Postprint of a Meta-Analysis on the Effects of Aerobic Exercise on Executive Function in Overweight and Obese Children

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Abstract

Background: Research has confirmed that executive function in overweight and obese children is closely associated with obesity, and a bidirectional relationship may exist. Aerobic exercise, as an effective intervention, can promote brain development and cognitive function, particularly executive function, but the quantitative relationship of its improvement effects requires further investigation.

Objective: To systematically evaluate the intervention effects of aerobic exercise on executive function-related indicators in overweight and obese children.

Methods: Randomized controlled trials examining aerobic exercise interventions on executive function in overweight and obese children were searched in CNKI, Wanfang Data Knowledge Service Platform, China Biology Medicine Database (CBM), Cochrane Library, PubMed, Embase, and Web of Science from inception to July 2023. The methodological quality of included studies was assessed using the Cochrane risk-of-bias assessment tool, and meta-analysis of outcome measures was conducted using RevMan 5.4 and Stata 16.0 software.

Results: Nine randomized controlled trials involving 940 overweight and obese children were included. Meta-analysis results indicated that a single bout of aerobic exercise could effectively enhance executive function in overweight and obese children (WMD=-6.98, 95%Cl=-11.89~-2.07, P=0.005). Subgroup analysis revealed that aerobic exercise with a single-session duration of <30 min showed no significant improvements in executive function subcomponents in overweight and obese children (WMD=-0.84, 95%Cl=-9.37~7.68, P=0.85), while aerobic exercise with a single-session duration of >30 min could improve inhibitory function (WMD=-10.50, 95%Cl=-19.15~-1.85, P=0.02). During long-term exercise intervention (8-week intervention period), aerobic exercise

improved interference control compared with the control group (WMD=-0.16, 95%Cl=-0.18~-0.14, P<0.000 01), but demonstrated no significant improvement effects on planning (WMD=4.20, 95%Cl=-8.34~16.73, P=0.51), attention (WMD=0.41, 95%Cl=-12.08~12.91, P=0.95), simultaneous processing (WMD=3.93, 95%Cl=-8.22~16.08, P=0.53), or successive processing (WMD=2.48, 95%Cl=-9.18~14.14, P=0.68).

Conclusion: Single-session long-duration aerobic exercise exerts selective positive effects on subcomponents of executive function in overweight and obese children. Long-term aerobic exercise with fixed frequency and duration can improve interference control ability, but produces no improvement effects in planning, attention, simultaneous processing, or successive processing.

Full Text

Meta-analysis of the Effects of Aerobic Exercise on Executive Function in Overweight and Obese Children

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Abstract

Background: Studies have confirmed that executive function in overweight and obese children is closely related to obesity and may involve a bidirectional association. Aerobic exercise, as an effective intervention, can promote brain development and cognitive function, particularly executive function, though the quantitative relationship of these improvements requires further investigation.

Objective: To systematically evaluate the intervention effects of aerobic exercise on executive function-related indicators in overweight and obese children.

Methods: Randomized controlled trials examining aerobic exercise interventions for executive function in overweight and obese children were searched in CNKI, Wanfang Data, CBM, Cochrane Library, PubMed, Embase, and Web of Science databases from inception to July 2023. Literature quality was assessed using the Cochrane Risk of Bias Assessment Tool, and meta-analysis of outcome indicators was performed using RevMan 5.4 and Stata 16.0 software.

Results: Nine randomized controlled trials involving 940 overweight and obese children were included. Meta-analysis showed that a single session of aerobic exercise intervention effectively improved executive function (WMD=-6.98, 95%CI=-11.89 to -2.07, P=0.005). Subgroup analysis revealed that single sessions lasting less than 30 minutes showed no significant differences in improving any executive function subcomponents (WMD=-0.84, 95%CI=-9.37 to

7.68, P=0.85), while single sessions longer than 30 minutes improved inhibitory function (WMD=-10.50, 95%CI=-19.15 to -1.85, P=0.02). For long-term interventions (8-week intervention period), aerobic exercise improved interference control compared with the control group (WMD=-0.16, 95%CI=-0.18 to -0.14, P<0.00001), but showed no significant improvement in planning (WMD=4.20, 95%CI=-8.34 to 16.73, P=0.51), attention (WMD=0.41, 95%CI=-12.08 to 12.91, P=0.95), simultaneous processing (WMD=3.93, 95%CI=-8.22 to 16.08, P=0.53), or successive processing (WMD=2.48, 95%CI=-9.18 to 14.14, P=0.68).

Conclusion: Single long-duration aerobic exercise sessions have selective positive effects on executive function subcomponents in overweight and obese children. Long-term aerobic exercise with fixed frequency and duration can improve interference control ability in overweight and obese children, but does not produce improvements in planning, attention, simultaneous processing, or successive processing.

Keywords: Overweight; Obesity; Child; Executive function; Aerobic exercise; Meta-analysis

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Childhood overweight and obesity have become global health concerns. Over recent decades, the prevalence of overweight and obesity among children has continued to rise in many countries. Research simulating growth trajectories from childhood obesity to adulthood has identified early obesity development as an important predictor of adult obesity. Existing evidence indicates that childhood overweight and obesity are closely associated with mental health, academic performance, and cognitive function, particularly executive function.

Executive function, as a higher-order cognitive process, represents a collection of multiple cognitive functions in the brain, essentially involving the processing, control, and coordination of cognitive processes including inhibition, working memory, cognitive flexibility, reasoning, problem-solving, and planning. Biological studies related to obesity have found that obesity leads to cognitive decline through pathways mediated by inflammation and appetite-regulating hormones, and this association may be bidirectional. Poor executive function may increase obesity risk by reducing self-regulation capacity. Therefore, addressing executive function issues in overweight and obese children is crucial for child health.

Currently, numerous studies have confirmed the beneficial effects of regular aerobic exercise in overweight and obese children, including improvements in physical fitness, motor performance, cognitive ability, and promotion of cognitive-neural development. Deeper research on the effects of aerobic exercise on executive function in overweight and obese populations has found that aerobic exercise can improve executive function by altering brain structure, remodeling white matter integrity, increasing total gray matter and cerebellar gray matter volume, and enhancing overall neural circuit efficiency. Additionally, aerobic exercise can reduce obesity-related pathways that impair executive function in

overweight and obese children and further control body weight. The intervention effects of aerobic exercise on executive function in overweight and obese children show certain dose-response relationships. Previous studies have indicated that increasing exercise duration and intensity dosage affects executive function in overweight and obese children.

Given the complexity of the relationship between aerobic exercise and executive function in overweight and obese children, and the controversy regarding dose-response relationships, this study employs meta-analysis to provide an objective systematic evaluation of existing research results, aiming to offer scientific exercise protocols for preventing and improving executive function in overweight and obese children, and to provide evidence-based support for aerobic exercise research in this domain.

Methods

1.1 Literature Search This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Computerized searches were conducted in CNKI, Wanfang Data, CBM, Cochrane Library, PubMed, Embase, and Web of Science databases from inception to July 2023. English search terms included: "Aerobic exercise," "Overweight," "Obesity," "Child," and "Executive Function." Chinese search terms included: "有氧运动" (aerobic exercise), "超重" (overweight), "肥胖" (obesity), "儿童" (child), and "执行功能" (executive function). The literature search strategy for the PubMed database is shown in Table 1 .

1.2 Inclusion and Exclusion Criteria **1.2.1 Inclusion Criteria:** (1) Study design: Only randomized controlled trials were included; (2) Participants: Overweight and obese children; (3) Intervention: The experimental group received aerobic exercise as the sole intervention, while the control group received different aerobic exercise protocols or no intervention; (4) Outcome measures: Executive function (and its sub-functions including inhibitory function, updating function, and shifting function), cognitive abilities, and executive function in children' s daily life.

1.2.2 Exclusion Criteria: (1) Non-randomized controlled trials; (2) Studies where full text could not be obtained to extract valid outcome data; (3) Studies where valid outcome data could not be extracted; (4) Duplicate publications; (5) Conference abstracts.

1.3 Data Extraction Two researchers independently reviewed the full text of included articles and extracted required information including first author name and publication year, sample size, intervention protocol, and outcome indicators.

1.4 Literature Quality Assessment Two researchers assessed the quality of included literature using the Cochrane Risk of Bias Assessment Tool, which

includes six items: random sequence generation, allocation concealment, blinding, completeness of outcome data, selective reporting, and other sources of bias. Each item was rated as low risk, high risk, or unclear risk. Disagreements between the two researchers were resolved by a third researcher.

1.5 Statistical Analysis Meta-analysis was performed using Stata 15.0 and RevMan 5.4 software. Since all outcome measures were continuous variables, weighted mean difference (WMD) was used when measurement tools and units were identical, while standardized mean difference (SMD) was used to eliminate dimensional effects when they differed, with 95% confidence intervals (CI) as the effect size indicator. Heterogeneity was assessed using the ^{2} test (significance level P=0.05), and I^2 and P values were calculated to evaluate the magnitude of heterogeneity among studies. If I^2<50% and P$ 0.1, $indicating low heterogeneity, a fixed-effects model was used; otherwise, a random-effects model was employed (I^{2} $50% and P<0.1), with further investigation of heterogeneity sources. Funnel plots were drawn for outcome indicators, and Egger' s test was used to assess publication bias. P<0.05 was considered statistically significant.

Results

2.1 Literature Screening Process and Results The initial search yielded 1,574 relevant articles from the databases. After removing duplicates, 979 articles remained. After reading titles and abstracts, 78 articles remained. Finally, 9 articles [18-19, 21-27] were included. The specific screening process is shown in Figure 1 [Figure 1: see original paper].

2.2 Basic Characteristics of Included Studies Among the 9 included studies, 7 were in English [18-19, 21-27] and 2 were in Chinese [23-24], involving a total of 940 overweight and obese children. Regarding outcome measures, 3 studies [22-24] used the Flanker task to report inhibitory control, 2 studies [23-24] used N-Back and More-odd shifting tasks to report working memory and shifting function, 2 studies used the Stroop task to report interference control [18, 25], 1 study [26] used the Wisconsin Card Sorting Test (WCST) to report executive function, 2 studies used the Cognitive Assessment System (CAS) to report executive function, and 1 study [27] used the d2 Test of Attention-Revised (d2-R test) to report attention. The basic characteristics of included studies are shown in Table 2 .

2.3 Methodological Quality Assessment Results The modified Jadad scale was used to assess seven aspects of methodological quality. Regarding randomization methods, 9 studies [18-19, 21-27] described the method for generating random sequences; non-random allocation was rated as high risk, and lack of description as unclear. For allocation concealment, 2 studies [19, 22] strictly implemented allocation concealment; otherwise, they were rated as high risk or

unclear if insufficient information was available. Regarding blinding, due to the nature of intervention studies, double-blinding of participants and researchers was impossible, so all 9 studies [18-19, 21-27] were rated as unclear risk. For completeness of outcome data, 8 studies [19, 21-27] completely reported data for all indicators, with missing outcome data not affecting intervention effects; otherwise, they were rated as high risk or unclear if not explicitly reported. Regarding selective reporting, 8 studies [18-19, 21, 23-27] had available study protocols or published reports that included expected outcomes, rated as low risk; otherwise, they were rated as high risk or unclear if insufficient information was available. For other sources of bias, 1 study [18] had a small sample size and was rated as high risk. The specific risk of bias assessment is shown in Figure 2 [Figure 2: see original paper] and Figure 3 [Figure 3: see original paper].

2.4 Effects of Aerobic Exercise on Executive Function in Overweight and Obese Children 2.4.1 Overall Effects on Executive Function: Among the 9 included studies, 3 [22-24] detailed the effects of aerobic exercise on executive function in overweight and obese children. Two of these measured executive function subcomponents [23-24]. Heterogeneity among studies was low (I^2=0, P=0.75), so a fixed-effects model was used. The results showed that compared with the control group, single-session aerobic exercise significantly improved executive function in overweight and obese children (WMD=-6.98, 95%CI=-11.89 to -2.07, P=0.005), as shown in Figure 4 [Figure 4: see original paper].

Based on current results and characteristics of included literature, subgroup analysis was performed to evaluate the effect of intervention duration on outcomes. Subgroup analysis showed that single 20-minute sessions (duration <30 minutes) of aerobic exercise produced no significant improvement in executive function subcomponents in overweight and obese children. Single 40-minute sessions (duration >30 minutes) improved inhibitory function (WMD=-10.50, 95%CI=-19.15 to -1.85, P=0.02). Meta-analysis results for other subcomponents are shown in Table 3 .

Due to different measurement instruments, Krafft' s study was not pooled with the other two for analysis. Qualitative description of the results revealed that aerobic exercise had a clear improving effect on executive function in overweight and obese children [22].

2.4.2 Effects on Interference Control: Two studies [18, 25] used the Stroop task to report results for color-word incongruent conditions. Heterogeneity among studies was relatively high (I^2=52%, P=0.06), so a random-effects model was used. The results showed that compared with the control group, aerobic exercise effectively improved interference control ability in overweight and obese children (WMD=-0.16, 95%CI=-0.18 to -0.14, P<0.00001), as shown in Figure 5 [Figure 5: see original paper].

2.4.3 Effects Assessed by CAS: Two studies [19, 21] used the CAS mea-

surement tool to report the effects of aerobic exercise on executive function in overweight and obese children from four aspects: planning, attention, simultaneous processing, and successive processing. Heterogeneity was low (I^2=0, P=1.00), so a fixed-effects model was used. The results showed that compared with the control group, aerobic exercise did not significantly improve planning (WMD=4.20, 95%CI=-8.34 to 16.73, P=0.51), attention (WMD=0.41, 95%CI=-12.08 to 12.91, P=0.95), simultaneous processing (WMD=3.93, 95%CI=-8.22 to 16.08, P=0.53), or successive processing (WMD=2.48, 95%CI=-9.18 to 14.14, P=0.68), as shown in Figure 6 [Figure 6: see original paper].

Subgroup analysis was conducted based on intervention duration to explore the dose-response relationship of aerobic exercise. The results showed that both low-dose and high-dose long-term moderate-intensity aerobic exercise interventions had no significant effect on planning, attention, simultaneous processing, or successive processing (P>0.05), as shown in Table 4 .

2.4.4 Effects Assessed by WCST and d2-R Test: One study each used the WCST and d2-R test, so only qualitative analysis was performed. CHEN et al. [26] found that 3 months of aerobic exercise, in addition to improving obesity and physical condition, was beneficial for improving the shifting component of executive function. GALLOTTA et al. [27] found that 5 months of school-based aerobic physical activity significantly improved attention in obese children.

2.5 Publication Bias Analysis Due to the small number of included studies, funnel plots were drawn and Egger' s test was performed only for literature reporting executive function, interference control, and CAS measures, as shown in Figure 7 [Figure 7: see original paper]A, B, C. Egger' s test results showed: for executive function, t=-3.27, P=0.006, indicating some publication bias likely due to small sample sizes; for interference control, t=-68.48, P<0.001, indicating some publication bias possibly due to different methods used; for CAS executive function, t=1.98, P=0.068, indicating no significant publication bias.

Discussion

Childhood overweight and obesity have become a global epidemic [28]. Obesity, as a chronic disease, leads to reduced quality of life and increased risk of premature death. Additionally, it is an important predictor of cognitive impairment, accelerated cognitive decline, and dementia [29]. In this context, many studies have explored the possible link between overweight/obesity and executive function [30]. Executive function is generally considered a higher cognitive process that enables goal-directed action and plays an extremely important role in daily life and mental health. It is crucial for resisting bad habits, automatic behaviors, and temptations, achieving goals, adapting to conflicting situations, and maintaining healthy body weight [31]. Research has found that declines in executive function are an important cause of overweight and obesity in children, and differences in executive function may affect lifestyle habits, making individuals susceptible to overweight. Lower executive function may be significantly associ-

ated with some dysfunctional eating behaviors [8, 32]. Numerous studies have confirmed the beneficial effects of intervention training on executive function in obese children [33-36], with aerobic exercise being widely used as an effective training method [37]. This study searched relevant literature domestically and internationally, ultimately including 9 randomized controlled trials involving 940 overweight and obese children.

Meta-analysis results showed that single short-duration aerobic exercise had selective effects on improving executive function in overweight and obese children, but single short-duration exercise interventions did not produce significant effects on inhibition, shifting, or updating functions. In contrast, single long-duration or long-term fixed-frequency and fixed-duration aerobic exercise showed better improvement effects on executive function.

The selective improvement effect of single short-duration aerobic exercise on executive function subcomponents in overweight and obese children may be related to the types of exercise items and the frequency of switching between exercises during training, which is consistent with SHUKLA' s research [38]. Furthermore, studies have found that long-term regular aerobic exercise can improve inhibitory function, consistent with previous research [33]. In the two studies using the Stroop measurement tool, aerobic exercise intervention showed significant improvement in color-word incongruent conditions, indicating that aerobic exercise can effectively improve interference control ability in overweight and obese children. ZHANG et al. [12] used the Stroop measurement tool and found that acute high-intensity interval exercise and high-intensity continuous exercise are likely effective exercise methods for promoting cognitive function and inhibitory function in overweight and obese children, corroborating our findings.

In WCST assessments, CHEN et al. [26] used moderate-intensity brisk walking, stair climbing, aerobic dance, and rope skipping as exercise protocols. After 3 months of intervention, statistical analysis found reduced non-perseverative error rates in the WCST. GUO et al. [33] used moderate-intensity games, rope skipping, running, and combat exercises as protocols. After 5 weeks of intervention, statistical analysis found significant improvements in all 13 WCST indicators, consistent with our included study results. Additionally, physical activity has a positive effect on improving attention in overweight and obese children. GALLOTTA et al. [27] conducted the d2-R attention test after 5 months of intervention, finding that participants' attention performance was significantly affected by time and that coordinative training intervention had the most significant effect on improving attention in overweight and obese children. CHOU et al. [25] used a determination test method in situations with continuous but rapidly changing acoustic and optical stimuli and found that 8 weeks of exercise game intervention based on baseball and basketball, conducted 3 times per week, could improve attention function performance in overweight and obese children. However, DAVIS et al. [21] found through CAS test indicator comparisons that aerobic exercise of the same intensity but different duration doses had no signifi-

cant effect on various CAS test indicators, consistent with our subgroup analysis results. Further analysis suggests this may be related to the type of exercise modality used in the study, and future research should explore optimal exercise methods for improving attention in overweight and obese children.

Other studies have found dynamic changes in cognitive improvement from aerobic exercise [40], which may be related to the degree of executive function impairment in overweight and obese children, while targeted aerobic exercise modalities still require further research.

Aerobic exercise affects brain function and executive function in overweight and obese children. LOGAN et al. [37] randomly assigned overweight and obese children to physical activity intervention and control groups and had them complete tasks manipulating inhibitory control. By evaluating changes in task performance and neural electrical intervention before and after, they found that 9 months of physical activity intervention could maintain neural electrical amplitude and prevent its decline, thereby demonstrating the benefits of physical activity intervention for cognitive and brain health in obese children. Long-term regular aerobic exercise causes changes in brain structure, leading to changes in brain cells and molecules that contribute to neural plasticity, releasing neurotrophic factors. Neurons in the hippocampus can obtain sufficient nutrition to increase their volume and ultimately enhance memory and cognitive function [41-42]. Research has found that short-term moderate-intensity exercise creates positive changes in brain activation patterns for executive function, leading to increased bilateral prefrontal activation levels in children when completing functional tasks, indicating that short-term exercise intervention can affect children' s executive function and underlying neural networks [19]. Short-term exercise leads to immediate release of neurotransmitters (dopamine, serotonin), hormones (norepinephrine, growth hormone), and other chemicals. Our results show that short-term moderate-intensity aerobic exercise has improving effects on executive function, consistent with previous research [43-44].

This study has several limitations: (1) The included studies had relatively small sample sizes, which may affect the results; (2) The included aerobic exercise interventions lacked follow-up studies, so it is unclear whether delayed effects exist between aerobic exercise intervention and executive function; (3) Only Chinese and English literature was included, which may produce result bias.

In summary, aerobic exercise has positive effects on improving executive function in overweight and obese children. Single aerobic exercise interventions have selective improving effects on executive function subcomponents. Subgroup analysis of single-session aerobic exercise duration found that interventions longer than 30 minutes were superior to those shorter than 30 minutes. Additionally, long-term aerobic exercise with fixed frequency and duration can improve interference control ability in overweight and obese children, but does not produce improving effects on planning, attention, simultaneous processing, or successive processing. This study integrates data from numerous independent studies using meta-analysis, improving the reliability and generalizability of conclusions.

Compared with single studies, meta-analysis can provide more precise effect size estimates, providing a solid foundation for future research hypotheses and study design. At the theoretical level, this study enriches the research field of executive function, particularly regarding childhood obesity. From a practical perspective, this study indicates that aerobic exercise, as a non-pharmacological intervention, may have positive effects on improving executive function in overweight and obese children, providing educators, mental health professionals, and parents with a simple, low-cost, and sustainable intervention strategy. In conclusion, this study not only strengthens the importance of aerobic exercise in promoting children' s physical and mental health but also provides a practical and feasible solution to address the global challenge of childhood obesity, which has far-reaching significance for future health promotion and disease prevention efforts.

Author Contributions: Zhao Rui was responsible for topic selection, design, and manuscript writing, and takes overall responsibility for the article; Chen Leqin was responsible for evaluation and guidance; Wu Yini was responsible for data collection and organization; Li Qianqian was responsible for table preparation.

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Note: Figure translations are in progress. See original paper for figures.