INPLASY

INPLASY202610036

doi: 10.37766/inplasy2026.1.0036

Received: 12 January 2026

Published: 12 January 2026

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Comparative effects of different exercise modalities on executive function in children with attention-deficit/ hyperactivity disorder: a systematic review and network meta-analysis protocol

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ADMINISTRATIVE INFORMATION

Support - No financial support or sponsorship has been received for this systematic review protocol. This review is being conducted as an independent academic research project without external funding.

Review Stage at time of this submission - Completed but not published.

Conflicts of interest - The authors declare no conflicts of interest, financial or non-financial, related to this systematic review. None of the authors have competing interests that might unduly influence judgments made in this review.

INPLASY registration number: INPLASY202610036

Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 12 January 2026 and was last updated on 6 March 2026.

INTRODUCTION

Review question / Objective The aim of this systematic review and network meta-analysis is to compare the effectiveness of different exercise modalities on executive function outcomes in children and adolescents with attention-deficit/hyperactivity disorder to better inform evidence-based non-pharmacological interventions. To this end, the proposed systematic review will address the following research question: Which exercise modality is most effective for improving executive function domains including working memory, inhibitory control, and cognitive flexibility in children and adolescents with ADHD when compared to other exercise interventions and control conditions? Secondary questions include determining whether treatment effects vary by age group, exercise supervision level, intervention duration, or specific executive function domain measured.

Rationale Attention-deficit/hyperactivity disorder affects approximately 5-7% of children worldwide and is characterized by persistent patterns of inattention, hyperactivity, and impulsivity that significantly impact academic, social, and behavioural functioning. Executive function deficits, including impaired working memory, inhibitory control, and cognitive flexibility, represent core neurocognitive features of ADHD that contribute substantially to functional impairment. While pharmacological interventions remain the primary evidence-based treatment, growing interest exists in non-pharmacological approaches, particularly exercise interventions, which show promise for improving both ADHD symptoms and underlying executive function deficits.

Recent systematic reviews have demonstrated that exercise interventions can improve executive function in children with ADHD, with effect sizes ranging from moderate to large across different domains. However, existing reviews primarily focus on comparing exercise to control conditions rather than comparing different types of exercise interventions directly. This creates a critical gap in understanding which specific exercise modalities may be most beneficial for improving executive function outcomes. Current evidence includes studies of aerobic exercise, resistance training, coordinative activities, mind-body interventions such as yoga and tai chi, cognitively engaging exercises like table tennis, and high-intensity interval training approaches.

The heterogeneity in exercise interventions studied makes it challenging for clinicians, educators, and families to make informed decisions about which type of physical activity program would be most beneficial for a specific child with ADHD. Network meta-analysis provides a powerful analytical approach to address this question by combining direct and indirect evidence to estimate the relative effectiveness of multiple interventions simultaneously. This approach will enable ranking of different exercise modalities and provide robust evidence to guide clinical practice guidelines and school-based intervention programs. Furthermore, understanding whether treatment effects vary by participant characteristics such as age, baseline severity, or intervention characteristics such as supervision level and duration will provide crucial information for personalizing exercise interventions for children with ADHD. This systematic review addresses identified gaps in current clinical practice guidelines, which provide limited specific guidance on exercise interventions despite growing evidence of their efficacy.

Condition being studied Attention-deficit/hyperactivity disorder is a neurodevelopmental condition characterized by persistent patterns of inattention, hyperactivity, and impulsivity that are inconsistent with developmental level and significantly impair functioning across multiple settings. The condition typically manifests in early childhood and affects academic performance, social relationships, and behavioral regulation. Executive function deficits represent core features of ADHD, encompassing difficulties with working memory (the ability to hold and manipulate information in mind), inhibitory control (the capacity to suppress inappropriate responses), and cognitive flexibility (the ability to shift between different mental sets or adapt to changing rules). These executive function impairments contribute significantly to the academic and social challenges experienced by children with ADHD and represent important intervention targets that may be responsive to exercise interventions.

METHODS

Search strategy The formal systematic database search was executed on 1 December 2025. All four databases PubMed, Scopus, Web of Science Core Collection, and SPORTDiscus) were searched on this date, covering publications from January 2010 to 1 December 2025. Earlier searches conducted prior to this date were preliminary scoping exercises used to inform the development of search strategies and eligibility criteria; they did not constitute the formal systematic search and were not used for study selection or data extraction.

Studies published between 1 December 2025 and the submission date of this review were not systematically searched and may not be captured in the review findings. This represents a limitation that is acknowledged in the manuscript.

PubMed search strategy: ((("Attention Deficit Disorder with Hyperactivity"[MeSH] OR "attention deficit hyperactivity disorder"[tiab] OR "ADHD"[tiab] OR "attention-deficit/hyperactivity disorder"[tiab] OR "hyperkinetic disorder"[tiab])) AND (("Executive Function"[MeSH] OR "executive function*"[tiab] OR "working memory"[tiab] OR "cognitive flexibility"[tiab] OR "inhibitory control"[tiab] OR "attention control"[tiab] OR "cognitive control"[tiab])) AND (("Exercise"[MeSH] OR "Physical Fitness"[MeSH] OR "Sports"[MeSH] OR "exercise"[tiab] OR "physical activity"[tiab] OR "aerobic"[tiab] OR "resistance training"[tiab] OR "strength training"[tiab] OR "yoga"[tiab] OR "tai chi"[tiab] OR "martial arts"[tiab] OR "coordinative"[tiab] OR "motor skill*"[tiab])) AND (("Child"[MeSH] OR "Adolescent"[MeSH] OR "child*"[tiab] OR "adolescent*"[tiab] OR "pediatric"[tiab] OR "paediatric"[tiab])) AND (("Randomized Controlled Trial"[PT] OR "Controlled Clinical Trial"[PT] OR "randomized"[tiab] OR "controlled"[tiab] OR "trial"[tiab]))

Similar strategies will be adapted for Scopus, Web of Science, SPORTDiscus, and PubMed using appropriate controlled vocabularies and database-specific syntax. Grey literature searching will include ProQuest Dissertations and Theses, clinical trial registries including ClinicalTrials.gov and WHO International Clinical Trials Registry Platform, and conference proceedings from relevant professional organizations. Reference lists of included studies and relevant systematic reviews will be hand-searched to identify additional eligible studies.

Participant or population The target population includes children and adolescents aged 6 to 18 years with a clinical diagnosis of attention-deficit/hyperactivity disorder established using standardized diagnostic criteria including DSM-IV, DSM-5, or ICD-10/11 criteria. Participants may represent any ADHD presentation including predominantly inattentive, predominantly hyperactive-impulsive, or combined presentation. Studies including participants with comorbid conditions such as learning disabilities, anxiety disorders, or oppositional defiant disorder will be eligible provided that ADHD represents the primary diagnosis.

Studies will be excluded if they include participants with intellectual disability, autism spectrum disorder, or other neurodevelopmental conditions as primary diagnoses, as executive function profiles and treatment responses may differ substantially in these populations. Studies including mixed populations of participants with and without ADHD will be included only if results are reported separately for the ADHD subgroup or if at least 80% of participants have confirmed ADHD diagnoses.

Participants may be receiving concurrent pharmacological treatment for ADHD provided that medication status is stable during the intervention period or is appropriately controlled in the study design. Studies will not be restricted based on setting, geographical location, or socioeconomic status to enhance generalizability of findings.

Intervention Exercise interventions of interest include structured physical activity programs designed to improve fitness, motor skills, or mind-body awareness that are delivered over multiple sessions with specified frequency, intensity, and duration parameters. Eligible intervention categories include aerobic exercise programs such as running, cycling, or swimming; resistance or strength training involving weights, resistance bands, or bodyweight exercises; coordinative training focusing on motor skill development, balance, and coordination; mind-body interventions including yoga, tai chi, qigong, or martial arts; cognitively engaging physical activities such as exergaming, table tennis, or dance; high-intensity interval training protocols; and multimodal programs combining different exercise types.

Interventions must be structured with clear protocols regarding frequency, duration, and intensity rather than general recommendations for increased physical activity. Single-session acute exercise studies will be excluded in favour of chronic training interventions delivered over multiple weeks to assess sustained effects on executive function. Interventions may be delivered in various settings including schools, clinical facilities, community centres, or home environments and may involve individual or group formats with varying levels of supervision.

Comparator Eligible comparators include other structured exercise interventions, attention control conditions, wait-list control groups, treatment as usual, or no intervention conditions. Studies comparing different exercise modalities head-to-head will be particularly valuable for network meta-analysis. Control conditions that provide attention and social interaction equivalent to exercise interventions will be preferred over passive controls to minimize non-specific effects.

Studies using active control conditions such as sedentary activities, educational programs, or standard physical education classes will be included. Comparisons with pharmacological interventions alone will be excluded unless combined with behavioural or educational components, as the focus of this review is on non-pharmacological intervention approaches.

Study designs to be included This review will include randomized controlled trials and controlled clinical trials with concurrent control groups that evaluate exercise interventions in children and adolescents with ADHD. Randomized controlled trials will be prioritized as they provide the highest quality evidence for intervention effectiveness. Controlled clinical trials using quasi-randomization or systematic allocation methods will be included if they otherwise meet eligibility criteria and provide adequate control for selection bias.

Crossover studies will be eligible provided that adequate washout periods are included between intervention phases and that baseline executive function measures are available for each phase. Cluster randomized trials conducted in school or clinic settings will be included with appropriate statistical handling of clustering effects in the analysis.

Single-group pre-post studies, case series, and observational studies will be excluded as they do not provide adequate control for confounding variables or natural developmental changes in executive function. Conference abstracts will be excluded unless sufficient methodological detail is available to assess study quality and extract necessary data for meta-analysis.

Eligibility criteria Inclusion criteria: Studies will be included if they meet all of the following criteria: participants are children or adolescents aged 6-18 years with clinically diagnosed ADHD using standardized criteria; interventions involve structured exercise programs delivered over

multiple sessions; study design is a randomized controlled trial or controlled clinical trial with concurrent controls; outcomes include validated measures of executive function domains; and studies provide sufficient statistical information to calculate effect sizes and standard errors.
Exclusion criteria: Studies will be excluded if participants include adults over 18 years of age; primary diagnoses include intellectual disability, autism spectrum disorder, or other neurodevelopmental conditions; interventions consist of single exercise sessions or unstructured physical activity recommendations; study designs are observational without concurrent control groups; outcomes focus solely on ADHD symptoms without executive function measurement; studies are published before 2010; studies are published in languages other than English; or insufficient statistical information is provided for meta-analysis inclusion.
Language restrictions will be imposed, with only studies published in English included in this review. Publication date restrictions will be applied, limiting inclusion to studies published from 2010 onwards to focus on contemporary exercise intervention approaches and executive function assessment methods. Studies will not be excluded based on geographical location, setting, or sample size provided they meet other eligibility criteria.

Information sources Electronic database searches were conducted in four databases: PubMed, Scopus, Web of Science Core Collection, and SPORTDiscus. These databases were selected to provide comprehensive and complementary coverage of the medical, sport science, and exercise science literature relevant to the research question. PubMed provides broad coverage of the biomedical and clinical literature; Scopus offers interdisciplinary coverage across health sciences and psychology; Web of Science Core Collection ensures access to high-impact peer-reviewed research across disciplines; and SPORTDiscus provides specialised indexing of exercise science, physical activity, and sports medicine literature. Together, these four databases encompass the primary publication venues for research on exercise interventions and executive function in paediatric ADHD populations.
Embase, PsycINFO, and Cochrane Central Register of Controlled Trials, which were listed in the original protocol, were not searched in the final review. This decision was made on practical grounds following a preliminary scoping of the literature, which indicated that the four databases selected provided sufficient coverage of the relevant literature without substantial additional yield from the remaining sources. This represents a deviation from the registered protocol and is acknowledged as a limitation.
Subject matter experts in pediatric ADHD and exercise science will be contacted to identify unpublished or ongoing studies that may meet inclusion criteria. Authors of included studies may be contacted to request additional data or clarify methodological details as needed for the analysis.

Main outcome(s) The primary outcomes are executive function measures assessed using validated neuropsychological tests or standardized rating scales. Executive function domains of interest include working memory measured by tasks such as the Digit Span, Spatial Span, or n-back tasks; inhibitory control assessed using measures such as the Stroop Test, Go/No-Go tasks, or Stop Signal Task; and cognitive flexibility evaluated using tasks such as the Wisconsin Card Sorting Test, Trail Making Test, or Task Switching paradigms.
Both performance-based neuropsychological measures and behavioral rating scales such as the Behavior Rating Inventory of Executive Function will be included as primary outcomes. Timing of outcome assessment must occur immediately post-intervention or within four weeks of intervention completion to capture proximal effects of exercise training. Studies must provide sufficient statistical information including means, standard deviations, and sample sizes or effect sizes with confidence intervals to be included in quantitative synthesis.

Additional outcome(s) Secondary outcomes include ADHD symptom severity measured using standardized rating scales such as the ADHD Rating Scale, Conners' Rating Scales, or Vanderbilt Assessment Scales; academic performance indicators including standardized achievement test scores or teacher ratings of academic functioning; behavioral outcomes such as on-task behavior, classroom behavior ratings, or social skills assessments; physical fitness measures including cardiovascular fitness, strength, or motor skills; and longer-term follow-up assessments of executive function or ADHD symptoms conducted more than four weeks post-intervention.
Quality of life measures, parent and teacher satisfaction with interventions, and adverse events or safety outcomes will also be extracted when reported. These secondary outcomes will provide important context for interpreting executive function findings and understanding the broader impact of exercise interventions on functioning in children with ADHD.

Data management Study selection will be conducted independently by two reviewers using standardized eligibility criteria with disagreements resolved through discussion or consultation with a third reviewer when necessary. Screening will be conducted in two phases including initial title and abstract screening followed by full-text review of potentially eligible studies.

Data extraction will be performed independently by two reviewers using standardized forms developed specifically for this review and piloted on a sample of included studies. Extracted data will include study characteristics, participant demographics and clinical characteristics, intervention details, comparison conditions, outcome measures and assessment timing, and statistical results. Authors will be contacted to request missing data or clarify methodological details when necessary.

Data will be managed using EPPI-Reviewer software for systematic review management and Zotero for reference management. Statistical analyses will be conducted using R software with the netmeta package for network meta-analysis and validated using MetaInsight web-based software for sensitivity analyses. All data extraction forms and statistical analysis code will be made publicly available to enhance transparency and reproducibility.

Quality assessment / Risk of bias analysis Methodological quality of included studies will be assessed independently by two reviewers using the revised Cochrane Risk of Bias tool for randomized trials (RoB 2) with domain-specific considerations for exercise intervention studies. Assessment domains include bias arising from the randomization process, bias due to deviations from intended interventions, bias due to missing outcome data, bias in measurement of outcomes, and bias in selection of reported results.

Particular attention will be paid to challenges inherent in exercise intervention research including difficulty blinding participants and intervention providers, potential for performance bias related to expectation effects, and selective outcome reporting especially given the multiple executive function measures commonly used in this population. Assessment of outcome measurement bias will consider whether assessors were blinded to group allocation and whether objective versus subjective outcome measures were used.

Overall quality of evidence for network meta-analysis will be evaluated using the GRADE approach adapted for network meta-analysis, considering study limitations, inconsistency, indirectness, imprecision, and publication bias. Confidence in network meta-analysis results will be assessed for each treatment comparison considering both direct and indirect evidence contributing to effect estimates.

Strategy of data synthesis Network meta-analysis was conducted using a Bayesian random-effects approach implemented in MetaInsight (version 4.0), with the netmeta and metafor packages in R (version 4.3.1) used for supplementary analysis and sensitivity checks. This represents a methodological refinement from the frequentist-primary approach described in the original protocol; both approaches were explored and yielded consistent results.

Network meta-analysis was feasible for only one primary outcome, inhibitory control accuracy, which was the only domain meeting the minimum threshold of ten studies with sufficient network connectivity ($k = 14$). The remaining primary outcomes (inhibitory control reaction time: $k = 9$ with sparse connectivity; working memory accuracy: $k = 8$; cognitive flexibility accuracy: $k = 5$) and secondary outcomes (ADHD symptoms: $k = 5$; motor performance: $k = 5$) did not meet the required threshold for robust network estimation. For these outcomes, conventional pairwise random-effects meta-analyses were conducted instead in RevMan Web. This deviation from the original protocol reflects the actual state of the available evidence rather than a change in analytical intent, and is acknowledged as a key limitation of the review.

Standardized mean differences will be calculated as the primary effect measure for continuous executive function outcomes, with random-effects models used to account for expected heterogeneity between studies. Network geometry will be examined through network plots showing all treatment comparisons and their connections.

Statistical heterogeneity will be assessed using I-squared statistics and tau-squared estimates. Network inconsistency will be evaluated using design-by-treatment interaction models and net heat plots to identify potential sources of inconsistency within the network. Treatment rankings will be generated using P-scores as frequentist analogues to surface under the cumulative ranking curves.

Pairwise meta-analyses will be conducted for treatment comparisons with sufficient direct evidence to complement network meta-analysis results. Missing data will be handled according to intention-to-treat principles when possible, with sensitivity analyses exploring the impact of different missing data assumptions on results.

Subgroup analysis Pre-specified subgroup analyses were conducted for two moderators where sufficient studies were available: (i)

participant age group (children aged 6–12 years vs. adolescents aged 13–18 years) and (ii) total exercise dosage, operationalised as the product of intervention duration (weeks), session frequency (sessions per week), and session length (minutes), classified as short (2,880 minutes). Subgroup analyses were performed in RevMan 5.4 and were restricted to the inhibitory control accuracy outcome, which was the only domain with sufficient studies.

Subgroup analyses by supervision level and medication status were not conducted due to insufficient variability and incomplete reporting across included studies. These represent deviations from the original protocol and are acknowledged as limitations. All subgroup comparisons were evaluated using chi-squared tests with a significance threshold of $p < 0.10$, and results are interpreted with caution given the small number of studies in each subgroup and the observational nature of such comparisons.

Sensitivity analysis Multiple sensitivity analyses will be conducted to assess the robustness of primary findings. These will include restricting analyses to studies with high methodological quality defined by low risk of bias ratings; excluding studies with high dropout rates exceeding 20% to assess the impact of missing data; comparing fixed-effects versus random-effects models to evaluate the influence of between-study heterogeneity assumptions; and excluding outlying studies with effect sizes exceeding three standard deviations from the pooled estimate.

Additional sensitivity analyses will examine the impact of different outcome measurement approaches by separating performance-based neuropsychological tests from behavioural rating scales, and restricting analyses to studies using blinded outcome assessment when feasible. Network meta-analysis results will be compared with pairwise meta-analysis results for treatment comparisons with adequate direct evidence to assess consistency between approaches.

Language restriction Language restrictions will be imposed on the literature search, with only studies published in English included in this systematic review. This decision was made to ensure feasibility of the review process given resource constraints while recognizing that the majority of high-quality research in this field is published in English-language journals. This approach may introduce some language bias but is necessary for practical implementation of the review.

Country(ies) involved China.

Other relevant information This systematic review protocol has been developed according to PRISMA-P guidelines for systematic review protocols and will be reported according to PRISMA-NMA guidelines for network meta-analysis. The review findings will inform evidence-based recommendations for clinical practice guidelines and school-based intervention programs serving children with ADHD.

Results will be disseminated through peer-reviewed publication, conference presentations, and knowledge translation materials for clinicians, educators, and families. All study materials including search strategies, data extraction forms, and statistical analysis code will be made publicly available through online repositories to enhance transparency and enable replication.

Keywords ADHD; attention-deficit hyperactivity disorder; executive function; exercise; physical activity; children; adolescents; network meta-analysis; systematic review.

Dissemination plans

Results of this systematic review and network meta-analysis will be disseminated through multiple channels to maximize impact on research, clinical practice, and policy. Primary dissemination will occur through publication in a high-impact peer-reviewed journal focusing on paediatrics, ADHD, or exercise medicine. The manuscript will be submitted to an open-access journal when possible to enhance accessibility.

Conference presentations will be delivered at relevant scientific meetings including paediatric, ADHD, and exercise science conferences to reach diverse professional audiences. Knowledge translation materials will be developed for clinicians, educators, and families including plain language summaries, clinical practice recommendations, and implementation guidance for school-based programs.

Findings will be shared with clinical practice guideline developers and professional organizations to inform evidence-based recommendations for non-pharmacological ADHD interventions. Social media and press releases will be used to enhance public engagement and awareness of research findings.

Contributions of each author

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