Liu <i>et al.</i> [36]	Cross-sectional study	417; 6-11y	China	Positive correlation between diet intake (processed meat, salty snacks) and hyperactivity index. Children's diet pattern is an important environmental impact factor for ADHD.
Ghanizadeh and Haddad [37]	Randomized controlled clinical trial	106; 5-14y	Iran	Encouraging the children with ADHD to increase their intake of recommended diet markedly improves their attention.

<sup>a</sup>High in total fat, saturated fat, refined sugar, and sodium; <sup>b</sup>High in ice cream, refined grains sweet desserts, sugar, and soft drinks; <sup>c</sup>High in processed meat, commercially produced fruit juices, pizza, snacks, sauces and soft drinks; <sup>d</sup>High intake of kimchi, grains, and bonefish, and low intake of fast-food and beverages.

The “unhealthy” dietary patterns identified in the different studies (such as “Western”, “fast food” or “sweet” patterns) were generally high in total fat, saturated fat, refined sugars, and sodium. The relationship observed between higher scores for the “unhealthy” dietary pattern and an increased odds for ADHD supports the hypothesis that highly processed and energy-dense foods are linked with ADHD symptomatology [24,34,35].

Howard *et al.* [24] suggested that children eating a “Western” diet, high in fried food, sweetened desserts and unbalanced, are also likely to have micronutrient and/or PUFA deficiencies. Iron, zinc or magnesium deficiencies and lower circulating levels of omega-3, higher levels of omega-6, and a lower omega-3 *versus* omega-6 ratio has been reported in children and adolescents with ADHD [8]. An inadequate micronutrient intake, coming from an unbalanced dietary pattern, could result in suboptimal brain function in children and adolescents [23]. Furthermore, Van Egmond-Fröhlich *et al.* [34] pointed out that ADHD symptoms might be associated with poor food selection rather than overeating in terms of volume.

“Unhealthy” or “junk foods” besides being usually high in fat and sugars may be rich also in artificial food colorings and preservatives, which could negatively affect ADHD symptoms [38]. It has been suggested, as it will be discussed below, that certain food additives may lead to hyperactivity or changes in neurotransmitter function [21]. An interesting point is that the relationship observed between poor dietary choices and ADHD may be bidirectional [24]. The results observed could be explained, especially for adolescents, by the tendency of them to experience emotional distress to crave fat-rich snack foods as a self-soothing strategy. Therefore, the results found could be more reflective of adolescent dietary preferences and cravings rather than nutritional factors alone. Also, it has been observed that a healthy diet is related to better family functioning [39] and given that families of children and adolescents with ADHD are more likely to face parenting challenges, it is possible that the relationship between a “unhealthy” dietary pattern and ADHD diagnosis is mediated by poor family functioning [24].

Despite the fact that conclusions of these studies are challenging, we cannot justify that a poor dietary choice is the responsible for ADHD. The idea that dietary factors are the exclusive and sufficient explanation for childhood behavioral problems may place a barrier in the way of access to appropriate evidence-based assessment and treatment – so placing the child at unnecessary risk [40]. Further studies are necessary to understand the role that the dietary pattern has in this disorder and to know which dietary approaches can benefit the ADHD symptomatology.

## 1.2. Restrictive dietary treatments for ADHD

There are mainly two dietary treatments for ADHD, which have been tested in repeated, randomized controlled trials: the artificial food colors elimination (AFCE) and the restricted elimination diets (RED).

### 1.2.1. Artificial food colorants elimination (AFCE)

The research within artificial food colorants and other additives began in the 1970s. Dr. Benjamin Feingold proposed a new diet called the “Kaiser Permanente diet” also known as the “K-P diet” or the Feingold diet. It was hypothesized that the hyperactivity and learning problems observed in certain schoolchildren were due to the ingestion of certain foods and food additives [41].

The K-P diet removed all foods containing artificial food colors and flavorings and certain preservatives and also food which naturally contain salicylates (Table 3). It was very popular during the 70s and 80s, although it received repeated criticism because solid scientific studies demonstrating its efficacy were very scarce [41] and subsequently support from professionals waned. The “K-P diet” is not longer used, but some of the recommendations, including the elimination of artificial colors, are still being applied. Indeed, two recent meta-analyses carried out concluded that artificial food colorants have small, but statistically significant adverse effect on ADHD symptoms in some children [38,42], even though the conclusions were based on studies of limited quality, as the authors themselves pointed out.

**Table 3.** Dietary guidelines of the “Kaiser Permanente diet”.

- To avoid all food, medications, and cosmetic which may contain artificial colors and flavors.
- To avoid all food that may contain preservatives such BHA, BHT, TBHQ and sodium benzoate <sup>a</sup>
- To avoid foods that naturally contain salicylates: almonds, apples, peaches, apricots, nectarines, cherries, grapes, raisins, oranges, plums, tomatoes, cucumber, coffee and tea.

<sup>a</sup> Those preservatives were later added to the list. Abbreviations: BHA, butylated hydroxyanisole; BHT, butylated hydroxytoluene; TBHQ, tertiary butylhydroquinone.

In the same direction, Stevenson *et al.* [43] concluded that the artificial food color elimination is a potentially valuable treatment for ADHD but its effect size remains uncertain, as does the type of child for whom it is likely to be efficacious. The authors added the urgent need for studies using more redefined methodologies with blind evaluation to unselected samples of children with ADHD and also the concern that some studies of food colorings and additives were undertaken some time ago, so the findings could be no clear as diet and food products have changed markedly.

The possible mechanisms by which the food colorants and other additives may trigger symptoms are not well understood [44]. Therefore, the controversy about the hypothesis that certain food colorants and additives mainly may cause hyperactivity and inattention in children both ADHD diagnosed or without this disorder is still open. Some authors strongly affirm that these additives do not cause ADHD [2,45], relying in the fact that the symptomatology of ADHD is different from those induced by artificial coloring [21,44]. The last ones have been associated with more irritability and insomnia than restlessness and inattention.

In 2007, a study funded by the Food Safety Agency (FSA) from UK and conducted by McCann *et al.* [21] had a high impact on the public opinion. The authors provided statistically evidence on the relationship between the consumption of certain mixtures of artificial food colorings (tartrazine, quinoline yellow, sunset yellow, azorubine, cochineal red and allura red) and an artificial preservative (sodium benzoate) and the increase of the hyperactivity in children of 3 years and also in children from 8 to 9 years. In view of these results, the FSA recommended to parents with hyperactive children to consider limiting the intake of these colorants and preservatives. The study, however, has certain methodology weaknesses, as the authors themselves recognized in their publication. The changes observed in the hyperactivity children were very small relative to the inter-individual variation, while the changes in behavior were not evident in all the studied children. Furthermore, it was not possible to extrapolate the study findings to each single additive, which was in the mixture assayed. Moreover, information about the possible biological mechanisms was not provided.

While neither the EFSA (European Food Safety Agency) nor the European Commission have issued any cautious recommendation, nowadays, in the European Union, is required on the food packaging the following warning “*This product may have adverse effect on activity and attention in children*” when sunset yellow (E110), quinoline yellow (E104), azorubine/carmoisine (E122), allura red AC (E129), tartrazine (E102) and cochineal natural red (E124) are employed in foods and beverages.

There is a consensus in the scientific community about the need for more studies on the association between artificial colorings and hyperactivity and ADHD. It is required some caution before advising a complete restriction of foods containing these colorings. The imposition of a diet completely free of artificial colorings should not be done until a reliable methodology is developed to identify which colorant or colorants may be responsible, and who is really sensitive to these compounds, given the inter-individual variation observed.

### **1.2.2. Restricted elimination diets (RED) or few foods diets**

A restricted elimination diet (also called oligoantigenic) removes most foods that may have antigenic or allergenic potential, such as milk and dairy products, eggs, nuts and some fruits, among others. It is thought that ADHD may be, in some children, a hypersensitivity reaction to certain foods [41,45,46]. Therefore, according to this allergic hypothesis, there would be foods that induce high levels of IgG, leading to a relapse in ADHD child behavior, while the intake of those that does not induce IgG or very low levels of them, would not cause a recurrence in ADHD symptoms [32,47]. While interesting the hypothesis, it has not yet been fully demonstrated. Pelsser *et al.* [45] carried out a study about restricted elimination diets with uncertain results. They did conclude that the children who responded to the dietary intervention, independently of whether IgG levels were high or low, showed a decrease of 20.8 points on the ADHD rating scale (ADHD Rating Scale) and 11.6 points on the Conners Scale (Conner's Score). However, the determination of IgG levels was not useful, since the levels of IgG and symptoms of ADHD were totally independent.

More recently a meta-analysis on ADHD, restriction diet and food color additives has been published [42], concluding that a restriction diet benefits some children with ADHD since it reduces ADHD symptoms; however, the authors themselves strongly recommended a renewed investigation of diet and ADHD. From a practical point of view, the restricted elimination diets are very difficult to follow, both for ADHD patients and for the families. Moreover, children and adolescents who are prescribed to follow a different diet than their friends may influence in their behavior, creating unnecessary stress situations [19,20].

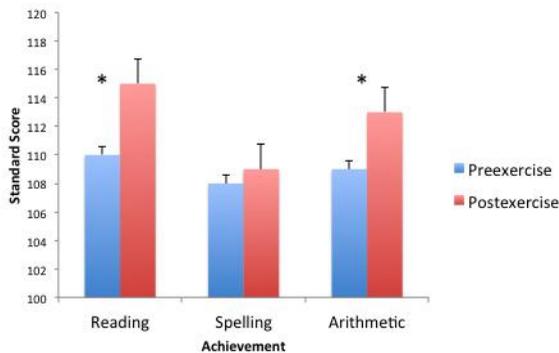
To summarize, restricted elimination diets may be beneficial, but large-scale studies are needed, using blind assessment, and including assessment of long-term outcome. On the other hand, artificial food color elimination is a potentially valuable treatment but its effect size remains uncertain, as does the type of child for whom it is likely to be efficacious. Three recommendations have been suggested for the design of future studies: 1) To

have a sample of children with ADHD who have not been selected on the basis of previous responses to food constituents, 2) To include observations of the children's behavior by a reporter who is truly blind as to dietary treatment, and 3) to control for nonspecific treatment effects [38,43].

## 2. The role of physical activity on ADHD

It is well established that physical activity (PA) has positive effects on mental health in both clinical and nonclinical populations. In the last decade, several studies have been addressed to study the potential benefits of exercise in children diagnosed with ADHD. The evidence suggests that physical exercise may have benefits in behavioral, neurocognitive, and scholastic performance [27,47,48] and in inhibitory control [47,49]. The etiology of ADHD and the putative mechanisms by which PA impacts cognitive performance suggest that PA might be particularly beneficial for ADHD individuals [27].

Pontifex *et al.* [48] concluded that moderately intense aerobic exercise might have positive implications for aspects of neurocognitive function and inhibitory control in children with ADHD, improving their school performance (Fig. 1). The children could better focus and were less distracted after a quick workout. Moreover, it seems that this type of exercise produces enhancements in reading and in mathematics [49]. This is interesting because children with ADHD have usually more learning problems in these two areas. On the other hand, moderate exercise sessions in ADHD's children have led to improvements in behavior and attention, but no relationship with academic performance has been found [50].



**Figure 1.** Mean (+SE) standard score for each session on each of the three academic performance tests done. Bars with \* are statistically different (adapted from [48]).

Other authors have investigated if the beneficial effects of short moderate PA are also helpful when exercise is carried out for longer periods of time. Thus, Verret *et al.* [50] demonstrated that, in addition to producing improvements in strength and motor skills, exercise showed a positive influence on the behavior and attention of ADHD's children. Also, the work done by Smith *et al.* [47] suggested that after 26 min of continuous moderate-to-vigorous physical activity daily over eight school weeks offered benefits to motor, cognitive, social, and behavioral functioning in young people exhibiting ADHD symptoms. Both authors [47,48] pointed out that the benefits of PA would act on the inhibitory control and the executive function. ADHD appears to have a strong impact on executive function, where processes related to learning and behavior are altered. Although it is not clear which elements are regulated by the executive function, it is believed to be related to cognitive processes such as memory, emotional control, activation, arousal, effort, organization and planning tasks [51].

On the other hand, the majority of exercise and cognition research has primarily focused on aerobic exercise but it is also important to consider forms of coordinative exercise, which includes exercises involving motor coordination and cognitive training. Yu-Kai Chang *et al.* [52] demonstrated that an aquatic exercise intervention, which involves both aerobic and coordinative exercises, influences positively on the restraint inhibition component of behavioral inhibition in children with ADHD.

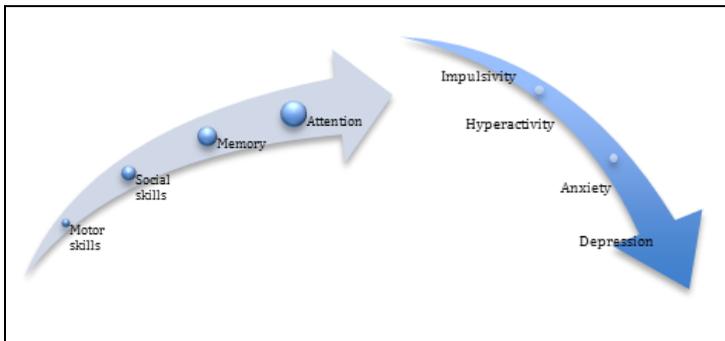
Research aimed to investigate the influence of PA in children with ADHD under drug therapy, such as methylphenidate, has also been carried out [53], demonstrating that the PA had a positive impact in ADHD symptomatology when medication was present, too. It was found that besides improving strength and motor skills, PA positively influences behavior and cognitive function such as attention in children under medication. Although there is limited research about how drugs affect the motor skills and physical lifestyle of children with ADHD, most of the studies agree that motor skills are improved as a result of PA [50]. In order to add support to those outcomes, future research should include greater executive functions assessment. Moreover, follow-up and additive effects of others therapies should be explored.

Children with ADHD might have lower participation in sport activities, because of their mood lability, disciplinary problems, poor self-esteem, anxiety and inattention. However, research evidence has showed that ADHD children who participated in three or more sports present fewer anxiety or depression symptoms than did those who participated in fewer than three sports. Another aspect worth to comment is the positive influence that PA has showed also in aerobic function, flexibility and cardiovascular fitness,

since children with ADHD have lower levels of them compared with typically developed children. Thus, when compared only between ADHD children the ADHD training group demonstrated more favorable levels of aerobic function and flexibility than the ADHD no training group after the PA intervention [54].

All these findings related to PA and improvement in ADHD symptomatology would support the hypothesis that the pathophysiology of ADHD is related with inadequate levels of certain neurotransmitters [55] such as serotonin, dopamine, and noradrenaline. PA increased the levels of these three neurotransmitters in the prefrontal cortex, which seems to be crucial for the attention and inhibitory control [51]. Individuals with ADHD might have neurochemical and neuroanatomical anomalies in this brain region, which could lead to neurotransmitter deficits and originating some of the cognitive problems related to the ADHD.

As a summary, the research done up to now seems to support the fact that physical exercise could establish itself as an adjunct treatment for people with ADHD [28,47,48,50]. It is recommended that clinicians, parents and teachers work together monitoring the participation of these children in physical and sports activities to help them improve their motor skills performance (Fig. 2).



**Figure 2.** Effects of exercise on ADHD children behavior.

### 3. Conclusions

The cause of ADHD is multifactorial, with a certain influence of the environmental factors, such as diet and physical activity. The multimodal treatment is recommended by principal clinical practice guidelines for ADHD and includes psychological, psychoeducational and pharmacologic

treatment. Nevertheless, the review of the published scientific evidence indicated that several dietary strategies and physical activity might also help to improve the quality of life of children and adolescents with ADHD. The main recommendation is to educate families and children: 1) to have healthy eating habits with a balanced diet, avoiding excessive consumption of saturated fats and simple sugars, foods with artificial colorants, a good consumption of fish, nuts and seeds, all of them rich in omega 3 and 2) to introduce into the routine of children and adolescents daily physical activity, adapted to their preferences and needs.

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