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Review article

Effects of physical exercise on attention deficit and other major symptoms in children with ADHD: A meta-analysis

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ABSTRACT

Purpose: To explore the effects of physical exercise intervention on the cardinal symptoms, motor skills and executive function among children with attention deficit hyperactivity disorder (ADHD).

Methods: Literature searches for randomized controlled trials (RCTs) were performed in PubMed, The Cochrane Library, Web of Science, Embase, CNKI, CBM, VIP and Wanfang databases from the time of database construction to March 28, 2021. Screening was conducted based on inclusion and exclusion criteria. The Cochrane bias risk assessment tools were used to evaluate methodological quality. Relevant data were analyzed with RevMan5.3.5 software, and Stata16.0 was used for publication bias tests.

Results: A total of 15 RCTs with 734 subjects were included. The meta-analysis showed that physical exercise can improve the attention of ADHD children (standardized mean difference [SMD] = −0.60, 95% confidence interval [CI] [−1.10, −0.11], $p < 0.01$), executive function (SMD = 1.22, 95% CI [0.61, 1.82], $p < 0.01$), and motor skills (SMD = 0.67, 95% CI [0.22, 1.12], $p < 0.01$). There were no significant effects on hyperactivity (SMD = 0.06, 95% CI [−0.26, 0.37], $p = 0.72$), depression (SMD = −0.72, 95% CI [−1.55, 0.11], $p = 0.09$), social problems (SMD = −0.27, 95% CI [−0.64, 0.09], $p = 0.14$), or aggressive behavior (SMD=−0.24, 95% CI [−0.69, −0.21], $p = 0.30$). Intervention duration and frequency might be the source of heterogeneity.

Conclusion: Physical exercise can help alleviate the symptoms of ADHD in children. Specifically, it can improve attention, executive function, and motor skills.

1. Introduction

Attention deficit hyperactivity disorder (ADHD) is the most common neurodevelopmental disorder in children (Thapar and Cooper, 2016). The global prevalence of ADHD is about 7.2% (Thomas et al., 2015), and it is 6.26% in China (Wang et al., 2017). The main characteristics of ADHD are inattention, hyperactivity, impulsivity, and inhibition, all of which affect children's behavior and executive function (Gapin and Etnier, 2010; American Psychiatric Association, 2013). These problems generally continue into adolescence and adulthood (American Psychiatric Association, 2013; Posner et al., 2020) and have adverse effects on their quality of life (Ross, 2006), hindering their physical and mental health. Pharmacotherapy is the most common treatment for ADHD, but it is usually accompanied by side effects (De Sousa and Kalra, 2012) such as headache, stomachache and lack of appetite (Liu et al., 2020). In recent years, researchers and clinicians have become more interested in physical activities and exercise interventions for ADHD children. Two studies demonstrated that exercise can ameliorate behavioral problems of ADHD children and improve their cognitive performance (Barnard--Brak et al., 2011; Wigal et al., 2013). Studies have found that moderate or high-intensity aerobic exercise can effectively improve the executive function of ADHD patients to varying degrees. Another report concluded that aerobic training may have long-term benefits on the executive function, attention, and behavior of this population (Den Heijer et al., 2017). Regular Tai Chi practice has positive effects on behavior, cognitive ability, and social interactions (Chen and Cheng, 2016), while yoga can stabilize mood and reduce opposing behaviors in ADHD children (Jensen and Kenny, 2004). However, similar high-quality research is needed to support it. Although there have been studies showing the role of physical exercise, the intervention programs used in each study are different.

There are meta studies showing that exercise has significant effects on the motor skills and executive functions among children with ADHD (Vysniauske et al., 2020; Liang et al., 2021). Children with ADHD have

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deficits in both executive function and motor skills. Studies have also shown that physical activity can significantly relieve anxiety, depression, aggressive behavior, as well as improve mind-set and social problems in children with ADHD (Zang, 2019). Most previous studies only included several indicators such as anxiety, depression, and aggressive behavior in children with ADHD, and there were relatively limited outcome indicators. This study has covered these indicators and added 4 subgroup analyzes based on previous studies, making a more comprehensive illustration of the relationships between those indicators and exercise. In order to further analyze the impact of physical exercise on ADHD children with hyperactivity symptoms and other diseases. The goals of this meta-analysis were to systematically conduct a quantitative analysis of randomized controlled trials (RCTs) on the intervention effects of physical exercise on ADHD children in China and other countries and provide evidence-based medicine evidence for clinical practice.

2. Methods

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis statement (Liberati et al., 2009) for the selection and use of research methods. The protocol for this study was registered with INPLASY (202140113).

2.1. Literature search

Eight Chinese and English electronic databases were searched (PubMed, The Cochrane Library, Web of Science, Embase, CNKI, CBM, Wanfang, and Weipu). The search period was from the inception of each database to March 28, 2021. We used key phrases and Medical Subject Heading (MeSH) terms as follows: exercise, sport, fitness, physical activity, Attention Deficit, Hyperactivity, Hyperkinetic Syndrome, Attention Deficit Hyperactivity Disorder, ADHD, ADD, randomized controlled trial. The search strategy adopted a combination of subject words and free words and used the Boolean operations "AND" and/or "OR" to combine (topic or title) connections. It was subjected to repeated prechecks and was supplemented by manual searches. The reference lists and related links of retrieved articles were examined to identify potentially eligible references for inclusion. The literature search was limited to English and Chinese.

2.2. Inclusion and exclusion criteria

The criteria for inclusion were as follows: (1) patients between 5 and 15 years old (children or adolescents diagnosed with ADHD); (2) randomized controlled trials (RCTs); (3) type of intervention (PE programs, or increased PE in addition to treatment in the control group); (4) primary outcomes of ADHD symptoms of hyperactivity and inattention, and secondary outcomes of depression, social problems, motor skills, and executive function. These outcomes were measured using a number of scales and tests. For example: Bruininks-Oseretsky Test; Child Behavior Checklist; Child Depression Inventory; Rey-Osterrieth Complex Figure; Test of Gross Motor Development-2; Wisconsin card sorting test. The exclusion criteria were (1) non-RCTs, (2) duplicate publications.

2.3. Study selection

The two researchers, according to the inclusion and exclusion criteria, selected the literature through independent double-blind tests. After reading the titles and abstracts of papers, the preliminary screening of the entire content of those papers was conducted in an effort to ruling out unqualified papers. If there was any disagreement on certain paper, a third author would join in to discuss and decide whether to include the paper.

2.4. Data extraction

Two researchers independently extracted the relevant information using a standardized form. The following information was extracted: (1) basic information (author, published year, country, trial design, subject characteristic, etc.); (2) experimental characteristics (movement form, time, frequency, cycle), and (3) outcome measures.

2.5. Risk of bias assessment

The Cochrane Collaboration tools were used to confirm random sequence generation, allocation concealment, blinding, incomplete outcome data, selective reporting, and other biases. Each item was determined as high risk, low risk, or unclear by the two authors. The process was conducted independently and reviewed by two researchers, and the third reviewer was consulted if there was a disagreement.

2.6. Data analysis and synthesis

We used Revman 5.3 software to conduct the data analysis. Continuous outcomes are expressed as standardized mean differences (SMDs) with 95% confidence intervals (CIs). Heterogeneity was tested by p value and I^2. If $p > 0.10$ and $I^2 < 50\%$, the heterogeneity was considered low enough to conduct a meta-analysis with a fixed-effect model. If $p < 0.10$, $I^2 > 50\%$, there was a high level of heterogeneity, and a random effect model was used. Sensitivity analysis was conducted by one-by-one exclusion method for individual studies. Descriptive analysis was performed if the heterogeneity was too large ($I^2 > 85\%$). Stata 16.0 software was used to test publication biases.

3. Results

3.1. Search results

The flow diagram illustrating the search and screening process is shown in Fig. 1. A total of 5171 articles were retrieved from the database search, 17 articles were manually retrieved from other resources, and 3872 articles were obtained after eliminating duplications. After reading the titles and abstracts, preliminary screening, full-text screening, and eliminating articles that did not meet the inclusion criteria, 15 articles were finally included in the meta-analysis.

3.2. Characteristics of the included trials

A total of 15 studies including 734 ADHD children were included in this study. The publication years of the included studies ranged from 1984–2019 Table 1. describes the basic characteristics, exercise types, time, frequency, period, and test methods of the included RCTs.

3.3. Risk of bias

The 15 papers included in this study were all RCTs. Two studies (Benzing and Schmidt, 2019; Silva et al., 2020; Oh et al., 2018) described the randomization methods in detail, and the rest only mentioned random allocation. One study (Benzing and Schmidt, 2019) described allocation concealment, but the methods of random allocation and blinding were not mentioned or described sufficiently in the others. Two RCTs (Benzing and Schmidt, 2019; Hoza et al., 2015) blinded both the subjects and researchers. Only one paper (Porter and Omizo, 1984) used a blinding method for result evaluation. All fifteen studies reported complete data Fig. 2. shows that there was a certain degree of bias in the included literature. One study (Benzing and Schmidt, 2019) was of high quality, and 14 were determined to have medium quality.

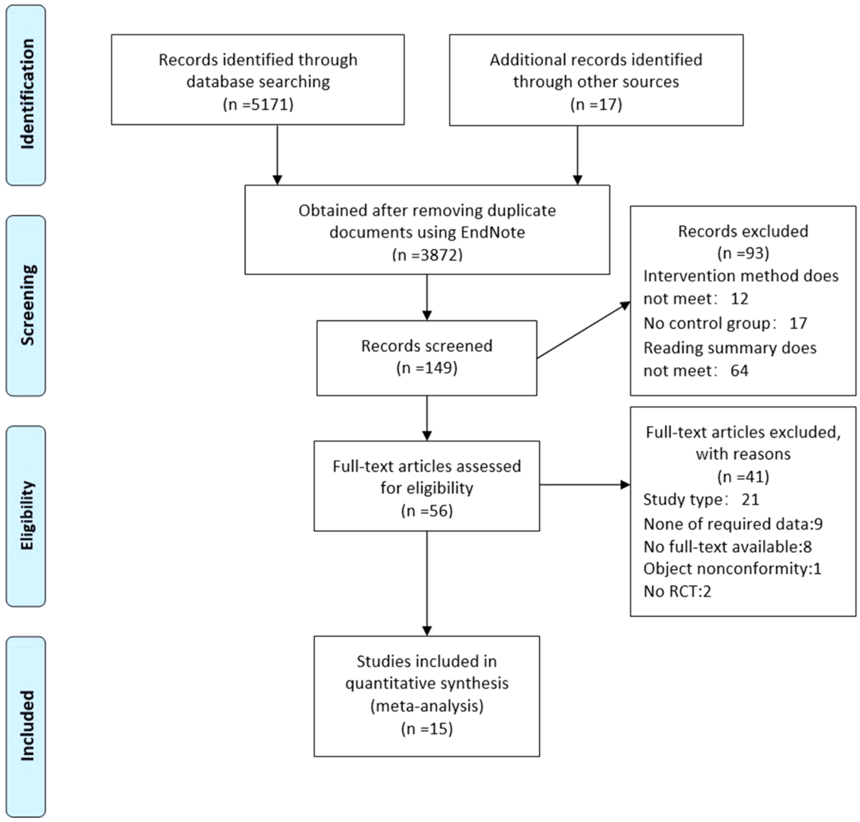

Fig. 1. Flow diagram.

3.4. Summary of the meta-analysis results

3.4.1. The effect of physical exercise on hyperactivity in ADHD children

Four studies (161 participants) evaluated the intervention effects of physical exercise on hyperactivity. Testing showed low heterogeneity ($I^2 = 0\%$, $p = 0.56$, Fig. 3). The meta-analysis results showed that the combined effect size was SMD = 0.06, 95% CI [−0.26, 0.37], $p = 0.72$, and the difference was not statistically significant.

3.4.2. The effect of physical exercise on attention in ADHD children

Nine studies (352 participants) evaluated the intervention effects of physical exercise on attention. There was a high degree of heterogeneity between the studies ($I^2 = 76\%$, $p < 0.01$, Fig. 4), so the random effects model is used for analysis. The combined effect size (SMD = −0.60, 95% CI [−1.10, −0.11]) indicated that physical exercise can effectively improve attention in ADHD children compared with the control group ($p < 0.05$).

3.4.3. The effect of physical exercise on depression in ADHD children

Four studies (98 participants) evaluated the intervention effect of physical exercise. As shown in Fig. 5, the heterogeneity test results were $I^2 = 71\%$, $p < 0.05$, indicating a high degree of heterogeneity, so the random effects model was used for analysis. The difference was not significant based on the combined effect size (SMD = −0.72, 95% CI [−1.55, 0.11], $p = 0.09$).

3.4.4. The effect of physical exercise on social problems in ADHD children

Four studies (117 participants) evaluated the intervention effects of physical exercise on social skill problems. There was a high degree of heterogeneity among the studies ($I^2 = 0\%$, $p = 1$, Fig. 6). The combined effect size showed that the difference between the ADHD and control groups was not statistically significant (SMD = −0.27, 95% CI [−0.64, 0.09], $p = 0.14$).

3.4.5. The effect of physical exercise on aggressive behavior in ADHD children

Three studies (78 participants) evaluated the effect of physical exercise on aggressive behavior. Since there was low heterogeneity among the studies ($I^2 = 0\%$, $p = 0.76$, Fig. 7). The combined effect size showed that the difference between the ADHD and control groups was not statistically significant (SMD = −0.24, 95% CI [−0.69, 0.21], $p = 0.30$).

3.4.6. The effects of physical exercise on motor skills in ADHD children

Four studies (191 participants) evaluated the intervention effects of physical exercise on motor skills. As shown in Fig. 8, there was low heterogeneity among the studies ($I^2 = 52\%$, $p = 0.10$). Based on the combined effect size (SMD = 0.67, 95% CI [0.22, 1.12], $p < 0.01$) physical exercise can effectively improve motor skills in ADHD children compared with the control group.

3.4.7. The effect of physical exercise on executive function in ADHD children

Eight studies (319 participants) evaluated the intervention effects of physical exercise on executive function. Given the high degree of heterogeneity among the studies ($I^2 = 81\%$, $p < 0.01$, Fig. 9), the random effects model was used. The combined effect size SMD = 1.22, 95% CI [0.61, 1.82] ($p < 0.01$) demonstrated that physical exercise can effectively improve the executive function of ADHD children compared with the control group.

No big heterogeneity change was found after certain item being removed one by one. And there was no essential change in the results of Meta-analyzes, indicating a relatively stable study result. To further explore the possible source of heterogeneity, the executive function was analyzed in subgroups according to the intervention duration, frequency and cycle (see Table 2), which suggested that the source of heterogeneity may be related to the intervention duration and frequency. Among them, in terms of the effect size, exercise lasting closed-skill exercise, 70

Table 1
. Characteristics of the included trials.

Ref.	Country	Main subject characteristics		Intervention arm				Control arm	Instruments
		Sample size (E/C) and sex ratio	Average age (E/C)	Exercise form	Time (min)	Frequency (times/ week)	Cycle		
Ahmed and Mohamed (2011)	Egypt	42 (27 M and 15 F)/ 42 (27 M and 15 F)	13.9/ 13.8	included upper limb, lower limb, trunk and neck aerobic exercises in addition to free running	40	3	10 weeks	No treatment control	1. Behavior Rating Scale
Benzing and Schmidt (2019)	Switzerland	28 (24 M and 4 F)/ 23 (19 M and 4 F)	10.46/ 10.39	Sports games	30	3	8 weeks	Waiting list control group	1. Flanker task 2. Color span backwards
Bustamante et al. (2016)	America	19 (13 M and 6 F)/ 16 (11 M and 5 F)	9.4/ 8.7	Aerobic exercise(structured play)	90	5	10 weeks	Sedentary attention control	1. Stop-signal inhibition task 2. Automated working memory assessment system
Hattabi et al. (2019)	Tunisia	20 (3 M and 17 F)/20 (2 M and 18 F)	9.95/ 9.75	Water aerobics	90	3	12 weeks	No intervention	1. ROCF 2. Stroop test
Hoza et al. (2015)	America	104 (58 M and 46 F)/ 98 (50 M and 48 F)	6.83	Aerobic exercise(game)	31	5	12 weeks	Sedentary classroom intervention	1. Conners Parent and Teacher Rating Scale
Jensen and Kenny (2004)	Australia	11 (11 M)/ 8 (8 M)	10.63/ 9.35	Yoga	60	1	20 weeks	Cooperative activities	1. Conners Parent and Teacher Rating Scale
Kadri et al. (2019)	Tunisia	20 (18 M and 2 F)/ 20 (18 M and 2 F)	14.5/ 14.2	Taekwondo+ Regular physical education	50	2	1.5 years	regular education	1. Stroop test
Memarmoghaddam et al. (2016)	Iran	19 (19 M)/ 17(17 M)	8.31/ 8.29	Aerobic exercise(include a progressive program and ball games)	90	3	8 weeks	No intervention	1. Stroop test 2. GO/NO go test
Pan et al. (2016)	China	16 (16 M)/ 16 (16 M)	8.93/ 8.87	Table tennis	70	2	12 weeks	No intervention	1. TGMD-2 2. Stroop test 3. WCST
García-Gómez et al. (2016)	Spain	15 (15 M)/ 15 (15 M)	9.08/ 8.90	Horseback riding + unmounted activities(group-based, professional trainer)	45	2	12 weeks	Waiting-list	1.BASC
Porter and Omizo (1984)	Australia	12 (12 M)/ 11 (11 M)	-	Muscle training+Relaxation exercises	25	3	5 weeks	Listen to the story	1. Nowicki-Strickland Scale 2. Matching Familiar Figures Test
Silva et al. (2020)	Brazil	10 (8 M and 2 F)/ 10 (6 M and 4 F)	12/12	Swim	45	2	8 weeks	No intervention	1. CDI 2. Test of trails 3. Corporal coordination test
Oh et al. (2018)	Korea	17 (15 M and 2 F)/ 17 (16 M and 1 F)	8.30/ 8.00	Horseback Riding + unmounted activities(group-based, professional trainer)	60	2	12 weeks	No treatment control	1. CBCL
Taft Yazd et al. (2015)	Iran	12 (10 M and 2 F)/ 12 (10 M and 2 F)	6–12	Sports training	-	3	6 weeks	medication	1. BOT-2
Liu and Yang (2018)	China	32 (16 M and 16 F)/ 32 (16 M and 16 F)	-	Orienteering Exercises	35	3	14 weeks	No intervention	1. Corsi block tapping test

BOT-2: Bruininks-Oseretsky Test; CBCL: Child Behavior Checklist; CDI: Child Depression Inventory; ROCF: Rey-Osterrieth Complex Figure; TGMD-2: Test of Gross Motor Development-2; WCST: Wisconsin card sorting test; BASC:behavior assessment system for children;"-": not reported

min per time, twice a week, and 12–14 weeks altogether showed higher effect size.

3.5. Publication bias and sensitivity analysis

We performed publication bias tests on outcome measures of attention issues in the included papers. The results showed that Egger's test $pr>|z| = 0.0153 < 0.05$, indicating that his paper has publication bias. But Begg's test showed that $pr>|z| = 1.9237 > 0.05$, indicating that the study might have slight publication bias. To explore possible causes of heterogeneity, we conducted a sensitivity analysis of the outcome indicators, and the combined effect was analyzed by eliminating individual studies one by one. Attention problems, and excluding individual studies had little effect on overall heterogeneity. The heterogeneities of other indicators after excluding single studies are shown in Table 3.

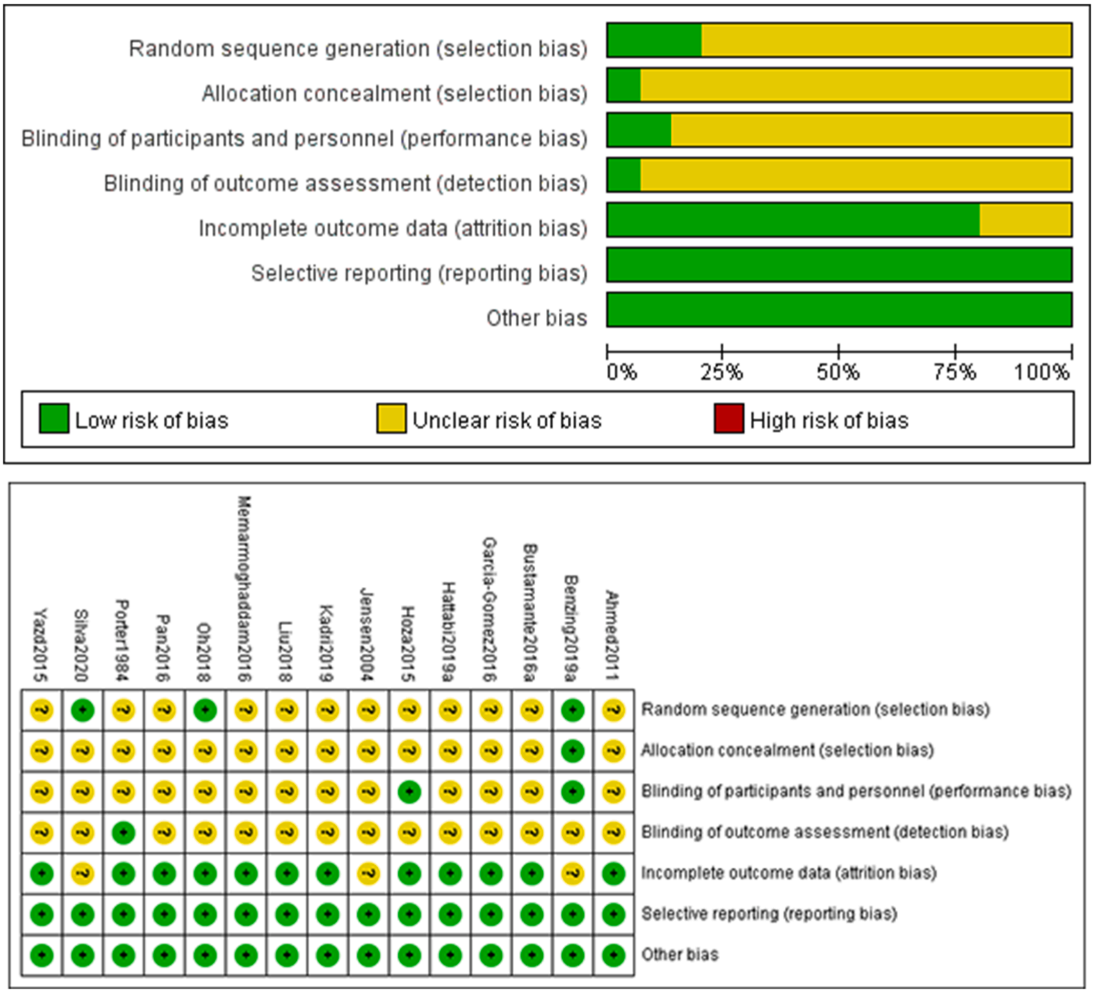

Fig. 2. Risk of bias assessment for the included studies.

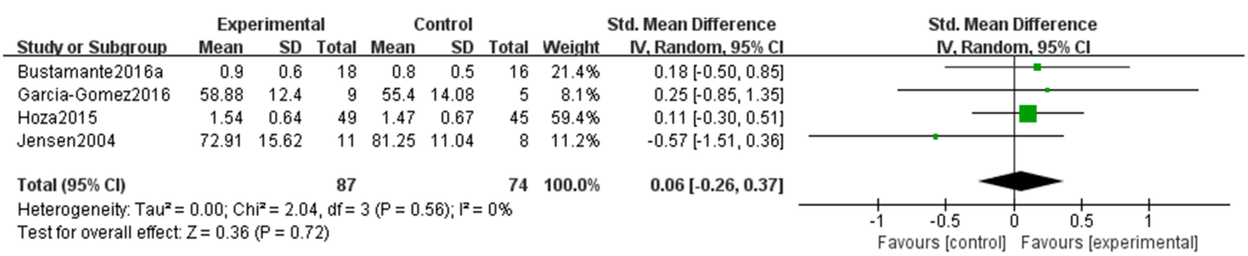

Fig. 3. Forest plot for change in hyperactivity symptoms with ADHD Child.

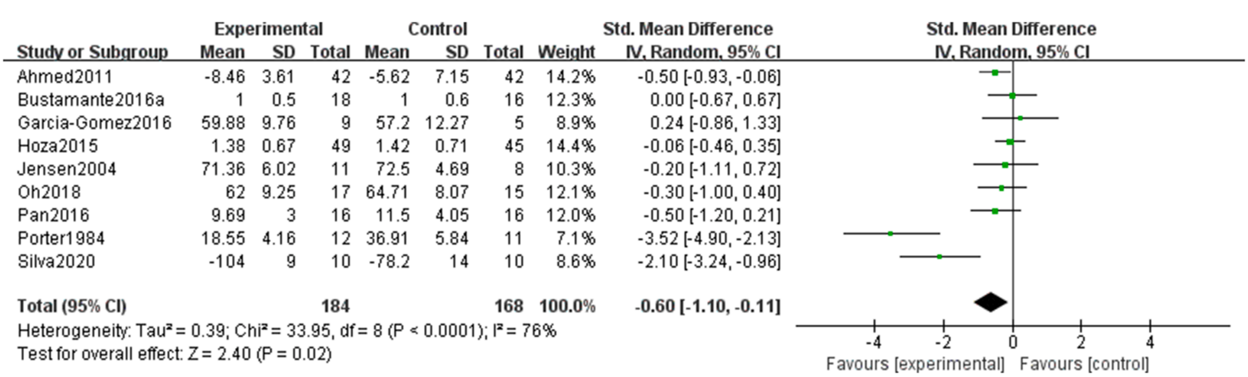

Fig. 4. Forest plot for change in attention problems with ADHD Child.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Garcia-Gomez2016	63.66	17.83	9	59.6	23.29	5	22.1%	0.19 [-0.90, 1.29]
Oh2018	59.69	7.95	17	65.14	10.81	15	28.5%	-0.57 [-1.28, 0.14]
Pan2016	5.63	5.28	16	7.5	3.65	16	28.7%	-0.40 [-1.10, 0.30]
Silva2020	10.2	2	10	16.4	3	10	20.7%	-2.33 [-3.52, -1.14]
Total (95% CI)			**52**			**46**	**100.0%**	**-0.72 [-1.55, 0.11]**

Heterogeneity: Tau² = 0.50; Chi² = 10.42, df = 3 (P = 0.02); I² = 71%
Test for overall effect: Z = 1.69 (P = 0.09)

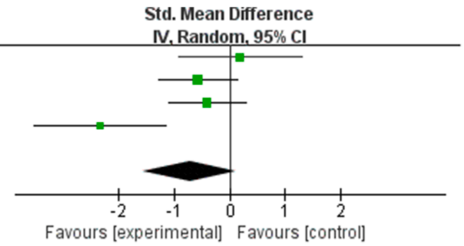

Fig. 5. Forest plot for change in depression with ADHD Child.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bustamante2016	-97	15	18	-92	15	16	29.0%	-0.33 [-1.00, 0.35]
Jensen2004	64.27	15.16	11	68	12.59	8	16.0%	-0.25 [-1.17, 0.66]
Oh2018	59.88	7.1	17	61.71	8.56	15	27.5%	-0.23 [-0.93, 0.47]
Pan2016	5.31	4.05	16	6.94	7.01	16	27.5%	-0.28 [-0.97, 0.42]
Total (95% CI)			**62**			**55**	**100.0%**	**-0.27 [-0.64, 0.09]**

Heterogeneity: Tau² = 0.00; Chi² = 0.04, df = 3 (P = 1.00); I² = 0%
Test for overall effect: Z = 1.47 (P = 0.14)

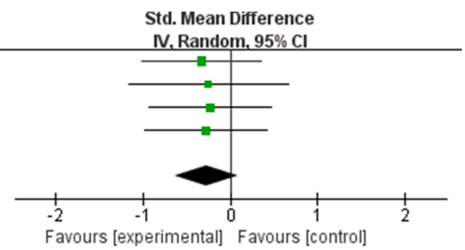

Fig. 6. Forest plot for change in social problems with ADHD Child.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Garcia-Gomez2016	57.22	17.92	9	58.6	20.77	5	17.0%	-0.07 [-1.16, 1.03]
Oh2018	61.63	10.07	17	62.86	11.48	15	42.0%	-0.11 [-0.81, 0.58]
Pan2016	9.69	7.45	16	13	7.11	16	41.1%	-0.44 [-1.15, 0.26]
Total (95% CI)			**42**			**36**	**100.0%**	**-0.24 [-0.69, 0.21]**

Heterogeneity: Tau² = 0.00; Chi² = 0.55, df = 2 (P = 0.76); I² = 0%
Test for overall effect: Z = 1.05 (P = 0.30)

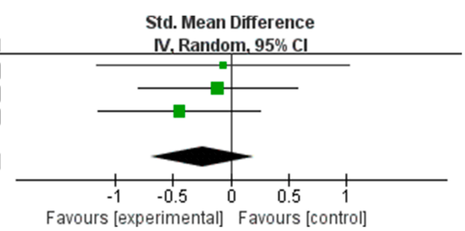

Fig. 7. Forest plot for change in aggressive behaviors with ADHD Child.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Ahmed2011	7.97	3.96	42	4.95	6.07	42	33.9%	0.58 [0.15, 1.02]
Benzing2019	103.77	8.51	28	101.27	6.39	23	28.4%	0.32 [-0.23, 0.88]
Pan2016	57	7.96	16	52.44	9.26	16	22.4%	0.51 [-0.19, 1.22]
Yazd2015	49.5	9.95	12	32.08	9.67	12	15.3%	1.71 [0.75, 2.67]
Total (95% CI)			**98**			**93**	**100.0%**	**0.67 [0.22, 1.12]**

Heterogeneity: Tau² = 0.11; Chi² = 6.19, df = 3 (P = 0.10); I² = 52%
Test for overall effect: Z = 2.90 (P = 0.004)

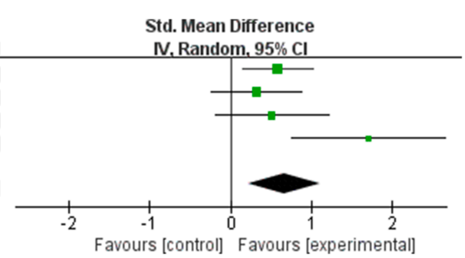

Fig. 8. Forest plot for change in motor skills with ADHD Child.

Study or Subgroup	Experimental Mean	Experimental SD	Experimental Total	Control Mean	Control SD	Control Total	Weight	Std. Mean Difference IV, Random, 95% CI
Benzing2019a	-537	88	9	-607	117	7	8.2%	0.65 [-0.37, 1.67]
Benzing2019b	15.54	3.8	9	14.44	3.92	8	8.4%	0.27 [-0.69, 1.23]
Benzing2019c	-874	156	10	-1,002	290	8	8.5%	0.54 [-0.41, 1.49]
Bustamante2016a	-370	247	9	-292	153	8	8.4%	-0.36 [-1.32, 0.61]
Bustamante2016b	93	8.1	9	92	14	8	8.4%	0.08 [-0.87, 1.04]
Hattabi2019a	-87.55	36.3	10	-105.15	28.37	10	8.7%	0.52 [-0.38, 1.41]
Hattabi2019b	22.8	1.94	10	17.95	0.84	10	6.8%	3.11 [1.72, 4.49]
Kadri2019	58.9	5.9	20	40.1	10.8	20	9.0%	2.12 [1.33, 2.91]
Liu2018	5.25	0.84	32	4.56	0.84	32	9.9%	0.81 [0.30, 1.32]
Memarmoghaddam2016	44.63	1.25	19	42	2.73	19	9.4%	1.21 [0.51, 1.91]
Pan2016	32.13	2.92	16	23.44	2.97	16	8.2%	2.88 [1.85, 3.90]
Silva2020	109	10	10	69.6	9	10	6.0%	3.97 [2.34, 5.59]
Total (95% CI)			**163**			**156**	**100.0%**	**1.22 [0.61, 1.82]**

Heterogeneity: Tau² = 0.89; Chi² = 58.82, df = 11 (P < 0.00001); I² = 81%
Test for overall effect: Z = 3.95 (P < 0.0001)

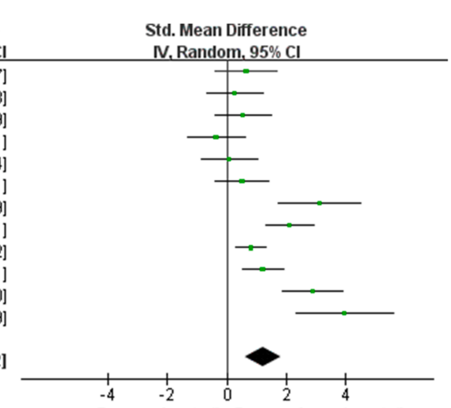

Fig. 9. Forest plot for change in executive function with ADHD Child.

Table 2
Subgroup analysis of executive function.

Overall	Q(df)	I^2(%)	SMD(95% CI)	P
Form of exercise				
open- skill exercise	26.40(7), $p <$ 0.001	73	0.76(0.18,1.34)	=0.01
closed-skill exercise	18.57(3), $p <$ 0.001	84	2.31(0.94,3.68)	=0.001
Session time (minutes)				
Short(≤50 min)	24.41(5), $p <$ 0.001	80	1.25(0.45, 2.06)	=0.002
Moderate(70 min)	-	-	2.88 (1.85, 3.90)	<0.001
Long(90 min)	19.99(4), $p <$ 0.00001	80	0.84(−0.11, 1.78)	=0.08
Frequency(week/ times)				
Low(2 times)	4.42(2), $p = 0.11$	55	2.79 (1.85, 3.72)	$p <$ 0.00001
Moderate(3 times)	13.71(6), $p <$ 0.03	56	0.91 (0.42, 1.40)	=0.0003
High(5 times)	0.40(1), $p = 0.35$	0	−0.13 (−0.81, 0.54)	=0.70
Length				
Short(8–10 week)	24.63(6), $p <$ 0.001	76	0.78 (0.03, 1.52)	=0.04
Moderate(12–14 week)	22.00(3), $p <$ 0.0001	86	1.74(0.53, 2.94)	<0.01
Long(1.5year)	-	-	2.12 (1.33, 2.91)	<0.00001

Table 3
Combined effect after excluding individual studies.

	Culled references	SMD	95% CI	P (Combined effect)	I^2/ %
Depression	García-Gómez et al. (2016)	−0.98	−1.94, −0.01	0.05	75
	Oh et al. (2018)	−0.81	−2.10, 0.49	0.22	81
	Pan et al. (2016)	−0.86	−2.13, 0.40	0.18	80
	Silva et al. (2020)	−0.37	−0.82, 0.09	0.11	0

4. Discussion

Meta-analysis studies have shown that exercise has a significant effect on the motor skills and executive function of children with ADHD (Vysniauske et al., 2020; Liang et al., 2021). Children with ADHD have deficits in both executive function and motor skills. A study by Seiffer et al. pointed out that moderate-intensity physical activity can be used as an alternative therapy for ADHD (Seiffer et al., 2022). A study by Xie et al. showed that physical activity can improve ADHD-related symptoms, especially inattention symptoms (Xie et al., 2021). These studies are consistent with the findings of this paper. Another meta-analysis, however, showed that physical exercise significantly relieved anxiety and depression, aggressive behavior, as well as improve mind-set and social problems in children with ADHD (Zang, 2019), which is inconsistent with the findings of this study. Our study further verifies some of previous studies, but there are different views in previous studies. Therefore, more high-quality researches are needed to identify the best dose relationships in the future. Physical exercise can affect the brain's structural growth and functional neurocognitive development, which in turn has lasting impacts on the development trajectory of ADHD (Berwid and Halperin, 2012). The main reason for cognitive deficits in ADHD children is the dysplasia of the frontal lobe of the brain, which severely hinders the collaborative work of multiple brain areas during cognitive processing. Exercise can ensure sufficient oxygen in each brain area and increase the level of cell metabolism (Jiang and Chen, 2013). Effectively optimize the connection between the brain areas of ADHD children, and also improve the consistency level of their neuronal activation, promote the perfection and development of cognitive function, thereby effectively improving cognitive function (Gunnell et al., 2019). Jensen and Kenny (2004) found that the hyperactivity and impulsive and aggressive behaviors of ADHD children improved after 60 min of yoga performed once a week for 20 weeks Flohr et al. (2004) prescribed low-to-medium-intensity bicycle exercises and found that the core symptoms of ADHD were reduced after exercise intervention. One study demonstrated that swimming can inhibit hyperactivity, impulsivity, and aggressive behavior in a rat model of ADHD while simultaneously alleviating short-term memory impairment. Swimming ameliorates ADHD symptoms by up-regulating dopamine levels and down-regulating dopamine D2 receptor expression (Ko et al., 2013). This is largely consistent with the results of this meta-analysis Silva et al. (2020). performed a study in which ADHD children participated in an 8-week swimming exercise protocol and found that selective attention was significantly improved compared with the control group Ahmed and Mohamed (2011). used a moderate-intensity aerobic exercise intervention (3 times/week for 40 min each time) and found significant improvements in the attention, motor skills, learning, and classroom behavior of ADHD children.

The results of this meta-analysis show that physical exercise can improve attention in this population, which is consistent with previous studies. Regular physical exercise can promote the activity of adrenal hormone receptors, and enhance dopamine and norepinephrine production and secretion, thereby improving concentration. Physical exercise can also help ADHD children process external information, improve coordination between brain regions required for distribution of attention and other specific areas, thereby enhancing attention. The fun and organization of sports activities are also conducive to improving concentration. Impulsive aggression is an unplanned and immediate response that reflects uncontrolled emotions and has negative consequences (Saylor and Amann, 2016). Chen and Cheng (2016) conducted a 16-week Tai Chi intervention on ADHD children and showed that the protocol decreased aggressive behavior to a certain extent Smith et al. (2013). had ADHD children participate in an 8-week sports games training protocol 5 times a week and found that subjects had greater inhibition and control performance on tasks, as well as fewer impulsive and aggressive behaviors. This is consistent with our findings. It may be that regular physical exercise help ADHD children form a directional action pattern, standardize their behavior, and become less impulsive and aggressive.

A growing body of evidence indicates that moderate-intensity aerobic exercise can improve executive function in individuals with ADHD, including improvements in inhibitory control, working memory, and cognitive flexibility (Smith et al., 2013; Chen et al., 2011; Soga et al., 2016; Cai et al., 2021), which is consistent with our findings. Studies have shown that physical exercise can improve ADHD executive function and strengthen attention. The study also found that (≥30 min per day, ≥40% intensity, ≥three days per week, ≥five weeks) can further improve attention, emotional control, etc. (Suarez-Manzano et al., 2018). Studies have shown that both moderate and high-intensity exercise can improve the physical condition of children with ADHD (Jeyanthi et al., 2019). Our findings suggest that closed-skill exercise which lasts 70 min each time, twice a week, and 12–14 weeks is the most beneficial for improving executive function in children with ADHD. Long-term physical exercise can activate the bilateral upper frontal gyrus, bilateral middle frontal gyrus, bilateral temporal lobe, and left inferior temporal lobe, which enhances executive function, whereas left anterior cingulate gyrus activation decreases (Chen et al., 2011). Motivating ADHD children to exercise can have a positive effect on neurocognitive function and inhibition control (Pontifex et al., 2013). Dopamine and norepinephrine play important roles in executive function (Del Campo et al., 2011). Exercise can promote the secretion of these neurotransmitters. Dopamine also has a regulatory effect, thereby reducing behavioral problems and improving executive function in

ADHD children. One study reported (Suarez-Manzano et al., 2018) that it is more conducive to the improvement of brain structure and function when individuals participate in 40% moderate-intensity exercise. With regard to motor skills, our results show that physical exercise can improve motor skills, which is consistent with the findings of a recent systematic review [46] Meßler et al. (2018). found that high-intensity interval training improved the physical fitness and motor skills of ADHD children. Therefore, exercise can help improve their physical fitness and physical and mental development. Judging from our results, physical exercise did not have significant effects on hyperactivity, depression, or social problems, which is slightly different from previous studies. However, after carefully reading the included literature and considering the overall effect sizes, we concluded that physical exercise can improve the symptoms of hyperactivity and depression in ADHD children. The reason for the discrepancies may be related to the small sample sizes and different exercise frequencies and protocols. At present, there are few studies on this topic, and the therapeutic effects of various intervention methods need to be confirmed with high-quality research. Compared with previous studies, this article adds new high-quality RCTs and new outcome indicators such as depression and aggressive behavior. Subgroup analyzes on executive function were also conducted in this paper through intervention duration, exercise frequency and exercise cycle so as to provide solid evidence for the point that physical exercise could relieve the symptoms and executive function among ADHD children. Future research should focus on observing the effects of different forms of physical exercise on the intervention effects of hyperactivity symptoms in ADHD children.

5. Limitations

Our findings should be considered in the context of certain limitations and deficiencies. The authenticity and reliability of the results may be affected by confounding factors such as differences in exercise intervention programs and methodological quality. (1) The included studies in this meta-analysis was only published in Chinese and English, which introduces certain limitations. (2) Few studies specifically described the random allocation concealment and the blinding methods of subjects, researchers, and outcome assessors. (3) The lack of large sample, multi-center, and long-term RCTs may affect the reliability of this meta-analysis. (4) Findings may be subject to different measurement methods, leading to heterogeneous results.

6. Conclusion

On the one hand, physical exercise can effectively improve attention, motor skills, and executive function in children with ADHD with no adverse side-effects compared with drug therapy. On the other hand, physical activity can not significantly improve hyperactivity symptoms, depression, social problems, or aggressive behavior. The results of this meta-analysis provide evidence for the use of long-term physical exercise protocols for this population. It is recommended that future researchers focus on exploring the intervention effects of various physical exercise methods considering the time, period, frequency, and intervention intensity to develop specific exercise programs that ameliorate core symptoms and enhance executive function in ADHD children. In future randomized controlled trials, intensity indicators needs to be added in physical exercise, showing the emphasis of exercise intensity function. At the same time, evidence for the optimal dose-effect relationship between exercise and ADHD should also be added.

Declaration of Competing Interest

The authors report no potential conflicts of interest.

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