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A study of the therapeutic effects of yoga on symptoms associated with ADHD in children: Systematic review and meta-analysis

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Abstract

Background: Attention-deficit/hyperactivity disorder (ADHD) is a chronic developmental disorder with a high prevalence in children and the long-term nature of treatment. Although the use of yoga as a non-pharmacologic treatment is increasing in the ADHD population, the conclusion of its effectiveness in treating symptoms in children with ADHD remains to be explored.

Objective: The primary goal of this meta-analysis was to systematically summarize and analyze the efficiency of yoga in treating symptoms such as attention problems, emotional problems, and behavioral control in children with ADHD, as well as to serve as a guide for further studies and therapeutic procedures in the management of ADHD in children.

Materials and methods: This study was conducted using the Cochrane Handbook and the PRISMA Guidelines Statement for Systematic Reviews. A total of five databases, PubMed, Embase, Cochrane, Web of Science, and Ovid, were searched up to December 2024. Excel was utilized for data extraction, and Review Manager was used for data processing, analysis, and literature quality evaluation.

Results: In all, nine publications were enrolled in the study, and 285 participants—142 in the experimental group and 143 in the control group—met the inclusion requirements. The intervention lasted between 2 and 20 weeks, and all study participants were between the ages of 3 and 15. The outcome metrics consisted of measures of five ADHD-related symptoms: inattention, sustained attention, hyperactivity/impulsivity, emotional instability, and anxiety.

Conclusion: The intervention of yoga had an ameliorative effect on several symptoms of inattention, sustained attention, emotional instability, and hyperactivity/impulsivity in children with ADHD, but not statistically significant on anxiety symptoms.

Keywords: Effect, Yoga, ADHD, Children

1 Introduction

ADHD is a neurodevelopmental illness that mostly affects children and is characterized by emotional impulsivity, hyperactivity, and a difficulty to maintain focus[1]. Epidemiological surveys indicate that up to 8% of children and adolescents globally have ADHD, a significant prevalence that has drawn attention from all around the world[2]. ADHD can severely affect children's memory, attention, emotion regulation, and response inhibition, and poses a significant challenge to their academic perfor-

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2. Ayano G, Demelash S, Gizachew Y, et al. The global prevalence of attention deficit hyperactivity disorder in children and adolescents: an umbrella review of meta-analyses[J]. Journal of Affective Disorders, 2023, 339: 860-866.

mance, social skills, and emotional stability[3,4]. Children with ADHD often have difficulty integrating into society and building relationships, and academic performance is often affected by procrastination and inattention[5]. Due to the long-term and chronic nature of the effects of ADHD, the symptoms usually persist into adulthood. This not only causes distress to the patients themselves but also imposes a heavy financial and psychological burden on families. Studies have shown that the financial cost of raising a child with ADHD can be five times that of an average child[6]. Therefore, exploring treatment options with lower costs and longer-lasting effects has become a focus of academic research.

Current treatments for ADHD symptoms include both pharmacologic and non-pharmacologic options. Medication often uses psychostimulant drugs such as methylphenidate or amphetamines to improve ADHD symptoms, and is currently the most common and effective treatment for ADHD[7,8]. However, overuse of drugs can result in adverse consequences like migraine, appetite loss, and insomnia, which can significantly disrupt children's everyday lives and impair their normal development[9]. Given this situation, non-pharmacological treatment has become an adjunctive treatment for ADHD disorders due to its advantages of low treatment cost and low side effects[10]. The benefits of physical activity in treating children with ADHD have been demonstrated by numerous studies. Montalva-Valenzuela et al. (2022) showed that

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3. Fried R, Chan J, Feinberg L, et al. Clinical correlates of working memory deficits in youth with and without ADHD: a controlled study[J]. Journal of clinical and experimental neuropsychology, 2016, 38(5): 487-496.

4. Anastopoulos A D, Smith T F, Garrett M E, et al. Self-regulation of emotion, functional impairment, and comorbidity among children with AD/HD[J]. Journal of Attention Disorders, 2011, 15(7): 583-592.

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10. Vancampfort D, Stubbs B, Van Damme T, et al. The efficacy of meditation-based mind-body interventions for mental disorders: a meta-review of 17 meta-analyses of randomized controlled trials[J]. Journal of psychiatric research, 2021, 134: 181-191.

physical activity or exercise improves executive functioning in children with ADHD primarily through aerobic physical activity and that 20 minutes of exercise per day can alleviate symptoms associated with ADHD in children with ADHD[11]. Furthermore, as supplemental therapy for kids with ADHD, the American Academy of Pediatrics suggests cognitive-behavioral, mental, and physical therapies (such as mindfulness, meditation, etc.)[12]. Zylowska et al. (2008) showed that mindfulness training can improve behavioral and neurocognitive deficits in patients with ADHD, alleviate symptoms such as anxiety, depression, and inattention, and is a feasible intervention[13].

In recent years, yoga as a chronic mind-body exercise has also been recognized as a prospective therapy for people with ADHD[14]. Yoga has shown positive effects on mental and physical states and has been shown to reduce stress in both clinical and non-clinical settings[15]. Additionally, research has documented the benefits of yoga practice on core areas related to ADHD such as self-regulation, attention, executive functioning, and emotional control[16,17,18]. All of these reported psychiatric symptoms are relevant to ADHD patients and provide theoretical support for yoga treatment of ADHD disorders. Although this part of the research is still in its early stages, studies on the possible advantages of using yoga exercises in the treatment of clinical patients

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11. Montalva-Valenzuela F, Andrades-Ramírez O, Castillo-Paredes A. Effects of physical activity, exercise and sport on executive function in young people with attention deficit hyperactivity disorder: a systematic review[J]. European journal of investigation in health, psychology and education, 2022, 12(1).

12. Wolraich M L, Hagan J F, Allan C, et al. Clinical practice guidelines for the diagnosis, evaluation, and treatment of attention-deficit/hyperactivity disorder in children and adolescents[J]. Pediatrics, 2019, 144(4).

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14. Donath L, Ludyga S, Hammes D, Rossmeissl A, Andergassen N, Zahner L, Faude O. Absolute and relative reliability of acute effects of aerobic exercise on executive function in seniors. bmc Geriatr. 2017;17(1):247.

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16. Bergen-Cico D, Razza R, Timmins A. Fostering self-regulation through curriculum infusion of mindful yoga: a pilot study of efficacy and feasibility [J]. Journal of Child and Family Studies, 2015, 24: 3448-3461.

17. Luu K, Hall P A. Hatha yoga and executive function: a systematic review[J]. The Journal of Alternative and Complementary Medicine, 2016, 22(2): 125-133.

18. Pascoe M C, Bauer I E. A systematic review of randomized control trials on the effects of yoga on stress measures and mood[J]. Journal of psychiatric research, 2015, 68: 270-282.

with ADHD are expanding[19]. Meanwhile, there are relevant studies evaluating the clinical use of yoga that suggest it may be beneficial for patients in the pediatric population[20]. Rosen et al. (2015) showed that children who practiced yoga experienced reductions in a wide range of physical indicators like unfavorable stress-reactive actions, disruption, bad emotions, frustration, fortitude, and exhaustion/inertia[21]. Several studies on children with a range of psychological, mental, and emotional problems have indicated that yoga is effective in improving children's mood[22], increasing children's self-esteem[23], reducing children's anger[24], and reducing children's anxiety[25]. The ability of yoga exercises to promote physical and mental health as well as influence subtle mental aspects of children makes it more appealing to study the use of yoga as a supportive therapy and alternative treatment for the treatment of ADHD disorders in children compared to the complexity and side effects associated with medication[26].

Despite the potential benefits of yoga interventions in the management of ADHD in children, there are some limitations of the existing studies. An analysis of the existing studies revealed that there are limitations in the selection of the study

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19. Jeter P E, Slutsky J, Singh N, et al. Yoga as a therapeutic intervention: a bibliometric analysis of published research studies from 1967 to 2013[J]. The journal of alternative and complementary medicine, 2015, 21(10): 586-592.

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24. Pandit S A, Satish L. When does yoga work? Long-term and short-term effects of yoga intervention among pre-adolescent children[J]. Psychological Studies, 2014, 59(2): 153-165.

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26. Manjunath I, Channappa V, Karthikeyan A. A Systematic Review of Yoga as a Supportive Treatment for Children with Attention-Deficit/Hyperactivity Disorder[J]. Cureus, 2024, 16(7).

population[27,28], the number of sample sizes[29], and outcome measures[30,31]. For example, studies by Jensen (2004) and Zahra Khayati (2021) only recruited boys with ADHD for their experiments, Petsche's (2016) study included just four pediatric patients with ADHD, and studies by Cohen (2018), Xue Luo (2023), and Abadi (2008) respectively used three scales, ADHD RS-IV, Chinese version of MTA SNAP-IV ADHD, and Child Symptom Inventore-4 to measure symptoms of attention and hyperactivity/impulsivity. Issues such as incomplete inclusion of study participants, small sample sizes, and inconsistent methods of effect assessment may affect the final results of the experiment. To address these uncertainties, this meta-analysis systematically summarizes and analyzes existing trials of yoga-based therapies for kids with ADHD to provide more consistent and comprehensive conclusions on the effectiveness of yoga interventions for children with ADHD, and inform the selection of future treatments for children with ADHD.

2 Material and methods

2.1 Literature search

The PRISMA Guidelines Statement for Systematic Reviews and the Cochrane Handbook for Systematic Reviews were used in the study. From the commencement of the investigation until its conclusion, five databases—PubMed, Embase, Cochrane, Web of Science, and Ovid—were searched. The search period spanned from the start of the study to December 2024. The literature search was organized around the subject and free terms of "yoga" and "ADHD", and the search strategy is shown in Table 1, based on which we also searched the reference lists of relevant articles or systematic reviews for additional articles.

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27. Jensen P S, Kenny D T. The effects of yoga on the attention and behavior of boys with attention-deficit/hyperactivity disorder (ADHD)[J]. Journal of attention disorders, 2004,7(4): 205-216.

28. Khayati Z, Shirazi M, Sanagouye Moharer G. The Effect of Yoga Education on Anxiety-Disorders in Patients with Attention Deficit/Hyperactivity Disorder[J]. Iranian Journal of Rehabilitation Research, 2021, 7(3): 10-19.

29. Petsche A. The effect of yoga on attention in students diagnosed with ADHD[J].2016.

30. Luo X, Huang X, Lin S. Yoga and music intervention reduces inattention, hyperactivity/impulsivity, and oppositional defiant disorder in children 's consumers with comorbid ADHD and ODD[J]. Frontiers in Psychology, 2023, 14: 1150018.

31. Abadi M S, Madgaonkar J, Venkatesan S. Effect of yoga on children with attention deficit/hyperactivity disorder[J]. Psychological Studies-University of Calicut, 2008, 53(2): 154.

Table 1. Search strategy on PubMed.

Search	PUBMED
#1	Attention Deficit Disorder with Hyperactivity [MeSH Terms]
#2	((((((((((((((((((((Attention Deficit Disorder with Hyperactivity[Title/Abstract]) OR (ADDH[Title/Abstract])) OR (ADHD[Title/Abstract]))) OR (Attention Deficit Disorders with Hyperactivity[Title/Abstract]) OR (Attention Deficit Disorders with Hyperactivity[Title/Abstract])) OR (Attention Deficit Disorders with Hyperactivity[Title/Abstract])) OR (Attention Deficit Hyperactivity Disorder[Title/Abstract])) OR (Attention Deficit-Hyperactivity Disorder[Title/Abstract])) OR (Attention Deficit-Hyperactivity Disorders[Title/Abstract])) OR (Deficit-Hyperactivity Disorder, Attention[Title/Abstract])) OR (Deficit- Hyperactivity Disorders, Attention[Title/Abstract])) OR (Disorders, Attention Deficit-Hyperactivity[Title/Abstract])) OR (Disorders. Attention Deficit-Hyperactivity[Title/Abstract])) OR (Hyperkinetic Syndrome[Title/Abstract])) OR (Syndromes, Hyperkinetic[Title/Abstract])) OR (Syndromes, Hyperkinetic[Title/Abstract])))) OR (Attention Deficit Disorder[Title/Abstract])) OR (Attention Deficit Disorders[Title/Abstract])) OR (Deficit Disorder, Attention[Title/ Abstract])) OR (Deficit Disorders, Attention[Title/Abstract])) OR (Disorder, Attention Deficit[Title/Abstract])) OR (Disorders, Attention Deficit[Title/Abstract])) OR (Brain Dysfunction, Minimal[Title/Abstract])) OR (Dysfunction, Minimal Brain[Title/Abstract])) OR (Minimal Brain Dysfunction[Title/Abs-
#3	(#1) OR (#2)
#4	yoga [MeSH Terms]
#5	(#3) AND (#4)

2.2 Inclusion criteria

Inclusion in the literature included the following criteria: (1) participants: ADHD symptoms in children aged 3 to 15 years old; (2) intervention: must include yoga; and (3) endpoints: documented results pertaining to the impacts of yoga on the health improvement status of kids with ADHD, including anxiety, emotional instability, sustained focus, inattention, etc.

2.3 Exclusion criteria

Studies with the following limitations were excluded: (1) non-English-language literature; (2) participants ≥18 years of age; (3) participants in healthy populations; (4) outcomes related to health-improvement status were not reported; and (5) conference abstracts, systematic reviews, and meta-analyses.

2.4 Literature quality evaluation

Using the risk of bias assessment tool developed by the Cochrane Collaboration. The standard of the included literature in this analysis was independently assessed by two assessors (XTM and YL). Seven criteria were used to systematically evaluate the literature's quality: (1) explanation of randomization procedures; (2) allocation scheme

for concealment; (3) the double-blind principle; (4) blinding principle for assessing findings; (5) completeness of data; (6) selectivity of presenting results; (7) appraisal of the existence of additional biases (Figure 1).

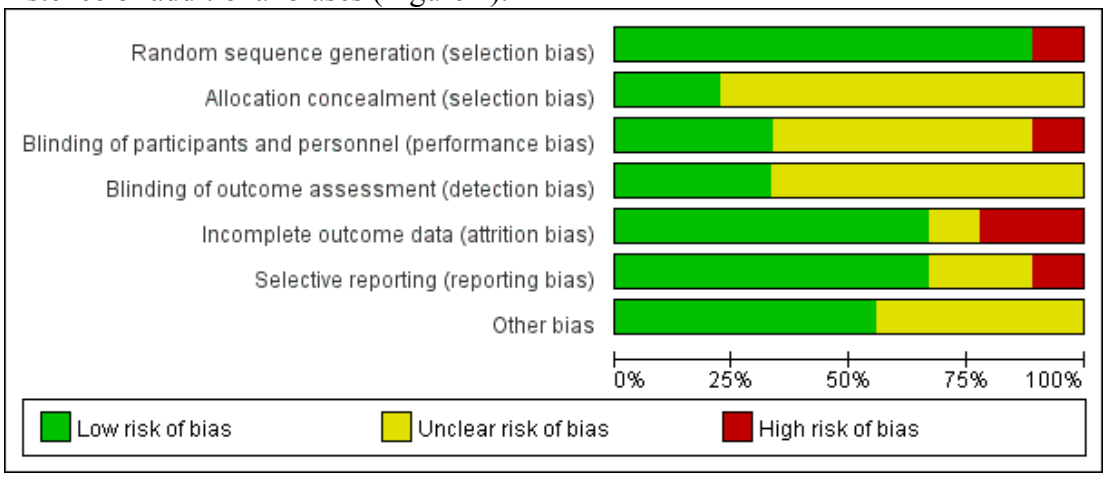

Figure 1. Quality evaluation of included studies.

2.5 Data Extraction

Information taken from each study included basic information about the article (first author, country, year of publication), subject characteristics (age, symptoms, number), intervention characteristics, and outcome indicators. Data extraction was performed independently by 2 evaluators (XTM and YL), with the first author extracting and making the relevant data from the study in a table and the second author scrutinizing the information. In cases where ADHD symptom scores existed for which data were not available but graphical displays were available (Reza Soroori Khorashad 2024). For data extraction, we used Engauge Digitizer version 11.1, a web-based program.

2.6 Effect size

All effect sizes were compared using standardized mean differences (SMDs), and the included studies used several measuring scales to evaluate the same symptoms of ADHD in accordance with the Cochrane Manual for the Systematic Evaluation of Interventions[32]. Five categories were used to classify symptoms associated with ADHD: anxiety, sustained attention, emotional instability, hyperactivity/impulsivity, and inattention. Since hyperactivity and impulsivity are frequently evaluated as a single set of core symptoms (Pauline S. Jensen 2004; Pauline S. Jensen 2023; Srinivasan Venkatesan 2008), they are regarded as such. We combined effect sizes by selecting the parent-measured version of the data with the guarantee that the scale would contribute effect sizes to the four outcome domains of inattention, hyperactivity/impulsivity, emotional instability, and anxiety Quantity in order to promote statistical independence of the data for studies that used multiple versions of the scale (i.e., parent and teacher versions) to measure the same ADHD symptoms (Pauline S. Jensen 2004).

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[32]. Higgins JPT TJ, Chandler J, Cumpston M, Li T, Page MJ, Welch VA (editors). Cochrane Handbook for Systematic Reviews of Interventions version 6.2 (updated February 2021). Cochrane (2021). Available online at: www.training.cochrane.org/handbook (accessed July 15, 2021).

2.7 Statistical analysis

Stata software version 15.1 and Review Manager software version 5.4 were used for all statistical analyses. In this study, effect sizes were determined by calculating SMD. Heterogeneity tests were expressed using I^2, with I^2 in the 0-50% range indicating low heterogeneity and in the 50-100% range indicating high heterogeneity. The data was integrated using a fixed-effects model for low heterogeneity and a random-effects model for high heterogeneity, based on the varying degrees of heterogeneity of the outcome indicators. The threshold for statistical significance was $p<0.05$. The five outcomes of this study (inattention, sustained attention, emotional instability, anxiety, and hyperactivity/impulsivity) were statistically analyzed using Review Manager 5.4.1, with a confidence interval (CI) of 95%.

3 Result

3.1 Results of Literature Screening

279 articles were found in the first search of five electronic databases; duplicates were eliminated, leaving 163 pieces. By screening the abstracts and full text, we excluded 4 non-English literature, 63 reviews, and conference papers, 7 full texts could not be found, 58 articles not related to the study topic, and 7 articles with different participant populations. Finally, a total of 9 papers were evaluated in full text and qualified for meta-analysis. Figure 2 depicts the unique PRISMA literature screening procedure. All included studies reported the following ADHD-related outcomes: inattention (n = 3), sustained attention (n = 4), hyperactivity/impulsivity (n = 3), mood instability (n = 2), and anxiety (n = 2).

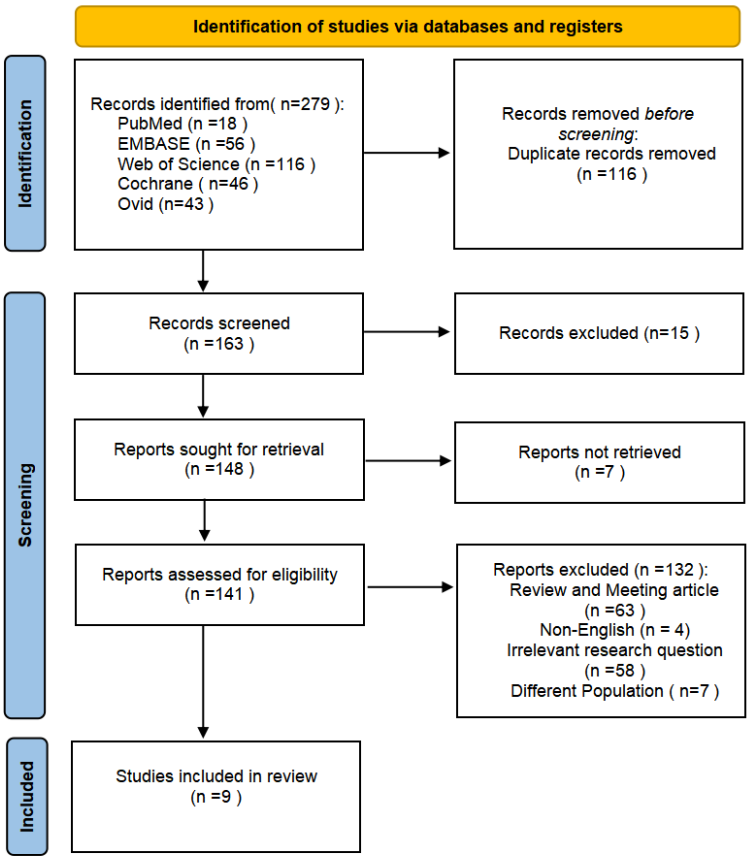

Figure2. The flow chart of literature inclusion screening.

3.2 Characteristics of included studies

First, the region and time of the included studies. Of the nine included papers, the study authors span multiple countries and regions, including China (Chien-Chih Chou 2017; Sheng Wang 2023; Xue Luo 2023), the United States (Samantha CL Cohen 2018), Australia (Pauline. S. Jensen 2004), Iran (Meysam Rezaei 2018; Zahra Khayati 2021), Canada (Reza Soroori Khorashad 2024), and India (Divided Attention 2008). All but two studies were published in 2017 or later. Second, study participants were included. There were 285 participants in all, 142 in the experimental group and 143 in the control group. Participants in one study were preschoolers, so four or more symptoms were chosen as the cutoff point for capturing children at risk for ADHD (Samantha CL Cohen 2018), and the remaining participants were children diagnosed with ADHD. The ages of the participants varied between studies, but all of the study participants were between the ages of 3 to 15 years old and in childhood. One study recruited only ADHD boys (Pauline. S. Jensen 2004) to participate, and the rest of the studies included both boys and girls. Third, the type of intervention included in the studies. All of their intervention types included yoga, with one study utilizing a yoga and medication form of intervention (Reza Soroori Khorashad 2024), and the remaining studies utilized yoga only for their interventions. During the intervention, all studies were conducted in researcher-designed experimental settings except one study that had ADHD children perform school and home yoga (Samantha CL Cohen 2018). Fourth, the duration of the intervention was included in the studies. The duration of each ses-

sion ranged from 10 to 60 minutes, with most sessions lasting 45 minutes (Meysam Rezaei 2018; Divided Attention 2008; Zahra Khayati 2021). The duration of the entire intervention ranged from 2 to 20 weeks, with most interventions lasting 8 weeks (Chien-Chih Chou 2017; Meysam Rezaei 2018; Reza Soroori Khorashad 2024; Zahra Khayati 2021), and one study took a daily yoga practice that lasted 2 weeks (Divided Attention 2008), and the rest of the studies practiced yoga intervention 1-3 times per week. The overall intervention dose of the experiment ranged from 5-20h, with the most common dose intervention being 12h (Reza Soroori Khorashad 2024; Divided Attention 2008; Zahra Khayati 2021), and the dose of this program (Pauline.S. Jensen 2004) up to 20 hours.

3.3 Quality assessment

Eight studies provided information about randomization procedures (Reza Soroori Khorashad 2024; Samantha CL Cohen 2018; Pauline. S. Jensen 2004; Sheng Wang 2023; Xue Luo 2023; Meysam Rezaei 2018; Srinivasan Venkatesan 2008; Zahra Khayati 2021), such as randomized crossover trials and randomized controlled trials, and were therefore assessed as having a low risk of bias. One study was assessed at high risk of bias due to a lack of description of randomization methods (Chien-Chih Chou 2017).

Two studies described an allocation concealment method in which allocation by a third party and randomized allocation were used (Reza Soroori Khorashad 2024; Xue Luo 2023) and were therefore assessed as having a low risk of bias. The remaining seven studies did not explain the allocation concealment methods and therefore indicated an uncertain risk of bias (Chien-Chih Chou 2017; Pauline. S. Jensen 2004; Samantha CL Cohen 2018; Sheng Wang 2023; Srinivasan Venkatesan 2008; Zahra Khayati 2021; Meysam Rezaei 2018).

According to one study, there was a substantial risk of bias because participants were not blinded (Meysam Rezaei 2018). Three studies were considered to be at low risk of bias due to describing double-blind methods (Samantha CL Cohen 2018; Srinivasan Venkatesan 2008; Xue Luo 2023). The remaining five studies did not explain the use of blinding of participants and personnel (Chien-Chih Chou 2017; Pauline. S. Jensen 2004; Reza Soroori Khorashad 2024; Sheng Wang 2023; Zahra Khayati 2021), thus suggesting an indeterminate risk of bias.

Since three studies offered comprehensive details regarding blinded outcome assessment, detection bias was deemed to be low risk (Pauline S. Jensen 2004; Samantha CL Cohen 2018; Xue Luo 2023). The other six studies were judged to be of uncertain risk because blinded outcome assessment was not described (Chien-Chih Chou 2017; Reza Soroori Khorashad 2024; Sheng Wang 2023; Srinivasan Venkatesan 2008; Zahra Khayati 2021; Meysam Rezaei 2018).

All six studies reported complete outcome data (Reza Soroori Khorashad 2024; Chien-Chih Chou 2017; Pauline. S. Jensen 2004; Sheng Wang 2023; Xue Luo 2023; Zahra Khayati 2021) and were therefore assessed to be at low risk of bias. One study was unsure whether the primary outcome of complete outcome data was reported (Samantha CL Cohen 2018) and was therefore judged to be at uncertain risk. Two studies reported incomplete outcome data (Srinivasan Venkatesan 2008; Meysam Rezaei 2018) and were therefore assessed as high risk of bias.

One study had selective reporting of outcomes (Samantha CL Cohen 2018) and was therefore deemed to be at high risk of reporting. There was insufficient data from two trials to assess the possibility of selective reporting of results (Srinivasan Venkatesan 2008; Meysam Rezaei 2018) and were deemed to have an unknown risk of reporting bias as a result. The remaining six studies were considered low risk because all required outcomes were reported (Chien-Chih Chou 2017; Pauline. S. Jensen 2004; Reza Soroori Khorashad 2024; Sheng Wang 2023; Xue Luo 2023; Zahra Khayati 2021).

3.4 Meta-analysis

Table 2 provides a summary of the study's characteristics.

Table 2. Basic information on the literature was included.

Author	Country	Yea	population	Number of people		Age (mean+SD)		Exercise condition		Outcome
				Exercise	Control	Exercise	Control	Exercise	Control	
Chien-Chih Chou	China	2017	children aged between 8 and 12 years old who had been diagnosed with ADHD by their psychiatric	24	25	10.71 (1.00)	10.30 (1.07)	Yoga	Normal life	Visual pursuit test: Accuracy rate
Samantha CL Cohen	America	2018	Children 3 to 5 years of age with four or more ADHD symptoms rated by	8	10	Months. 52 (7)	Months. 46 (10)	Yoga	Regular classroom and home acti-	Distractibility Errors of Commission
Pauline S. Jensen	Australian	2004	Boys diagnosed with ADHD by specialist pediatricians and	11	8	10.63 (1.78)	9.35 (1.70)	Yoga	cooperative games and	a. DSM-IV Inattentive b. DSM-IV Hyperactive/ Impulsive c. Global In-

Sheng Wang	China	2023	30 children with ADHD	15	15	6.92 (1.55)	6.06 (1.31)	Yoga	did not receive any tre-	instability of emotion
Xue Luo	China	2023	60 children with attention-deficit/hyperactivity disorder (ADHD) comorbid	15	15	4.94 (0.70)	5.07 (0.88)	Yoga	do not intervene	a. Inattention b. Hyperactivity/impulsivity
Meysam	Iran	20	Children with	7	7	7-11		Yoga	do not	Commission Errors
Reza Soroori Kho-	Canada	2024	Children with ADHD who had not received	22	23	13.7 (1.5)		methylphenidate	methylphenidate	Divided Attention
Divided Atten-	India	200	40 boys and girls with ADHD	20	20	10.1 (0.99)		Yoga	Non-therapy	a. Inattention b. Hyperactivity/impulsivity
Zahra Khayati	Iran	2021	male primary school students with attention deficit/hyperactivity	20	20	not mentioned		Yoga	a waiting list for education	Generalized-overanxious anxiety

3.4.1 Attention problems

A total of 3 articles (Pauline. S. Jensen 2004; Xue Luo 2023; Srinivasan Venkatesan 2008) that have measured inattention extracted the data measured using the inattention subscale in the experimental and control groups after the completion of the intervention for Meta-analysis. Since the included studies showed a significant degree of heterogeneity (I^2=91%), the analysis was conducted using a random effects model. The results of the investigation indicated that the total impact of inattention (SMD =-1.73; 95%CI=-3.48~0.03; p=0.05) was statistically significant, suggesting that yoga improves inattention in children with ADHD (Figure 3).

A total of 4 articles reported the effect of yoga on sustained attention in children with ADHD (Chien-Chih Chou 2017; Samantha CL Cohen 2018; Meysam Rezaei 2018; Reza Soroori Khorashad 2024). The combination of the results revealed a considerable degree of heterogeneity (I^2=82%), so a random-effects model was employed. The meta-analysis re-

vealed that yoga practice helped children with ADHD symptoms pay attention for longer periods of time (SMD=1.78; 95%CI=0.67-2.88; p<0.05), and the difference was statistically significant (Figure 4).

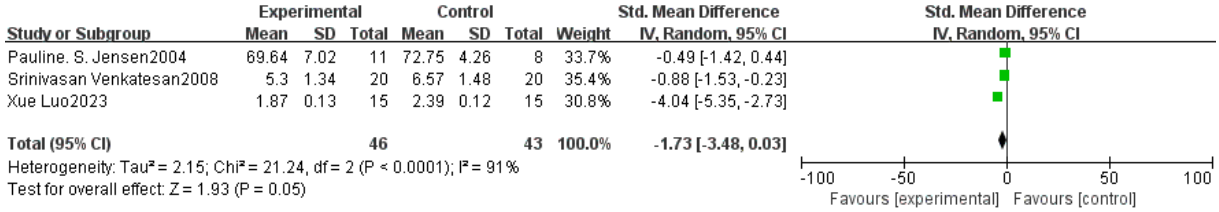

Figure 3. Standardized mean difference in the Attention Deficit Scale. SMD-standardized mean difference; CI-confidence SMD-standardized mean difference; CI-confidence interval.

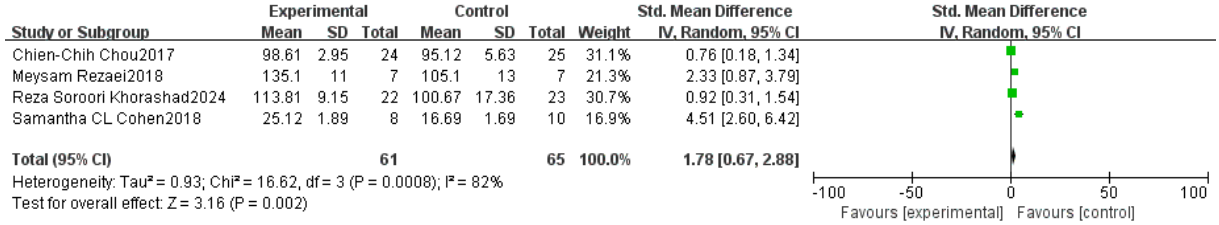

Figure 4. Standardized mean difference in the Sustained attention. SMD-standardized mean difference; CI-confidence interval.

3.4.2 Emotional problems

According to 2 studies, yoga helps children with ADHD who struggle with emotional instability (Pauline S. Jensen 2004; Sheng Wang 2023). Following the analysis of the mergeable data, the meta-analysis employed a random-effects model because to the considerable inter-study heterogeneity (I2=60%) in the aggregated data. According to the results, yoga was successful in reducing emotional instability in children with ADHD (SMD=-1.43; 95%CI =-2.47~-0.39; p<0.05), suggesting that yoga had a statistically significant overall effect on emotional instability (Figure 5).

A total of 2 studies measured anxiety (Pauline. S. Jensen 2004; Zahra Khayati 2021). The mergeable data were analyzed, and high heterogeneity was noted within the merged results (I^2=94%), so a random-effects model was chosen for the analysis. Meta-analysis showed that the overall effect of anxiety (SMD=-1.76; 95%CI=-4.54~1.07; p>0.05) was not statistically significant, indicating that yoga exercise was not statistically significant in improving anxiety in children with ADHD (Figure 6).

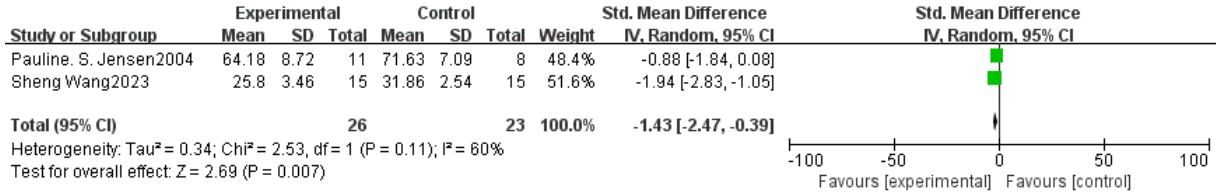

Figure 5. Standardized mean difference in the Emotional Instability Scale. SMD-standardized mean difference; CI- confidence interval.

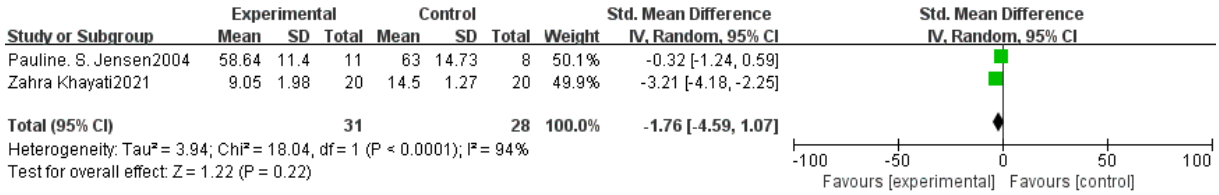

Figure 6. Standardized mean difference in anxiety scales. SMD-standardized mean difference; CI-confidence interval.

3.4.3 Behavioral control

Three research examined how yoga affected children with ADHD symptoms' hyperactivity and impulsivity (Pauline S. Jensen 2004; Xue Luo 2023; Srinivasan Venkatesan 2008). When the findings were combined, a high degree of inter-study heterogeneity (I2=89%) was discovered; as a result, a random effects model was employed for the analysis. A meta-analysis revealed that the experimental group of kids with ADHD symptoms of hyperactivity/impulsivity improved (SMD=-1.79; 95%CI=-3.46 to -0.13; p<0.05) in comparison to the control group, and the difference was statistically significant (Figure 7).

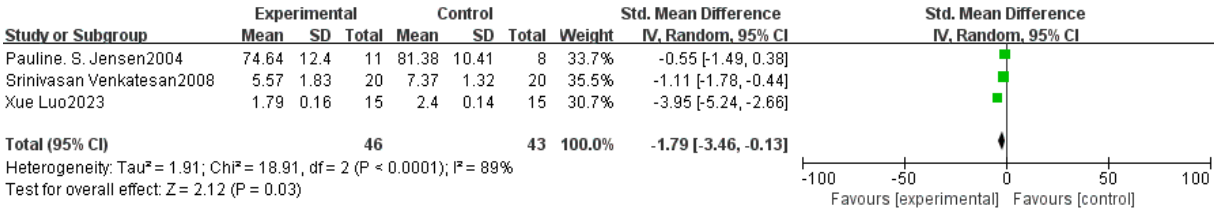

Figure 7. Standardized mean difference in the hyperactivity/impulsivity scale. SMD-standardized mean difference; CI- SMD-standardized mean difference; CI-confidence interval.

3.5 Sensitivity analysis

Meta-analysis revealed high heterogeneity (I^2>80%) in the analyses of inattention, sustained attention, emotional instability, anxiety and hyperactivity/impulsivity. Although the small amount of literature may be an important reason for the high heterogeneity, other factors need to be considered as well. First, there were significant differences in the length and frequency of interventions across studies, with some studies having shorter interventions (<4 weeks) and others having interventions of more than 4 months. Second, there were differences in the range of assessment of the measurement tools used in the included studies, with some studies, for example, using the Parent and Teacher Rating Scales-The ADHD RS-IV Preschool version to measure indicators of inattention and hyperactivity/impulsivity outcomes in children with ADHD (Samantha CL Cohen 2018), and some studies used the MTA SNAP-IV ADHD Rating Scale questionnaire to measure inattention and hyperactivity (Xue Luo 2023), which could also be a potential source of high heterogeneity. Similarly, differences in participant age and gender could also contribute to high heterogeneity, such as some studies with participants aged 3-7 years and some between 12-15 years as well as some studies with participants comprising only boys. Finally, differences in the type of intervention and setting may also be a source of high heterogeneity. For example, some studies used a yoga + medication form of intervention, while some studies conducted a combination of school and home yoga.

4 Discussion

This study comprehensively assessed the effect of yoga intervention on inattention, sustained attention, emotional instability, anxiety, and hyperactive/impulsive symptoms in children with ADHD through a systematic review and Meta-analysis. The results showed that yoga intervention had statistically significant effects on inat-

tention, sustained attention, emotional instability, and hyperactivity/impulsivity symptoms in ADHD children ($p<0.05$), but the improvement in anxiety symptoms did not reach statistical significance. This finding provides new evidence to support the effectiveness of yoga as a non-pharmacological intervention for children with ADHD and also reveals the variability in the effects of yoga on different symptoms.

4.1 Effects of Yoga on Attention in Children with ADHD

The present study found that yoga intervention significantly improved inattention and sustained attention problems in children with ADHD. This is consistent with the findings of Jensen (2004), who found that yoga improved attention duration and selective attention in children with ADHD[29]. In addition, Harrison et al. (2004) study also showed that yoga improves executive functions, including attentional control and working memory, in children with ADHD[33]. Improvements in attention may be related to the following mechanisms: on the one hand, yoga practice emphasizes focus, self-control, and cognitive flexibility, which are the core elements of attention problems, and through asana practice, breath control, and meditation, yoga enhances prefrontal cortex activity, improves working memory, inhibitory control, and cognitive flexibility, and thus enhances attention levels[34]. On the other hand, it has been shown that two neurotransmitters, dopamine and norepinephrine, play a key role in attention regulation, and yoga practice can increase the secretion of dopamine and norepinephrine, thus improving patients' attention problems[35].

4.2 Effects of Yoga on the Emotions of Children with ADHD

Lack of emotional control and regulation is one of the main characteristics of ADHD children, which not only affects their social interactions but also poses a challenge to academic performance and overall quality of life. Meta-analysis of the present study showed that yoga intervention was significantly effective in improving emotional instability in children with ADHD, but did not reach statistical significance in terms of improvement in anxiety symptoms.

The significant improvement in emotional instability may be related to the following mechanisms of yoga: on the one hand, breathing control (e.g. abdominal breathing, alternate nostril breathing) and relaxation techniques (e.g. yoga resting techniques) in yoga practice can activate the parasympathetic nervous system and reduce heart rate and blood pressure levels, thus alleviating tensions, and providing an effective help in

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33. Harrison L J, Manocha R, Rubia K. Sahaja yoga meditation as a family treatment program for children with attention deficit-hyperactivity disorder [J]. Clinical Child Psychology and Psychiatry, 2004, 9(4): 479-497.

34. Tang Y Y, Hölzel B K, Posner M I. The neuroscience of mindfulness meditation[J]. Nature Reviews Neuroscience, 2015, 16(4): 213-225.

35. Field T. Yoga clinical research review[J]. Complementary therapies in clinical practice, 2011, 17(1): 1-8.

emotional instability[36]. On the other hand, studies have shown that yoga practice can regulate the levels of mood-related neurotransmitters, such as increasing the secretion of gamma-aminobutyric acid (GABA) and 5-hydroxytryptophan (5-HT), both of which have a calming effect, and can be effective in alleviating the symptoms of emotional instability[37].

The result of the non-significant effect of anxiety improvement may be influenced by the following factors: first, the small number of included studies, only two, did not allow for sufficient heterogeneity analysis, thus limiting the generalizability of the results. Second, it was concluded from the literature that the duration and frequency of their yoga interventions may not be sufficient to have a significant effect on anxiety symptoms. The study by Hagen et al. (2014) indicated that short-term yoga interventions have a limited effect on the improvement of anxiety symptoms and that longer-term and more frequent interventions are needed[38]. In addition, improvement in anxiety symptoms may require more direct neurophysiological regulatory mechanisms, such as modulating anxiety by affecting functional connectivity in the amygdala and prefrontal cortex[39].

4.3 Effects of Yoga on Behavioral Control in Children with ADHD

This study found that yoga was effective in improving hyperactive/impulsive symptoms in children with ADHD. In exploring the reasons for yoga's improvement, we need to consider the developmental mechanisms in pediatric patients with ADHD. Higher levels of hyperactivity and impulsivity in adolescents are associated with slower cortical thinning, particularly in the prefrontal cortex, which is essential for impulse management, inhibitory control, and other processes[40]. It has been noted that yoga practitioners show greater ventral lateral prefrontal cortex (vlPFC) activation during Stroop tasks compared to controls and that it has been shown to have favorable

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[36]. Brown R P, Gerbarg P L. Sudarshan Kriya yogic breathing in the treatment of stress, anxiety, and depression: part I-neurophysiologic model[J]. Journal of Alternative & Complementary Medicine, 2005, 11(1): 189-201.

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effects in terms of improvement in hyperactivity/impulsivity symptoms[41]. It has also been suggested that brain activity patterns change after yoga practice, altering neural functions related to behavioral control, which in turn positively affects behavioral performance in children with ADHD[42].

All things considered, yoga offers special advantages for individuals with ADHD over other forms of therapy, especially in the formative years. Through its special breathing and meditation techniques, yoga helps children with ADHD establish a solid basis for self-regulation at the crucial stage of cognitive and emotional regulation development[43,44]. Since children are more vulnerable to the negative effects of medications than adults are, and because long-term medication use can harm children's neurological and psychological systems irreparably, yoga, as a non-pharmacological intervention, has the advantage of having no serious side effects. On the one hand, it is more appropriate for the long-term care of families with children who have ADHD due to its low cost. Yoga, on the other hand, aims to have a long-lasting good impact on all aspects of daily life and academic achievement for children with ADHD by fostering and enhancing the patient's inner self, in contrast to drugs that directly target neurotransmitters. Overall, yoga therapy during childhood may benefit ADHD patients' physical and mental development better and progressively lessen the negative symptoms of the disorder.

5 Limitations

Even though the random effects model is frequently used for meta-analyses, it has certain limitations. For example, if there are few studies, the data gathered from the study will be imprecise, therefore the findings should be evaluated with caution[45]. The FS and PACES analyses in this study showed high heterogeneity of the data, which may be caused by the following reasons: first, although we optimized the homogeneity problem of the studies by strict inclusion criteria, we were unable to obtain all the relevant data due to the limitations of the included literature, which may have affected the results of our analyses. Second, inconsistency in the measurement of the outcome metrics and the diversity of the metrics may also be the cause of high heterogeneity; ADHD symptoms encompass a variety of aspects such as attention problems,

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41. Machado Y C, Oliveira M, Lima J L F, et al. Effects of yoga on impulsivity in patients with and without mental disorders: a systematic review[J]. BMC Psychiatry, 2024, 24(1): 267.

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mood problems, executive functioning, and social functioning, but there is no uniform standard for the measurement of these outcome indicators. Third, we need to be aware of meta-analysis's inherent limitations. For instance, it is impossible to totally rule out the possibility of publication bias, which could skew our results because research with noteworthy results are more likely to be published.

6 Conclusions

This systematic review and meta-analysis examined the effects of an intervention using yoga on five symptoms of inattention, sustained attention, emotional instability, anxiety, and hyperactivity/impulsivity in children with ADHD. While yoga did not approach statistical significance for anxiety symptoms, we did find that it significantly reduced the symptoms of inattention, sustained attention, emotional instability, and hyperactivity/impulsivity in children with ADHD. This study offers significant proof that yoga is a successful non-pharmacological treatment for ADHD in kids. It also implies that more research is necessary to better understand how yoga affects anxiety symptoms and to improve intervention techniques. Despite some limitations, this study provides an important reference point for future research and clinical practice.

Author's contribution

Conceptualization, XTM, YL and JH; methodology, XTM; software, XTM; check, XTM, YL and HJ; formal analysis, XTM; investigation, XTM; resources, XTM; data curation, XTM; writing - rough preparation, XTM and YL; writing - review and editing, XTM; visualization, XJL; supervision, HCJ; project administration, XTM; receiving funding, JH. All authors have read and agreed with the published version of the manuscript.

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Data Availability Statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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