

## Effects of Exercise Modalities on Executive Function in Overweight or Obese Children and Adolescents: A Network Meta-Analysis Postprint

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### Abstract

Background: Compared with healthy-weight individuals, overweight or obese children and adolescents often exhibit executive function deficits, which may exacerbate overweight/obesity and induce other diseases. Exercise has been proven to promote executive function, but the relative merits of different exercise modalities require further investigation. Objective: To explore the optimal exercise modality for improving executive function in overweight or obese children and adolescents. Methods: Databases including CNKI, Wanfang Data Knowledge Service Platform, Cochrane Library, PubMed, Embase, and Web of Science were searched to collect randomized controlled trials of exercise interventions on executive function in overweight or obese children and adolescents, with the search period from database inception to October 2024. Two independent researchers conducted literature screening and data extraction. RevMan 5.4 and Stata 18.0 software were used for network meta-analysis, with standardized mean difference (SMD) and its 95% CI as effect measures to compare differences among exercise modalities and calculate the surface under the cumulative ranking curve (SUCRA) values for ranking. The Cochrane risk-of-bias assessment tool was used for risk-of-bias evaluation, and Egger's test was conducted for publication bias analysis. Results: A total of 10 Chinese and English articles were included, involving 675 overweight or obese children and adolescents aged 8-15 years. The outcome measures were inhibitory control, working memory, and cognitive flexibility. For improving inhibitory control, compared with the no-exercise group, physical education games (SMD=-1.75, 95%CI=-2.83~-0.68,  $P<0.05$ ), ball sports (SMD=-1.93, 95%CI=-3.87~-0.10,  $P<0.05$ ), and physical fitness training (SMD=-1.20, 95%CI=-2.40~-0.05,  $P<0.05$ ) all significantly improved inhibitory control levels in overweight or obese children and adolescents, with ball sports having the largest SUCRA value and ranking first. For improving working memory in overweight or obese children and adolescents, ball

sports (SMD=-1.02, 95%CI=-1.68~-0.36,  $P<0.05$ ) were superior to physical fitness training. For improving cognitive flexibility in overweight or obese children and adolescents, ball sports (SMD=-1.22, 95%CI=-1.90~-0.54,  $P<0.05$ ) were superior to physical fitness training. Conclusion: Compared with other exercise modalities, ball sports demonstrate relatively superior effects in improving executive function in overweight or obese children and adolescents. In practical intervention processes, the synergistic combination of ball sports with intensity, duration, frequency, and volume should be considered comprehensively. Future research should further enrich evidence related to executive function improvement in overweight or obese children and adolescents to develop more precise and efficient exercise prescriptions.

## Full Text

### Preamble

#### **Evidence-Based Medicine: A Network Meta-Analysis of Exercise Modalities for Improving Executive Function in Overweight or Obese Children and Adolescents**

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### Abstract

**Background:** Overweight or obese children and adolescents exhibit executive function deficits compared to healthy-weight populations, which may exacerbate obesity and predispose individuals to other diseases. While exercise has been shown to promote executive function, the relative merits of different exercise modalities require further investigation.

**Objective:** To identify the optimal exercise modality for improving executive function in overweight or obese children and adolescents.

**Methods:** We searched China National Knowledge Infrastructure (CNKI), Wanfang Data, Cochrane Library, PubMed, Embase, and Web of Science databases for randomized controlled trials of exercise interventions targeting executive function in overweight or obese children and adolescents from database inception to October 2024. Two independent researchers conducted literature screening and data extraction. Network meta-analysis was performed using RevMan 5.4 and Stata 18.0 software, with standardized mean difference (SMD)

and 95% confidence interval (CI) as effect measures. We compared differences among exercise modalities, calculated cumulative ranking probability area under the curve (SUCRA) values, and ranked interventions. Risk of bias was assessed using the Cochrane tool, and publication bias was evaluated with Egger' s test.

**Results:** Ten Chinese and English-language studies involving 675 overweight or obese children and adolescents aged 8–15 years were included. Outcome measures included inhibitory control, working memory, and cognitive flexibility. For inhibitory control improvement, sports games (SMD=-1.75, 95%CI=-2.83 to -0.68,  $P<0.05$ ), ball sports (SMD=-1.93, 95%CI=-3.87 to -0.10,  $P<0.05$ ), and physical training (SMD=-1.20, 95%CI=-2.40 to -0.05,  $P<0.05$ ) all significantly improved inhibitory control compared to no-exercise controls, with ball sports achieving the highest SUCRA value and ranking first. For working memory improvement, ball sports (SMD=-1.02, 95%CI=-1.68 to -0.36,  $P<0.05$ ) were superior to physical training. For cognitive flexibility improvement, ball sports (SMD=-1.22, 95%CI=-1.90 to -0.54,  $P<0.05$ ) were also superior to physical training.

**Conclusion:** Compared to other exercise modalities, ball sports demonstrate superior effects in improving executive function in overweight or obese children and adolescents. Practical interventions should consider the synergistic combination of ball sports with intensity, duration, frequency, and volume. Future research should strengthen the evidence base to develop more precise and effective exercise prescriptions.

[**Key words**] Overweight; Obesity; Executive function; Child; Adolescent; Exercise; Network meta-analysis

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## Introduction

Childhood and adolescent obesity represents a critical public health concern. In China, the obesity rate among children aged 7–17 years increased dramatically from 0.2% to 7.9% between 1980 and 2020. Overweight and obesity in children and adolescents are associated with increased risks for numerous diseases, including insulin resistance, diabetes, and cardiovascular disease. Accumulating evidence indicates that overweight or obese children and adolescents exhibit widespread deficits in executive function. Executive function comprises higher-order cognitive processes that generate coordinated, goal-directed behaviors, encompassing three core components: inhibitory control, working memory, and cognitive flexibility. Inhibitory control refers to the ability to regulate attention, behavior, thoughts, and emotions to overcome strong internal predispositions and external temptations. Deficient inhibitory control renders individuals more

susceptible to impulsivity, habitual responses, and environmental influences. Working memory involves the capacity to maintain and manipulate information over short periods, which is closely related to self-control and behavior guidance. Stronger working memory helps resist short-term unhealthy dietary temptations and establish long-term healthy behaviors. Cognitive flexibility denotes the ability to maintain or shift attention according to demands, emphasizing flexible switching between multiple tasks and behavioral responses, and is built upon the other two core components. It is associated with stress resilience and creativity in daily life. Low executive function, particularly poor inhibitory control and working memory, can trigger obesity-related behaviors such as reduced physical activity and disordered eating patterns, and may also lead to attention deficit disorders, depression, anxiety, and cardiovascular disease. Improving executive function in overweight or obese children and adolescents is beneficial for weight management and disease prevention.

Numerous studies have confirmed that exercise can improve executive function in overweight or obese children and adolescents, focusing on investigating the effects of different exercise modalities, intensities, and durations. Increased physical activity benefits executive function, with moderate-intensity exercise showing optimal effects on inhibitory control and working memory, while cognitive flexibility improvement requires moderate-to-high intensity interventions. Intervention duration, frequency, and session length all exert selective effects on inhibitory control, working memory, and cognitive flexibility. Research has demonstrated that exercise modality significantly affects executive function test performance, with open-skill sports showing better effects than closed-skill sports. Physical activities incorporating high cognitive demands and open environments are more conducive to executive function development. One study found that soccer practice with multiple cognitive tasks produced greater executive function improvements than conventional soccer training. However, the relative effectiveness of different exercise modalities remains inconclusive. Therefore, this study employed network meta-analysis to compare the effects of different exercise modalities on executive function (inhibitory control, working memory, and cognitive flexibility) in overweight or obese children and adolescents, aiming to identify the optimal exercise modality and provide evidence-based recommendations.

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## Methods

This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. We searched CNKI, Wanfang Data, Cochrane Library, PubMed, Embase, and Web of Science databases for literature published from database inception to October 2024. English search terms included “Executive Function,” “Overweight,” “Obesity,” “Child,” “Teenager,” and “Exercise.” Chinese search terms included “运动” (exercise), “超重” (overweight), “肥胖” (obesity), “儿童” (child), “青少年” (adolescent), and “执行功能” (executive

function). A fuzzy search strategy was employed using Boolean logic operators “AND” to connect subject terms. The PubMed search strategy is detailed in .

### 1.2.1 Inclusion Criteria

1. Study population: overweight/obese children and adolescents
2. Intervention duration: \$ \$4 weeks
3. Study design: randomized controlled trials
4. Intervention: exercise-based
5. Outcome measures: the three core executive function components (inhibitory control, working memory, cognitive flexibility, or alternative terminologies such as inhibition, updating, and shifting)

### 1.2.2 Exclusion Criteria

1. Cross-sectional and review studies
2. Studies with unavailable or incomplete data
3. Conference papers
4. Duplicate publications or studies with unclear or redundant data

### 1.3 Literature Screening and Data Extraction

After completing the literature search, two independent researchers conducted screening and data extraction using EndNote software to remove duplicates. Disagreements were resolved by a third researcher through discussion. Extracted data included first author, publication year, sample size, age, intervention details, duration, frequency, and outcome measures. Interventions were categorized based on the provided protocols.

### 1.4 Quality Assessment

Study quality was evaluated using the Cochrane risk of bias assessment tool in RevMan 5.4, covering six domains: selection bias, performance bias, detection bias, attrition bias, reporting bias, and other biases. Each domain was rated as low risk, unclear risk, or high risk.

### 1.5 Statistical Analysis

Network meta-analysis was conducted using RevMan 5.4 and Stata 18.0. Continuous outcomes were pooled using standardized mean difference (SMD) and 95%

confidence interval (CI). Global and local inconsistency tests were performed to assess direct and indirect comparisons across exercise modalities. When direct and indirect comparisons showed consistency ( $P > 0.05$ ), a consistency model was adopted. Effect sizes and 95% CIs were interpreted, and interventions were ranked by SUCRA values (higher values indicating better effects). Due to insufficient study numbers for working memory and cognitive flexibility outcomes, meta-analysis was not performed; only effect size calculations and narrative synthesis were conducted. Publication bias was assessed using Egger's test, with significance set at  $\alpha = 0.05$ .

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## Results

### 2.1 Literature Screening Process and Results

The initial search yielded 1,520 records (CNKI:  $n=24$ , Wanfang:  $n=35$ , Cochrane Library:  $n=602$ , PubMed:  $n=263$ , Web of Science:  $n=411$ , Embase:  $n=185$ ). After deduplication, 1,255 records remained. Following title and abstract screening, 60 articles were retrieved for full-text review. After excluding 50 ineligible studies, 10 studies were finally included (2 Chinese, 8 English). The screening process is illustrated in [Figure 1: see original paper].

The total sample size across the 10 included studies was 675 overweight or obese children and adolescents, aged 8-15 years. Basic characteristics of included studies are presented in . For outcome measures, nine studies reported inhibitory control, four reported cognitive flexibility, and four reported working memory. Based on the provided intervention protocols, exercise modalities were categorized into four groups plus a no-exercise control: sports games, ball sports, martial arts practice, physical training, and no-exercise control .

### 2.3 Risk of Bias Assessment

The Cochrane tool was used to assess seven bias domains across the 10 included studies. All studies described random sequence generation methods (low risk). Only two studies described allocation concealment, while the remainder provided insufficient information. Regarding blinding, only one study implemented double-blinding; two studies blinded participants, and two blinded outcome assessors. Seven studies reported complete outcome data, two had incomplete information, and one had missing data (high risk). All studies reported planned outcomes without other bias sources (low risk). Overall, the included studies carried some potential bias risk, primarily in blinding of intervention protocols, likely due to the nature of exercise interventions.

#### 2.4.1 Network Relationship and SUCRA Ranking for Inhibitory Control

The network diagram showed a closed loop among physical training, no-exercise control, and sports games. Most studies directly compared no-exercise control versus sports games and physical training versus sports games. SUCRA ranking based on effect sizes and probability sorting revealed the following order for improving inhibitory control in overweight or obese children and adolescents: ball sports (SUCRA=82.8) > sports games (SUCRA=80.4) > physical training (SUCRA=50.6) > no-exercise control (SUCRA=16.3) > martial arts practice (SUCRA=14.5) [Figure 4: see original paper].

#### 2.4.2 Effects of Different Exercise Modalities on Inhibitory Control

Nine studies evaluated inhibitory control. Compared to no-exercise control, sports games (SMD=-1.75, 95%CI=-2.83 to -0.68,  $P<0.05$ ), ball sports (SMD=-1.93, 95%CI=-3.87 to -0.10,  $P<0.05$ ), and physical training (SMD=-1.20, 95%CI=-2.40 to -0.05,  $P<0.05$ ) all significantly improved inhibitory control. No significant difference was found between martial arts practice and no-exercise control ( $P>0.05$ ). Pairwise comparisons among other exercise modalities showed no statistically significant differences ( $P>0.05$ ) [Figure 5: see original paper].

#### 2.5 Direct Comparisons for Working Memory and Cognitive Flexibility

For working memory improvement, ball sports (SMD=-1.02, 95%CI=-1.68 to -0.36,  $P<0.05$ ) were superior to physical training; no significant difference was found between sports games and physical training ( $P>0.05$ ). For cognitive flexibility improvement, ball sports (SMD=-1.22, 95%CI=-1.90 to -0.54,  $P<0.05$ ) were superior to physical training; no other pairwise comparisons showed significant differences ( $P>0.05$ ) [Figure 6: see original paper].

#### 2.6 Consistency and Publication Bias Analysis

Global and local inconsistency tests for inhibitory control showed no significant inconsistency across studies ( $P>0.05$ ). Further consistency testing of the closed loop yielded 95%CI=0.00-3.89, indicating good consistency; therefore, a consistency model was adopted. Egger's test revealed no evidence of publication bias ( $T=0.18$ ,  $P>0.05$ ).

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## Discussion

The positive effects of exercise on executive function have been well-established. However, the relative superiority of different exercise modalities remains unclear. This network meta-analysis compared the effects of various exercise modalities

on executive function (inhibitory control, working memory, cognitive flexibility) in overweight or obese children and adolescents. We found that sports games, ball sports, and physical training all effectively improved executive function, consistent with previous research. Mechanistically, regular long-term exercise can alter brain structure, enhance plasticity, and strengthen activation in brain regions associated with cognitive performance, such as the dorsolateral and ventrolateral prefrontal cortex and anterior cingulate cortex. Exercise-induced adaptive changes in cortical regions involved in cognitive tasks may underlie these improvements. Additionally, exercise promotes increases in norepinephrine and brain-derived neurotrophic factor (BDNF), which benefit executive function. In this study, long-term martial arts practice showed a non-significant trend for improving inhibitory control, possibly because the included martial arts interventions lacked cognitively challenging tasks, unpredictable environmental information, and complex movements, resulting in insufficient brain region activation.

Our findings indicate that ball sports are the optimal modality for improving inhibitory control in overweight or obese children and adolescents compared to other exercise types. Recent evidence suggests open-skill sports produce more significant executive function improvements than closed-skill sports. Studies have shown that moderate-intensity ball sport interventions effectively enhance inhibitory control, and meta-analyses indicate ball sports may be the best approach for improving inhibitory control in children with attention deficit hyperactivity disorder. Our results align with this evidence, strongly supporting ball sports as a superior modality for inhibitory control improvement. Ball sports incorporate more information stimuli and complex movement elements than sports games or physical training, which may explain their superior effects. At the molecular level, ball sports induce greater brain adaptive changes, including higher BDNF concentrations, increased hippocampal volume, and neurogenesis in cerebellar and cerebral cortices. Ball sports also more effectively activate relevant brain regions and strengthen inter-regional connectivity, with greater gray and white matter volume increases in the dorsolateral prefrontal cortex, hippocampus, and cerebellum, thereby more effectively improving inhibitory control.

For working memory and cognitive flexibility, ball sports demonstrated superior effects compared to physical training, consistent with previous evidence. However, our findings contradict some studies that found no significant effects of ball skill training on cognitive flexibility, possibly due to differences in study populations (learning-disabled children vs. typically developing children). The high cognitive demands and complex movements in ball sports may be less suitable for learning-disabled populations. Ball sports also provide greater enjoyment and positive emotions, promoting dopamine release, which may contribute to their superior effects over physical training. The cognitive tasks involved in ball sports may further enhance working memory and cognitive flexibility, though some meta-analyses have found mixed results for cognitively challenging sports games, possibly due to differences in inclusion criteria, populations, and inter-

ventions.

Based on dose-response analyses, meta-analyses, and systematic reviews, we provide evidence-based recommendations for using ball sports to improve executive function in overweight or obese children and adolescents. For exercise modality, we recommend basketball or tennis practice for inhibitory control improvement. For intensity, moderate-to-high intensity is recommended for inhibitory control, while moderate intensity is suggested for working memory and cognitive flexibility. For dosage, we recommend 8-12 weeks, 2-3 sessions per week, 30-60 minutes per session. These recommendations consider both weight loss benefits and exercise enjoyment, as weight reduction itself improves executive function. This provides a low-cost, practical recommendation for educators, parents, health practitioners, and guideline developers.

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## Limitations and Future Directions

This study has several limitations. First, including only peer-reviewed, full-text Chinese and English literature may introduce publication and language bias. Second, the limited number of included studies prevented dose-response analyses and meta-regression to determine optimal exercise prescriptions, which may introduce methodological bias. Future research should increase focus on exercise interventions specifically for overweight or obese children and adolescents, as this population exhibits executive function deficits that, when improved, benefit weight management and disease prevention. Third, classification of exercise modalities based on original study protocols may involve some subjectivity, though we conducted internal discussions to minimize bias. Future studies should further validate these recommendations. Fourth, the small number of included studies limits the ability to conduct large-scale meta-analyses to establish dose-response curves and identify minimum effective thresholds or optimal dosage ranges for this population. Additionally, the included studies carry potential bias risks, particularly in blinding and allocation concealment, which should be addressed in future research.

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## Conclusion

Compared to other exercise modalities, ball sports demonstrate superior effects in improving executive function in overweight or obese children and adolescents. Ball sports show particular advantages for inhibitory control, working memory, and cognitive flexibility. These findings support the development of targeted health promotion prescriptions for this population.

**Author Contributions:** QUAN Jialin was responsible for conceptualization, design, and writing; ZHU Lin provided overall guidance, evaluation, and manuscript review; SU Yu contributed to manuscript review; CHEN Zekai

contributed to manuscript review and data evaluation; CHEN Ziqi and ZHANG Zhuofan contributed to data collection, organization, and evaluation.

**Conflict of Interest:** The authors declare no conflict of interest.

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

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