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Effects of Characteristics of Physical Activity on Children'S Cognition and Academic Performance Based on the Meta-Analysis

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Abstract: *This meta-analysis was conducted to evaluate the effect of various forms of physical activity on children's cognition and academic performance, detect the characteristics of physical activity that promote the development of the cognitive function, and identify which cognitive dimension benefits the most from characteristic physical activity. We also aimed to distinguish the characteristics of physical activity that promoted non-executive cognitive functions, core executive functions, and metacognition, respectively. Web of Science, PsycINFO, SPORTDiscus, ERIC databases were searched for relevant literature published between 2000 and 2020. The random-effects model was used to calculate the combined effect size (ES) and the corresponding 95% confidence interval (95%CI), and subgroup analysis was performed. I2 statistics were used to evaluate the heterogeneity of each study, with small, medium, and large heterogeneity being represented by < 25%, 25%-50%, and > 50%, respectively. The results showed that acute physical activity had small-to-medium and above-medium positive effects on inhibiting executive function and cognitive flexibility, respectively. However, chronic physical activity had small-to-medium and above-medium positive effects on the working memory of executive function and non-executive cognitive function, respectively. Physical activity with high cognitive effort obviously benefited core executive function, while the non-executive cognitive function was more advanced by aerobic exercise. In addition, an aerobic exercise designed to increase physical strength promoted working memory, while inhibition benefited from cognitively physical activity requiring high cognitive effort (or cognitive engagement). For children aged 6 to 12, regular physical activity exercises that continued for several weeks were more likely to improve multiple cognitive areas, especially the core executive function and non-executive cognitive function, compared to acute exercise intervention, and these effects were affected by the characteristics of physical activity. Third, several weeks of physical activity that required cognitive effort or was cognitively challenging appeared to be more effective in improving cognitive performance than aerobic exercise.*

Keywords: *Physical activity; cognition; academic performance; children; meta-analysis*

1. Introduction

Numerous studies have reported on the benefits of physical activity on cognitive function in children, highlighting the physical activity as a necessary factor for children's growth and integration into the environment [1]. Currently, children are likely to spend far less time per day doing physical activity, both in and out of school, compared to children a decade ago. This substantial increase of time spent on sedentary behavior among children is worrying. Previous studies have shown that, in addition to the obvious benefits of moderate-to-high intensity physical activity for children's physical health [2,3], this type of physical activity is also related to key cognitive function, which may influence academic performance of children. Some studies identified a positive correlation between physical activity and academic performance [4,5]. However, others did not find a significant impact of physical activity on cognition or learning, i.e., no correlation between the two factors [6], or even a negative correlation [7].

Over recent years, the research in this field has gradually expanded from the potential effect of physical activity on cognition and academic performance to explore the influence of physical activity characteristics [8,9]. Physical activity characteristics may have greater benefits in terms of cognitive function due to their inherent cognitive requirements or motor requirements. Therefore, it is of great importance to identify and determine the characteristics of physical activity interventions that could effectively promote cognitive development and the pathways and mechanisms of these effects. Some researchers have suggested that compared with simple aerobic exercise alone aimed at improving

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cardiovascular function, cognitively challenging and cognitively participatory physical activities are more beneficial to cognitive development [10,11]. Cognitive engagement refers to the allocation of attention and the degree of cognitive effort required for completing an activity [12]. For example, compared with sports activities such as long-distance running that involves more repetitive, automated actions and relatively low cognitive participation, tennis requires strategic planning, concentration, and relatively high cognitive engagement, and thus is believed to have a greater impact on executive function. Previous studies have also shown that physical activities that require physical effort, emotional engagement, and social participation challenge core cognitive functions [13], as well as cognitive skills such as goal setting, problem-solving, and self-regulation, considering such cognitive skills depend on the efficiency of core executive functions such as inhibitory control [14]. The relationship and mechanism between physical activity and cognition are receiving widespread attention, including attempts to increase the complexity, creativity, and diversity of physical activity items to affect cognitive function [15].

Although the above-mentioned mechanisms have different potential backed by different reasoning and evidence, it is still not clear if the effect of physical activities on improving children's cognitive functions and academic performance depends on the duration of the physical activity (acute or long-term chronic) or the characteristics of exercise intervention (simple aerobic or cognitive participation). Consequently, we used the effect size to conduct meta-analysis and discuss the possible factors causing inconsistent research results, comprehensively analyze and evaluate existing studies on similar topics, and integrate the results of independent studies to obtain general conclusions.

2. Materials and Methods

In order to reduce publication bias and promote transparency in the research process, the study was registered on the international PROSPERO platform in September 2020, following the PRISMA Guidelines for guidance and evaluation criteria. The details of the specific agreement plan can be accessed at http://www.crd.york.ac.uk/PROSPERO/ to inquire (the registration identification code is CRD42020208173).

2.1 Literature search

In order to avoid selection bias, database search was the main method, supplemented by manual retrieval. First, we conducted a comprehensive and systematic advanced search of the four electronic databases, i.e., Web of Science, PsycINFO, ERIC, and SPORTDiscus, searching for randomized or non-randomized intervention studies investigating the effects of physical activity on children's cognition and academic performance published between 2000 and September 2020.

The search terms included the combination of subject terms and free terms compared with the official thesaurus of the database, which was intervention (physical activity), outcome (cognition and academic performance), research object (children), and research design (intervention studies with various study designs). Finally, it was combined with relevant truncation terms to form a search strategy and used in each electronic database after revision.

2.2 Eligibility criteria

Inclusion criteria were the following: (1) Participants: subjects were physically and mentally healthy children aged 6 to 12, regardless of gender, weight, race, and socioeconomic status. (2) Intervention: intervention content or characteristics refer to the quantity, duration, frequency, pattern, type, and intensity of physical activity, including sports programs or events of physical activity intervention with quantitative or qualitative characteristics. (3) Comparison/Control: studies with appropriate control conditions or control groups. (4) Outcomes: cognitive performance assessment of non-executive cognitive function, core executive function, or metacognition. (5) Study design: empirical studies, with experimental intervention research designs, such as randomized controlled trials, non-randomized controlled trials, or pre - and post-experimental control studies.

Additionally, the following conditions were also considered for the literature to be included: (1) Literature topic: the main study content was on the relationship between physical activity and cognitive function or academic performance, i.e., the included study were those that investigated the influence or relationship between certain types of physical activity and children's cognitive function or academic performance. (2) Measurement tools: the included study needed to report effective measurement tools

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for children's cognitive indicators, as well as effective standardized measures or scores for academic examinations, and provide raw data so that they can be included in the analysis. (3) Data: Since the included literature needed to explore the relationship between any type of physical activity and at least one child's cognitive or learning-related outcome, the relationship was also to be reported with quantitative indicators. (4) Literature features: a one-time scientific journal article written in English and published between 2000 and 2020.

Following are the exclusion criteria: first, studies that included adults were excluded. Also, groups outside the age range of 6 – 12 were excluded. Children with any physical condition or diagnosed cognitive impairment that would impede or limit their ability to participate in a physical activity program were also excluded. (2) The intervention features or measures needed to completely target physical activity and studies involving other healthy behaviors, such as diet or relaxation and meditation training with a low or no physical activity component, were excluded. If data on the effectiveness of physical activity programs on cognitive or academic performance variables could not be separately extracted, studies that combined physical activity with nutritional interventions and other health interventions were excluded. (3) If the measurement method was not clear and the results were not completely reported, the studies were excluded. Also, the data reported by structural equation model, regression analysis, or other statistical methods were excluded. (4) Review articles, organizational guidelines, editorial letters, and expert opinions were all excluded so as to avoid repetition and wrong weighting of documents or publications that tend to be frequently cited or discussed.

2.3 Data extraction and quality assessment

First, the full text of the selected literature was obtained, and the data and descriptive characteristics of each study that met the pre-established inclusion criteria were collected. The extracted details included: publication year; author's country; research characteristics; sample size and age of research participants, including intervention and control group; research design, including intervention conditions and duration of physical activity under control conditions, etc.; the type or task characteristics of physical activity intervention, and the specific plan design of physical activity intervention; major assessment methods or test tools related to cognitive academics, and outcome measures.

Second, since the inclusion criteria of the experimental literature on physical activity intervention in children's cognition and academic performance were mainly based on the PICOS principle of evidence-based medicine, the Cochrane intervention system evaluation system, which is the most authoritative tool in the field of evidence-based medicine, was used to evaluate whether the included literature could produce reliable results for methodological quality assessment of the risk of bias.

2.4 Statistical analysis

2.4.1 Data synthesis and Meta-analysis

In this study, RevMan 5.3 and Stata 15.1 software were used for comprehensive quantitative analysis of the data. Considering the different results and cognitive measurement units used in the study, and the outcome indicators of cognition and academic performance were continuous variables, weighted mean difference (WMD) or standardized mean difference (SMD) before and after the intervention was used for such measurement data, and its 95% confidence interval (95% CI) were calculated as the effect scale of the results. SMD and its 95% CI were used as the effect scale of the results when the measurement unit or test method of each index was different. Conversely, for the remaining outcome measures, WMD and its 95% CI were used as the effect scale of the results. Among them, SMD < 0.2 was mini effect size, $0.2 \leq$ SMD < 0.5 was small effect size, $0.5 \leq$ SMD < 0.8 was medium effect size, and SMD ≥ 0.8 was large effect size. Meanwhile, Hedges'g value was used to adjust the sample size. Hedges'g value was explained by Cohen's criterion to distinguish the small (< 0.2), medium (0.5), and large (> 0.8) effect sizes.

Q test and I2 statistical analysis were used to test heterogeneity among different studies, and $P < 0.05$ was considered statistically significant. Q statistic was used to judge heterogeneity between studies, and I2 value was used to evaluate heterogeneity quantitatively. If $P > 0.01$ and I2 < 50%, it meant that the heterogeneity was acceptable, and the results of multiple similar studies can be considered as homogeneous, and the fixed-effects model was used for meta-analysis; if $P<0.01$, I2$\geq$ 50%, it meant that the heterogeneity among the studies was large.

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2.4.2 Subgroup analysis

In order to further analyze the heterogeneity of effect size and investigate the potential sources of heterogeneity, subgroup analysis was conducted according to classification variables. These categorical variables included intervention model or procedure (such as intervention type, task characteristics), intervention time or duration, and similar. In this study, the types of intervention were divided into: first, extracurricular physical activities, exercises carried out in or outside the school after class and after school; second, in-class physical activities, activities carried out in the physical education class; third, comprehensive physical activities, such as active recess activities or big recess activities, physically active academic courses (embodied learning courses). In terms of task characteristics, the quantitative and qualitative characteristics of physical activity intervention were distinguished and were divided into: enhanced physical activity aimed at increasing the time or intensity of physical activity; and cognitive, a physical activity aimed at increasing the cognitive demands of physical activity tasks.

3. Results

3.1 Research screening

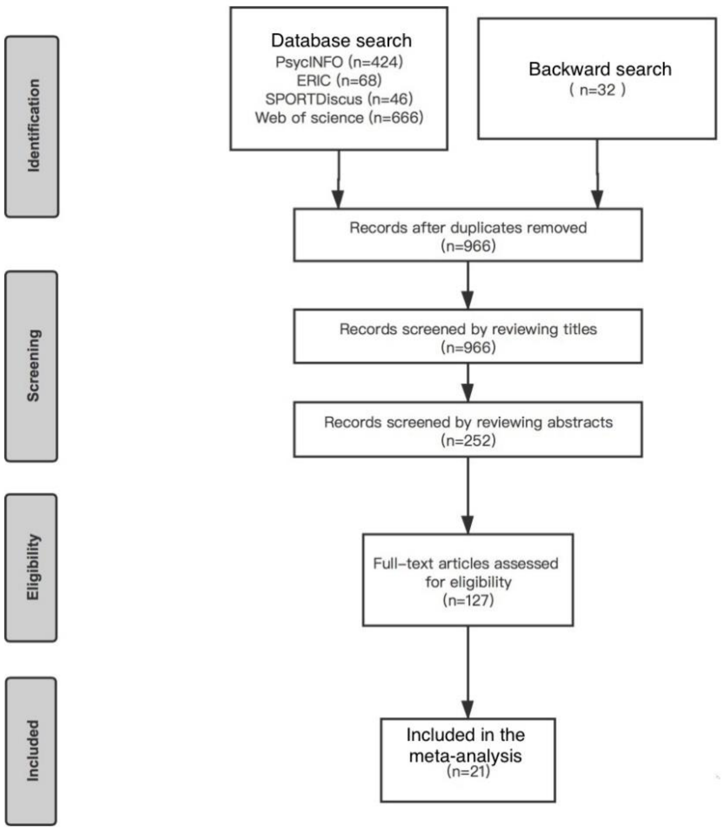

Figure 1: The PRISMA flow chart.

The flow of the research screening process is shown in Figure 1. The search in this study generated 1204 citations from electronic database records. After deleting duplicate content, 966 titles with matching keywords were identified, and 252 published abstracts were further screened. According to inclusion and exclusion criteria, 21 unique citations were finally eligible to be included in this systematic analysis study. The basic information of the included literature, the type and methodological characteristics of the research, the characteristics of the research object, and the outcome measurement indicators of the intervention measures are shown in Table 1.

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Table 1: Characteristics of the included studies

Author	Published years	Country	Intervention duration	Subgroup	Experimentdesign	Sample size (Male: Female)	Sample age	Measurement tool	Outcome indicator	Intervention type
Ahamed et al.	2007	Canada	16 mon	Intervention	RCT	214(107:107)	10.2±0.6	CAT-3	Academic performance	School-based physical activities
				Regular practice		73(36:37)	10.2±0.6			
Alesi et al.	2016	Italy	6 mon	Football	CCT	24(Female)	8.78±1.12	FDS/BDS/CB/TVD/VD/TL	Executive function (refresh/inhibit) Metacognition (plan)	Football practice
				Meditation		20(Female)	9.25±0.85			
Anne et al.	2020	Netherlands	14 wee	Control	RCT	430(219:211)	9.15±0.67	Standardized test	Academic performance (reading/mathematics/spelling)	Physical education
				Aerobic exercise		221(114:117)	9.33±0.64			
				Cognitive Engagement		240(107:133)	9.06±0.60			
Benzing et al.	2016	Switzerland	15 min	Control	Inter-group	21	14.38±1.02	D-KEFS	Executive function (inhibition/cognitive flexibility)	Physical activity based on video games
				"Shape Up"		21	14.61±1.22			
				Running		23	14.52±1.03			
Best et al.	2012	United States	23 min	Low CE Low PA	Intra-group	33(20:13)	8.1±1.3	Flanker	Executive function	Sports videogames
				High CE Low PA						
				Low CE High PA						
				Low CE High PA						
Calvert et al.	2019	United States	10 min	Meditation	Intra-group	40	10.0 - 12.0	DCCS/Flanker/PCT/PSMT	Executive function (inhibition control/cognitive flexibility)	Acute physical activity
				Mild exercise		62				
				Moderate exercise		48				
				Strenuous exercise		46				
Chen	2014	China	30 min	3rd grade control	CCT	17(9:8)	9.12±0.33	Flanker/2-back/More-odd	Executive function (inhibition/working memory/conversion)	Jogging
				3rd grade PA		17(9:8)	9.24±0.44			
				4th grade control		27(14:13)	11.14±0.35			
				4th grade PA		22(9:13)	11.07±0.27			
Cooper	2018	England	60 min	Exercise	RCT	39(20:19)	12.3±0.7	Stroop/Sternberg/TMT	Executive function (working memory)	Basketball
				Rest		39(20:19)	12.3±0.7			
Crova	2013	Italy	6 mon	Enhanced PE	CCT	37(20:17)	9.6±0.5	RNG	Executive function (working memory/inhibition/refresh)	Cognitively challenging physical activities/Physical education
				Course-based PE		33(15:18)	9.6±0.5			
Davis	2007	United States	15 wee	Low dose	CCT	33	9.2±0.84	CAS	Planning/attention/simultaneity and subsequent processing	Aerobic exercise
				High dose		32				
				Control		29				
Egger	2019	Switzerland	20 wee	Combination	Pre-test and post-test experimental design	47(21:26)	7.94±0.40	Reverse color memories/Flanker/Mixed Flanker	Executive function (refresh/inhibit/transition) Academic performance (mathematics/reading/spelling)	Cognitive participatory physical activities between classes
				Aerobic		49(21:28)	7.96±0.36			
				Cognition		46(22:24)	7.82±0.41			
Fisher et al.	2011	England	10 wee	Strong oxygen-consuming	RCT	32	6.1±0.3	CANTAB(SSP/SWM)/CAS	Planning/attention/simultaneity and subsequent	Physical education

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Author	Published years	Country	Intervention duration	Subgroup	Experimentdesign	Sample size (Male: Female)	Sample age	Measurement tool	Outcome indicator	Intervention type
				PE					processing	
				Standardized PE		32	6.2±0.3		Executive function (working memory)	
Greeff	2016	Netherlands	44 wee	Intervention	RCT	249(116:133)	9.0±0.7	Golden Stroop/BDST/VBDST/WCST	Executive function (inhibition/working memory/cognitive flexibility)	physically active academic courses
				Control		250(110:140)	8.2±0.7			
Howie	2015	United States	10 min	Meditation class activity	Intra-group	96(62:34)	10.7±0.6	TMT/Number memories /Mathematical fluency test	Executive function (working memory) Academic performance (mathematics)	Brain BITES activity
				Classroom exercise between classes						
Jäger	2015	Switzerland	20 min	Sports game	CCT	54(19:35)	11.22±0.55	N-back/Flanker/Shifting block Flanker	Executive function (refresh/inhibit/transition)	Game/Running
				Aerobic exercise		62(34:28)	11.27±0.54			
				Cognitive game		60(30:30)	11.35±0.57			
				control		58(25:33)	11.32±0.52			
Kvalø	2016	Norway	10 mon	Intervention	RCT	217	10.0 - 11.0	Stroop/Verbal fluency test /DST/TMT	Executive function (inhibition/working memory/cognitive flexibility)	Physically active academic courses
				Control		212				
Lubans	2018	Australia	12 mon	Intervention	RCT	693(333:660)	12.96±0.56	National examination	Academic performance: Mathematics	School physical Activities
				Control		728(298:430)	12.90±0.52			
Ludyga	2017	Switzerland	8 wee	Exercise	CCT	19(5:14)	12.5±0.7	Stroop	Executive function (inhibition control)	Aerobic and coordinated mixed exercise
				Control		16(8:8)	12.4±0.7			
Mavilidi	2018	Australia	4 wee	TWM-E	CCT	29(15:14)	10.22±0.27	Flanker/n-back/South Australian spelling test / Grammar punctuation test	Executive function (inhibition/working memory) Academic performance (Spelling/Grammar)	PA Embodied learning PA (Thinking While Moving in English program)
				Control		26(14:12)	10.29±0.42			
Riley et al.	2016	Australia	6 wee	Intervention	CCT	142	11.1 ± 0.76	Standardized mathematics progress achievement test	Academic performance: Mathematics	Physical activity integration project
				Control		98	11.1 ± 0.70			
Tottori et al.	2019	Japan	4 wee	HIIT	CCT	27(17:10)	10.0 ± 1.0	DSF/DSB/Tower of Hanoi	Executive function (working memory) Metacognition (plan)	High-intensity interval training (HIIT)
				Control		29(14:15)	10.4 ± 1.1			

Notes: mon = months, wee = weeks, min = minutes, CE = Cognitive Engagement, PA = Physical Activity, PE = Physical Education, RCT = Randomized Controlled Trial, CCT = Controlled Clinical Trail, CAT-3 = Canadian Achievement Test, FDS = Forward Digit Span test, BDS = Backward Digit Span test, CB = Corsi Block Tapping test, TVD = Times of Visual Discrimination, VD = Accuracy of Visual Discrimination, TL = Tower of London task, WCST = Wsiconsin card sorting test, D-KEFS = Delis-Kaplan Executive Function System, DCCS = Dimensional Change Card Sorting, PCT = Pattern Comparison Test, PSMT = Picture Sequence Memory Test, TMT = Trail Making Test, RNG = Random Number Generation Task, CAS = Cognitive Assessment System, CANTAB = Cambridge Neuropsychological Test Battery, SSP = Test of Spatial Memory Span, SWM = Test of Spatial Working

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Memory, BITES = Better Ideas Through Exercise, DST = Digit Span Task, BDST = Backward Digit Span Task, VBDST = Visual Backward Digit Span, TWM-E = Thinking While Moving in English program),DSF = Digit Span Forward test, DSB=Digit Span Backward test.

3.2 Quality assessment

The Cochrane bias risk assessment tool built into the Revman software provided by the Cochrane collaboration organization can provide visual results, as shown in Figure 2. The whole quality evaluation graph consisted of two parts: the percentage of each grade of the quality evaluation graph (Risk of Bias graph) and the grade of a specific item of each study (Risk of bias summary). As shown in the figure, the bias risk assessment tool mainly evaluated the bias risk from the 6 aspects, using 7 items, which were selection bias, including random sequence generation and allocation concealment; performance bias, including blinding of participants and personnel; detection bias, including blinding of outcome assessment; attrition bias, including incomplete outcome data; reporting bias, including selective reporting, and other bias. Different assessment results were made for each item according to the bias risk assessment criteria. Therefore, different colors (green, red, yellow) and symbols (“+”, “—”, “? ”) were used in the figure to indicate “low-risk bias”, “high-risk bias” and “unclear bias” respectively.

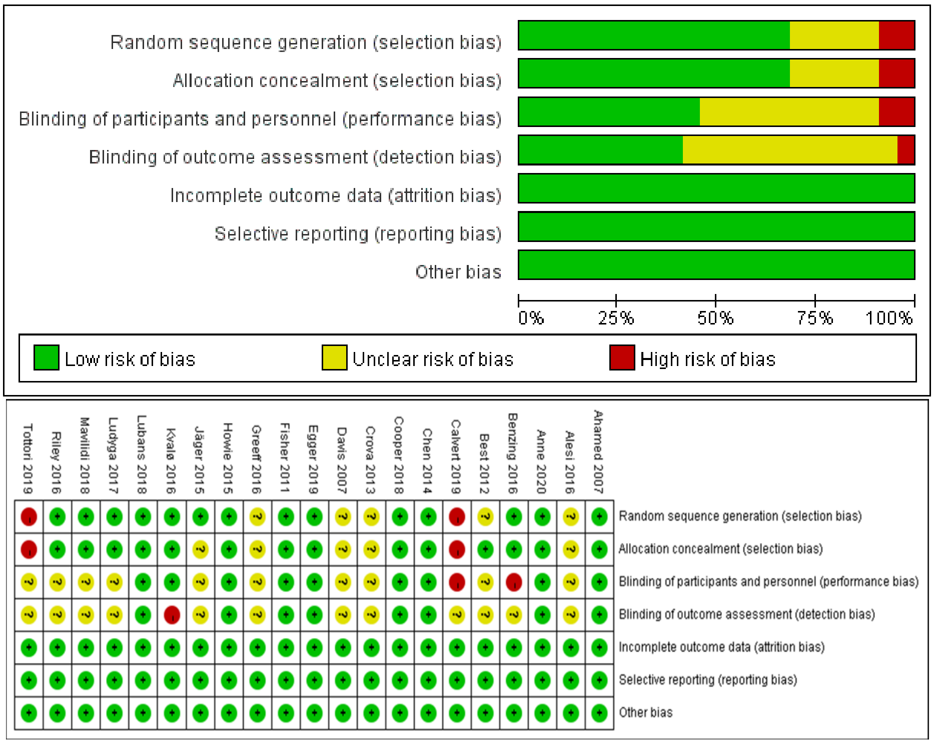

Figure 2: Literature quality evaluation.

3.3 Main results

3.3.1 The influence of an acute physical activity

Among all the studies included in the meta-analysis, 7 studies explored the influence of an acute physical activity on cognitive function or academic performance (I2 = 87%; Q = 217.18; p <0.001), as shown in Table 2. Among these studies, 5 reported positive results for at least one outcome indicator measurement, 1 study reported no significant results, and 1 study reported negative results. In general, an acute physical activity resulted in a small to moderate improvement in cognitive function or academic performance (Hedges’g = 0.27; p = 0.003). No significant effect of acute physical activity on executive function was found (P = 0.085), and there was significant heterogeneity among these studies (I2 = 91%; P < 0.001). Data from the subgroup analysis of each dimension of executive function showed that an acute physical activity had a small to moderate positive effect on inhibitory function (Hedges'g = 0.29; P = 0.044), and a highly positive effect on cognitive flexibility (Hedges'g = 0.71; P < 0.001). No significant effect was found on working memory.

In terms of academic performance, there was no overall significant effect of acute physical activity

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on academic performance (P = 0.148), and the test mainly focused on multiplication calculation problems related to mathematics. Moreover, there were significant differences among studies (I2 = 98%; Q = 204.81; P < 0.001).

Among all studies investigating the effects of an acute physical activity, 9 studies focused on the effects of aerobic exercise alone, which resulted in a small to moderate positive effect (Hedges'g = 0.21; p = 0.011). There were 12 studies that focused on discovering the effects of cognitive participatory physical activities and did not show a significant improvement effect.

Table 2: Meta-analysis results and potential moderators that affected the effects of physical activity on cognition and academic performance

	Meta-analysis effect size			Heterogeneity		
	Hedges' g	95% CI	*p*	I^2	Q	*p*
Acute physical activity	0.27	[0.10,0.47]	0.003**	87.11%	217.18	<0.001***
Executive function	0.19	[-0.03,0.41]	0.085	91.03%	156.02	<0.001***
Inhibition	0.29	[0.01,0.57]	0.044*	97.20%	210.96	<0.001***
Working memory	0.21	[-0.06,0.62]	0.180	96.50%	172.42	<0.001***
Cognitive flexibility	0.71	[0.41,1.01]	<0.001***	46.00%	7.41	0.116
Academic performance						
Mathematics	0.38	[0.10,0.62]	0.148	98.50%	204.81	<0.001***
Task characteristics/Physical activity type						
Aerobic exercise	0.21	[-1.96,-0.26]	0.011*	97.30%	490.45	<0.001***
Cognitive participation	0.16	[-0.31,0.63]	0.502	91.90%	123.74	<0.001***
Long-term physical activities	0.46	[0.11,0.73]	<0.001***	64.92%	48.46	<0.001***
Executive function	0.34	[-0.23,0.92]	0.002*	34.40%	21.21	0.095
Inhibition	0.08	[-0.09,0.25]	0.357	63.70%	27.55	0.002*
Working memory	0.29	[0.10,0.62]	0.037*	58.80%	31.58	0.003*
Cognitive flexibility	0.16	[0.01,0.35]	0.023*	0.00%	0.67	0.716
Non-executive cognitive function	0.89	[0.24,1.54]	0.007*	92.00%	100.37	<0.001***
Metacognition	0.41	[-0.60,1.43]	0.429	94.90%	0.41	<0.001***
Academic performance						
Mathematics	0.05	[-0.13,0.04]	0.307	0.00%	0.12	0.989
Reading	0.15	[-0.15,0.49]	0.226	99.50%	367.18	<0.001***
Language	0.04	[-0.11,0.19]	0.577	0.00%	0.11	0.945
Task characteristics/Physical activity type						
Aerobic exercise	0.26	[0.14,0.47]	0.001**	0.00%	4.65	0.589
Cognitive participation	0.63	[0.12,0.99]	0.006**	62.80%	48.39	<0.001***

Note: CI = confidence interval

*p<0.05，**p<0.01，***p<0.001

3.3.2 The influence of long-term chronic physical activity

A total of 14 included studies implemented longitudinal long-term physical activity exercise programs for children, and explored their influence on cognition and academic performance (I2 = 65%; Q = 48.46; p <0.001). Among these studies, 10 reported positive results in at least one outcome indicator measurement, 4 studies reported no significant findings, and no studies reported negative results. Long-term chronic physical activity programs resulted in overall small to moderate improvements in cognition and academic performance (Hedges' g = 0.46; P≤0.001).

Longitudinal long-term physical activity program had a small to moderate positive effect on executive function (Hedges'g = 0.34; p = 0.002). The examination of the sub-dimensions of executive function revealed that the positive effect of a long-term exercise intervention on working memory was small to moderate (Hedges'g = 0.29; p = 0.037), while a slight positive effect was also found in cognitive flexibility (Hedges'g = 0.16; p = 0.023). However, no significant effect of long-term physical activity program on inhibitory function was found (p = 0.357). In addition, there were 6 studies that focused on the effect of long-term physical activity exercise programs on academic performance, and the heterogeneity in the investigation of the performance of various subjects was mainly reflected in reading (I2 = 99%; Q = 367.18; p < 0.001). However, when further investigating the academic performance of each different subject, longitudinal long-term physical activity did not have a significant effect on mathematics (p = 0.307), reading (p = 0.226), and language learning (p = 0.577).

In the studies focusing on a long-term physical activity exercise plan, the type of physical activity or the characteristics of the exercise task were investigated, and it was found that 3 studies focused on aerobic exercise alone, and 9 studies focused on cognitively participatory physical activities. There were also 2 studies that included both aerobic exercise alone group and cognitively participatory activity group. Small to moderate positive effects were found for aerobic exercise alone (Hedges'g = 0.26; p = 0.001),

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while the effect of cognitive participatory physical activity had moderate to large positive effects (Hedges'g = 0.63; p=0.006).

3.3.3 The influence of the intervention on non-executive cognitive function, executive function, and metacognition

No studies measured improvement in non-executive cognitive function with an acute physical activity intervention. Still, the long-term physical activity plan had a great influence on non-executive cognitive performance, such as non-verbal ability and spatial ability, which did not depend or were only minimally dependent on executive function. The combined effect size of physical activity on non-executive cognitive performance was 0.89 (p = 0.007).

The influence of physical activities on metacognition was mainly reflected in the situation of long-term regular exercise. The analysis of this high-level executive function showed that its combined effect size was 0.41, which indicated that long-term exercise intervention had a moderately positive effect on metacognition.

Task characteristics based on exercise intervention referred to whether physical activity types quantitatively enhanced physical aerobic exercise or qualitatively enriched cognitive participatory physical activity. The analysis showed that the influence of exercise intervention on various cognitive functions was significantly moderated by task characteristics, as shown in Table 3. Core executive function benefited from rich cognitive participatory physical activities (ES = 0.54; p = 0.044), while non-executive cognitive function benefited from aerobic intervention alone (ES = 0.21; p = 0.038), i.e., most of the non-executive cognitive functions were improved to the greatest extent during quantitative aerobic exercise alone. Finally, metacognition representing high-level executive functions could only be improved by enhancing aerobic exercise (ES = 0.19; p = 0.049).

Table 3: Subgroup analysis of task characteristics of exercise or physical activity type on cognition

Task characteristics/Physical activity type	Effect size	95% CI	*p*
Executive function			
Aerobic exercise	0.00	[-0.17,0.17]	0.981
Cognitive participation	0.54	[0.02,1.05]	0.044
Non-executive cognitive function			
Aerobic exercise	0.21	[0.07,0.35]	0.038
Cognitive participation	-	-	-
Metacognition			
Aerobic exercise	0.19	[-0.02,0.40]	0.049
Cognitive participation	-	-	-

Note: CI = confidence interval
*p<0.05, **p<0.01.

In addition, as shown in Table 4, in terms of the sub-functions of core executive functions, working memory was mainly promoted by aerobic exercises that enhanced physical strength (ES = 0.28; p = 0.029), while inhibition control mainly benefited from cognitive participatory physical activity (ES = 0.49; p = 0.037). Any type of intervention could not improve cognitive flexibility.

Table 4: Subgroup analysis of the influence of task characteristics of exercise or physical activity type on executive functions

Task characteristics/Physical activity type	Effect size	95% CI	*p*
Inhibition			
Aerobic exercise	0.30	[0.15,0.45]	0.071
Cognitive participation	0.49	[0.05,0.93]	0.037
Working memory			
Aerobic exercise	0.28	[0.04,0.52]	0.029
Cognitive participation	0.44	[0.05,0.83]	0.716
Cognitive flexibility			
Aerobic exercise	0.19	[-0.02,0.40]	0.311
Cognitive participation	0.16	[0.02,0.31]	0.054

Note: CI = confidence interval
*p<0.05, **p<0.01.

4. Conclusion

This meta-analysis revealed that acute physical activity had limited positive effects on children's cognitive function, and its positive effects were only found in the inhibition of executive function and

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cognitive flexibility, while long-term physical activity had positive effects in the areas of cognitive flexibility and working memory. Overall, acute physical activity did not directly improve executive function. Long-term physical activity intervention was very effective for promoting children's cognitive development, especially the core executive function. In addition, the effects of physical activity on core executive function, non-executive function, and metacognition were moderated by the task characteristics or types of exercise intervention (aerobic exercise alone or cognitive, physical activity). The results showed that continuous cognitive participatory physical activity for several weeks had the greatest benefit. First, compared to acute physical activity, a regular physical exercise intervention plan that continued for several weeks was more likely to improve executive function. Second, in the intervention program of several weeks, cognitively challenging physical activity seemed to be more effective in improving cognitive performance than aerobic activity alone.

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