

Research Progress on Physical Exercise Interventions for Executive Function in Children and Adolescents with Autism Spectrum Disorder

Yuanyuan Liu^{1,2}

¹School of Educational Science, Jiangsu Normal University, Xuzhou, China

²Zhuxiang School of Futian District, Shenzhen, China

Email: 2693371736@qq.com

How to cite this paper: Liu, Y. Y. (2026). Research Progress on Physical Exercise Interventions for Executive Function in Children and Adolescents with Autism Spectrum Disorder. *Open Journal of Social Sciences*, 14, 292-322.

<https://doi.org/10.4236/jss.2026.144017>

Received: March 3, 2026

Accepted: April 14, 2026

Published: April 17, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.

This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

The executive dysfunction theory posits that individuals with autism spectrum disorder (ASD) exhibit deficits in executive function (EF), adversely affecting their individual development, school readiness, and academic achievement. Emerging evidence suggests that physical exercise can effectively improve EF in children with ASD. This article systematically reviews studies on physical exercise interventions for EF in children and adolescents (aged 3 - 18 years) with ASD. Existing interventions are categorized into five types based on exercise modality: ball sports, martial arts, combat sports, acute exercise, and game-based exercise. Through an age-stratified analysis of research evidence within each category, this review elucidates the current state, efficacy, and limitations across different developmental stages (preschool, school-age, and adolescence). The underlying neural mechanisms are also discussed, aiming to provide a comprehensive understanding of the progress in exercise-based EF interventions for ASD and inform the development of early motor intervention strategies.

Keywords

Physical Exercise, Autism Spectrum Disorder (ASD), Executive Function, Intervention

1. Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder emerging in early childhood, characterized by core deficits in social interaction and commu-

nication, restricted interests, and repetitive or atypical behaviors ([American Psychiatric Association, 2013](#)). The prevalence of ASD continues to rise globally. An updated systematic review of global prevalence studies published between 2012 and 2021 indicates a median global prevalence of approximately 1%, exceeding 2% in some high-income countries ([Zeidan et al., 2022](#)). In 2025, using big data from the Beijing Municipal Health Commission, Chinese scholars reported an ASD prevalence of 10.5/1000 (approximately 1.05%) among six-year-old children, a figure generally consistent with international levels ([Zhao et al., 2025](#)). To date, the etiology of autism remains unclear, and the increasing prevalence underscores the growing importance of early intervention for ASD.

Executive function (EF) refers to a set of interrelated higher-order cognitive abilities required for goal-directed behavior, including inhibitory control, working memory, and cognitive flexibility. Its development spans childhood, progressing most rapidly during the preschool years ([Diamond, 2013](#)). In preschool-aged children, EF primarily encompasses self-regulation, inhibitory control, working memory, and cognitive flexibility ([Rodger et al., 2022](#)). Research has demonstrated that EF development is closely related to children's individual development, school readiness, and academic achievement ([Cirino et al., 2018](#)), with EF positively predicting performance in early school readiness domains such as arithmetic, literacy, and reading ([Zelazo, 2015](#)). The executive dysfunction theory suggests that children with ASD exhibit underdeveloped EF compared to their typically developing peers ([Hill, 2004](#)). Meta-analytic studies indicate that EF deficits are prevalent in the ASD population ([Demetriou et al., 2018](#); [Macoun et al., 2021](#)). Damasio and Maurer were among the first to suggest that children with autism might have EF deficits ([Ezema et al., 2023](#)), based on observed behavioral similarities between individuals with autism and patients with vestibular system damage. Subsequently, numerous studies have validated this perspective ([Ruggeri et al., 2021](#); [Dijkhuis et al., 2021](#); [Lai et al., 2017](#); [Wang et al., 2022](#)).

A growing body of research indicates that EF plays a significant role in the development of children with ASD. On one hand, EF influences the development of core autistic symptoms ([Fernandez-Prieto et al., 2021](#); [Hodgdon et al., 2022](#); [Torske et al., 2018](#); [Zimmerman et al., 2020](#)); on the other hand, it also affects other developmental aspects such as school readiness and adaptive functioning ([Pellicano et al., 2017](#); [Patrick et al., 2020](#)). Therefore, interventions targeting EF deficits in ASD may positively impact overall development ([Ameis et al., 2020](#)). The multi-path theoretical model posits that physical exercise interventions can promote EF development in children through four pathways: improving physiological states, enhancing motor skill levels, developing situational interaction abilities, and improving psychological states ([Chen et al., 2021](#)). Physical activity (PA) refers to any bodily movement requiring energy expenditure and the demonstration of fundamental motor skills ([Rafiei Milajerdi et al., 2021](#)). Research suggests that PA is an effective form of intervention for EF in ASD ([Fang et al., 2019](#); [Trott et al., 2022](#); [Pan et al., 2017](#); [Liang et al., 2022](#); [Varigonda et al., 2020](#)). Furthermore,

Ludyga et al. (2021) found that EF in individuals with ASD is closely related to their muscular strength, further supporting previous findings.

To systematically understand the progress of research on PA interventions for EF in ASD, this paper systematically reviews domestic and international studies from the past decade on different types of PA interventions targeting EF in children and adolescents with ASD. Based on a classification by exercise modality, the evidence is further stratified and integrated according to three developmental stages: preschool (3 - 6 years), school-age (7 - 12 years), and adolescence (13 - 18 years). The conclusions and findings of existing studies are summarized, and research trends and age distribution characteristics are analyzed, aiming to provide a comprehensive overview of current research progress in exercise-based EF interventions for ASD and offer new directions for future precision interventions targeting specific age groups.

2. Ease of Use

This systematic review is reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.

2.1. Search Strategy

The following electronic databases were systematically searched: PubMed, Web of Science, PsycINFO, China National Knowledge Infrastructure (CNKI), and Wanfang Data Knowledge Service Platform. The search period covered January 2013 to December 2025. A combination of MeSH terms and free-text keywords was used. The specific search strategy for PubMed was: (“autism spectrum disorder” OR “autism” OR “ASD”) AND (“executive function” OR “working memory” OR “inhibitory control” OR “cognitive flexibility”) AND (“physical activity” OR “exercise” OR “sport” OR “physical education” OR “intervention”) NOT (“review” OR “meta-analysis” [Publication Type]). Equivalent search strategies were adapted for other databases. Reference lists of included articles and relevant reviews were also screened to identify additional potentially eligible studies.

2.2. Inclusion and Exclusion Criteria

Inclusion criteria were: 1) Participants: Children or adolescents (≤ 18 years) with a clinical diagnosis of ASD; 2) Intervention: Any form of physical exercise intervention (e.g., ball sports, martial arts, combat sports, acute exercise, game-based exercise) with an intervention duration ≥ 2 weeks (excluding acute exercise studies); 3) Study design: Randomized controlled trials (RCTs), quasi-experimental studies, or single-group pre-posttest designs; 4) Outcome measures: At least one core component of EF (inhibitory control, working memory, cognitive flexibility); 5) Language: English or Chinese, published in peer-reviewed journals or as degree theses.

Exclusion criteria were: 1) Reviews, meta-analyses, conference abstracts, case reports; 2) Non-exercise interventions (e.g., cognitive training, medication, die-

tary interventions); 3) Inability to obtain full text or incomplete data; 4) Duplicate publications.

2.3. Study Selection and Data Extraction

Two reviewers independently screened titles and abstracts to exclude obviously irrelevant studies, followed by a full-text review for final inclusion, resulting in 298 articles. Disagreements were resolved through discussion or consultation with a third reviewer, and ultimately 25 articles were included in the review (see **Figure 1**). Data were extracted using a pre-designed form, including: first author, publication year, country, sample characteristics (age, sex, sample size), intervention type, intervention details (frequency, intensity, duration), control condition, EF measurement tools, and main results.

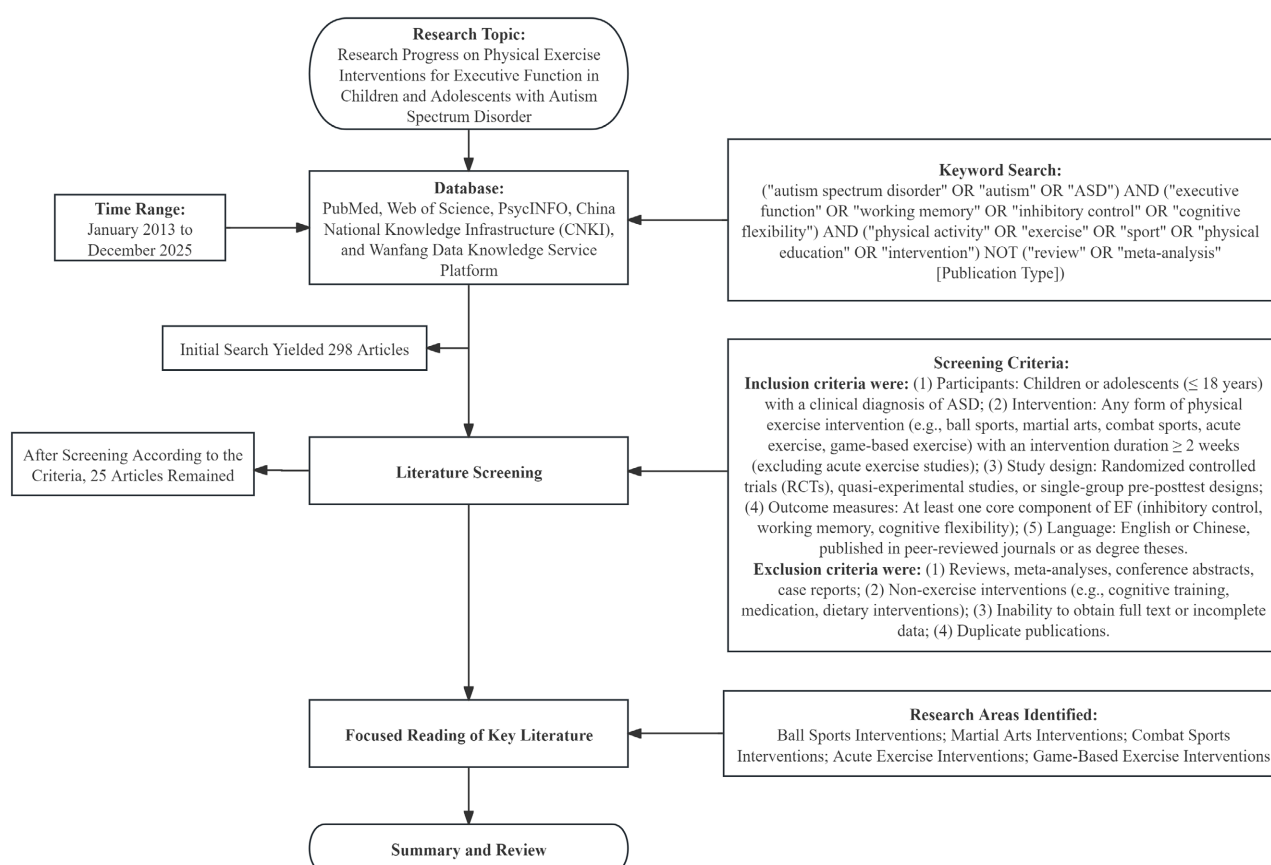


Figure 1. Diagram of the literature retrieval and screening.

2.4. Methodological Quality Assessment

A formal risk of bias assessment was not conducted for the included studies. The primary aim of this review was to provide a narrative synthesis of the literature on PA interventions for EF in children with ASD, rather than to perform a quantitative meta-analysis. Furthermore, considerable heterogeneity in intervention types and outcome measures across studies precluded meta-analytic pooling of effect

sizes. Therefore, methodological quality scores were not assigned. This limitation should be considered when interpreting the study findings.

3. Types of Physical Exercise Interventions for ASD

Numerous studies have demonstrated that physical exercise, as a non-pharmacological intervention with minimal side effects, can significantly improve EF in children with ASD (Trott et al., 2022; Liang et al., 2022). These positive effects have also been widely validated in typically developing children, with PA confirmed to promote cognitive development by improving brain structure and function (Gunnell et al., 2019). However, intervention effects are not homogeneous; different types of PA may differentially impact EF through distinct cognitive demands, motor complexity, and levels of social interaction. Diamond & Ling (2019) noted that mere aerobic or resistance training may be less effective for enhancing EF compared to activities rich in cognitive challenge, highlighting the need to differentiate intervention types. Based on the existing literature, PA interventions for EF in children with ASD can be broadly categorized into ball sports interventions, martial arts and combat sports interventions, acute exercise interventions, and game-based exercise interventions. To systematically evaluate the efficacy of each intervention type, this section describes each study using a uniform framework, focusing on study design, sample characteristics, key intervention parameters (intensity, duration, frequency, period, cognitive demand), and intervention effects.

3.1. Ball Sports Interventions

Ball sports are a common intervention modality in studies targeting EF in children with ASD, encompassing various activities such as basketball, table tennis, soccer, and complex ball skill activities. The research participants span from preschool to adolescence, but primarily focus on school-age children.

The effectiveness of basketball interventions has been validated in multiple studies involving both preschool and school-age children. Wang (2020) employed a 2 (group: experimental, control) \times 2 (time: pre-test, post-test) quasi-experimental design with 32 preschool children with ASD aged 3 - 6 years (experimental group $n = 17$, control group $n = 15$). The experimental group underwent a 12-week mini-basketball program (5 sessions/week, 40 min/session, moderate intensity, heart rate 128 - 148 bpm). The program integrated basic basketball movements with physical games, delivered in group sessions allowing one parent to accompany the child. Cognitively, children needed to attend to instructions, remember movement sequences, and adjust responses according to the context. EF was assessed using the Childhood Executive Functioning Inventory (CHEXI, parent-report), measuring working memory, inhibition, and regulation. Results showed significant improvement in working memory for the experimental group post-intervention (time \times group interaction, $P = 0.013$). For inhibition, post-test scores were lower than pre-test in the experimental group, with a significant interaction effect ($P = 0.033$), suggesting the intervention helped control the decline

in inhibitory ability. No significant change was found in regulation ($P = 0.052$). No follow-up assessment was conducted.

In school-age children, [Tse et al. \(2019\)](#) used an RCT design with 40 children with ASD aged 8 - 12 years, randomly assigned to an intervention group ($n = 19$) or control group ($n = 21$). The intervention group received 12 weeks of basketball skill learning (2 sessions/week, 45 min/session, moderate intensity). Cognitively, children needed to maintain attention and engage cognitive processes while learning basketball skills. EF was assessed using a Go/No-go task for inhibitory control and Corsi block-tapping and digit span tasks for working memory. Results indicated significant improvement in inhibitory control (false alarm rate) in the intervention group compared to controls. However, no significant group differences were found in working memory measures. Follow-up data were not reported.

[Wu et al. \(2025\)](#) employed an RCT design with 22 children with ASD aged 6 - 12 years, randomly assigned to an experimental group ($n = 11$) or control group ($n = 11$). The experimental group underwent 12 weeks of basketball training (3 sessions/week, 60 min/session, moderate intensity, target heart rate 70% HRmax). Training combined basketball skill acquisition with physical exercises, requiring children to coordinate movements and achieve goals in a dynamic environment. EF was assessed using the Stroop color-word test, n-back task, and task-switching paradigm for inhibitory control, working memory, and cognitive flexibility, respectively. Results showed significant improvements in the experimental group across multiple EF measures compared to controls ($P < 0.01$), with large effect sizes (e.g., Hedge's $g = 3.02$ for Stroop incongruent accuracy). These findings align with [Wang \(2020\)](#), suggesting that higher frequency and intensity basketball training may yield more comprehensive EF improvements.

Table tennis interventions have primarily targeted school-age children. [Pan et al. \(2017\)](#) used a crossover design with 22 children with ASD aged 6 - 12 years, randomly assigned to an intervention group or control group. Phase 1 (12 weeks): the intervention group received table tennis training (2 sessions/week, 70 min/session, moderate intensity), while the control group received no intervention. Phase 2: the control group received the same intervention, and the intervention group entered a follow-up period. Table tennis training integrated motor skills with EF training, requiring children to process task changes in a dynamic environment (e.g., hitting based on color or number instructions). Motor skills were assessed using the Bruininks-Oseretsky Test of Motor Proficiency, Second Edition (BOT-2), and EF using the Wisconsin Card Sorting Test (WCST). Results showed significant improvements in motor skills (hand coordination, body coordination, strength and agility) and WCST indices (total correct, perseverative responses, conceptual level responses) in the intervention groups in both phases. Follow-up assessment indicated that the effects of Phase 1 intervention were maintained for at least 12 weeks, suggesting good long-term benefits of table tennis interventions.

Soccer interventions have also focused on school-age children. [Ji et al. \(2022\)](#) used a three-group RCT design with 100 children with ASD (mean age 12.5 - 13.1

years), randomly assigned to a virtual training group ($n = 34$, Xbox 360 soccer game), physical exercise group ($n = 33$, soccer skills training), or control group ($n = 33$). The physical exercise group received 6 weeks of soccer training (3 sessions/week, 1 hour/session, moderate intensity, Brog RPE 10 - 13), including passing drills, shooting practice, and coordination exercises; cognitive demand was moderate. The virtual training group played virtual soccer games at low intensity. EF was assessed using backward digit span for working memory, Flanker task for inhibitory control, and Stroop test for cognitive flexibility. Results showed that both intervention groups performed significantly better than controls on all three EF measures post-intervention, with no significant difference between the two intervention modalities. However, follow-up assessment 3 weeks after intervention cessation showed declining EF in both intervention groups, suggesting limited sustainability of effects.

For complex ball skills, [Zhu et al. \(2017\)](#) used a pre-posttest between-subjects design with 31 children with ASD aged 6 - 12 years, divided into an experimental group ($n = 17$) and control group ($n = 14$). The experimental group underwent 20 weeks of adapted physical education (APE) intervention (3 sessions/week, 120 min/session). The intervention used a task progression approach: the first 6 weeks involved simple ball exercises (e.g., passing with a teacher, low cognitive demand), and the remaining 14 weeks involved complex ball skill training (requiring simultaneous attention to peer positions and execution of passing, hitting, jumping, high cognitive demand). Visual working memory was assessed using a change detection task. Results showed significantly better visual working memory in the experimental group post-intervention ($\eta^2 = 0.284$), indicating that complex ball skill training effectively improves visual working memory in children with ASD.

In summary, ball sports interventions have accumulated substantial empirical evidence for improving EF in children with ASD. For basketball, improvements in inhibitory control are consistently reported ([Tse et al., 2019](#); [Wu et al., 2025](#)), but findings for working memory are mixed, possibly related to intervention frequency and intensity: 5 sessions/week yielded significant working memory improvements, while 2 sessions/week did not. Table tennis training improved motor skills and specific EF indices, with preliminary evidence of long-term effects lasting at least 12 weeks ([Pan et al., 2017](#)). Soccer training positively affected all three core EF components, but effects declined within 3 weeks post-intervention, highlighting the need for improved sustainability ([Ji et al., 2022](#)). Complex ball skill training significantly improved visual working memory with a large effect size ($\eta^2 = 0.284$, [Zhu et al., 2017](#)). Regarding age distribution, existing research predominantly targets school-age children (6 - 12 years), with only preliminary exploration in preschool children (basketball) and a notable lack of studies in adolescents.

3.2. Martial Arts Interventions

Mind-body interventions, rooted in martial arts principles, are approaches that promote healthy development by adjusting psychological activities to influence

physical functions. Traditional Chinese mind-body interventions, as a branch of this category, are increasingly attracting scholarly attention, with existing research encompassing forms such as Triarchic Bodypathway Relaxation Technique and Nei Yang Gong.

School-age children are the primary focus of martial arts intervention research. Chan et al. (2011) employed a single-subject pre-posttest design to compare the effects of a traditional Chinese mind-body intervention (Dejian Mind-Body Intervention, DMBI) and traditional behavioral/cognitive intervention on EF and memory in a 9-year-5-month-old low-functioning child with autism. DMBI, developed by Shaolin Chan (Zen), Wu (martial arts), and Yi (medicine) practitioners over four generations, includes four components: Chan practice, mind-body exercises, dietary monitoring, and opening the orifices. The intervention involved 15 min of face-to-face guidance weekly in the first month, followed by 15 min monthly for 7 months, combined with daily home practice (nasal drops twice daily, nose bridge massage 36 times nightly, standing meditation 1 - 2 times/week). EF and memory were assessed using the Hong Kong SAR (China) List Learning Test (HKLLT) for memory and inhibition, the Children's Color Trails Test (CCTT) for inhibition and cognitive flexibility, and the Behavior Rating Inventory of Executive Function (BRIEF) (parent version) for global EF. Results showed significant improvements in inhibition, cognitive flexibility, and memory after 8 months of DMBI, with functioning improving from "severely to moderately impaired" to "low average to average" range. In contrast, no significant changes were observed during the preceding 12 months of traditional cognitive intervention.

Building on this, Chan et al. (2013) used an RCT design with 48 children with ASD aged 6 - 17 years, randomly assigned to a Nei Yang Gong group (initial $n = 24$, final $n = 20$) or a Progressive Muscle Relaxation (PMR) group (initial $n = 24$, final $n = 20$). The Nei Yang Gong intervention included five movements (quiet standing, shoulder relaxation, nose bridge massage, energy circulation exercises, passive Dan Tien breathing) performed in a fixed sequence accompanied by specific music segments, each round lasting 5 minutes. Sessions lasted 1 hour (including instruction and practice), twice weekly for 4 weeks. Intensity was based on relaxation (children could stop when tired), and cognitive demand was moderate (simple movements manageable even for children with moderate intellectual disability). The PMR group followed audio instructions to tense and relax body parts sequentially, with sessions lasting approximately 20 minutes. Both groups also practiced at home. Self-control was assessed using the Tower of London Test, CCTT, and Five-Point Test, supplemented by parent questionnaires (ATEC and self-control behavior questionnaire) and EEG recordings. Results showed significantly greater improvements in self-control in the Nei Yang Gong group compared to the PMR group (Cohen's $d = 0.84 - 0.86$). EEG findings further revealed significantly enhanced theta activity in the anterior cingulate cortex (ACC) post-intervention in the Nei Yang Gong group, providing neurophysiological evidence for the intervention's effectiveness. No follow-up assessment was conducted.

For adolescents, [Chan & Sze \(2008\)](#) used a single-subject design with a 16-year-old adolescent with Asperger's disorder who underwent a 3-month mind-body intervention. The intervention included Triarchic Bodypathway Relaxation Technique (TBRT; 15 min nightly before sleep, guided by audio recording for sequential relaxation of the body's front, back, and sides) and Natural Dan Tien Breathing (NDTB; daily practice, gently placing hand on Dan Tien area ~1.3 cm below navel, naturally observing the Dan Tien during inhalation and the nose during exhalation). The intervention emphasized passive relaxation, with biweekly face-to-face follow-ups. Total intervention time over 3 months was less than 6 hours. Cognitive demand was moderate (passive listening and relaxed observation, no active concentration required). Self-control was assessed using maternal behavioral observation records combined with the Conners' Continuous Performance Test II (CPT II). Results showed significant improvements in emotional control (temper tantrums reduced from at least once daily to an average of once weekly, an improvement of >85%; recovery time shortened from 5 - 10 min or up to 1 hour to 1 - 3 min), behavioral control (repetitive behaviors reduced from 2 - 3 times daily to once daily), and more flexible problem-solving. No follow-up assessment was conducted.

In summary, martial arts interventions for EF in children with ASD share several common characteristics. In terms of intervention design, these interventions typically emphasize relaxation, involve low intensity (minimal physical exertion), and have moderate cognitive demands (simple movements; some interventions involve passive listening and relaxed observation, manageable even for children with moderate intellectual disability). Regarding intervention effects, existing studies demonstrate positive outcomes in inhibitory control, cognitive flexibility, memory, and self-regulation. The EEG evidence from [Chan et al. \(2011, 2013\)](#) (increased prefrontal theta cordance and ACC theta activity) provides neurophysiological support for these effects. In terms of age distribution, current research primarily focuses on school-age children, with limited exploration in adolescents (only a single case study) and no studies in preschool children, warranting future investigation.

3.3. Combat Sports Interventions

Combat sports involve motor skills related to attacking, defending, and evading. Due to their comprehensive demands on attention, self-control, and memory of movement sequences, combat sports are increasingly being explored as interventions for EF in children with ASD. Existing research covers mixed martial arts (MMA) and karate, primarily targeting school-age children.

[Phung & Goldberg \(2019\)](#) used an RCT design with 34 children with ASD aged 8 - 11 years, randomly assigned to an MMA intervention group (n = 14) or a control group (n = 20). The 13-week intervention (2 sessions/week, 45 min/session) included 5 min of etiquette (meditation, breathing exercises), 15 min warm-up, 20 min main activity (progressively complex striking and grappling combina-

tions), and 5 min cool-down. Cognitive demand increased progressively, with movement sequences gradually increasing from 2 - 3 steps to 4 - 13 steps, requiring active engagement of behavioral inhibition, working memory, and cognitive flexibility, supplemented by meditation and breathing exercises for emotional regulation. EF was directly assessed using the Hearts & Flowers computerized task (measuring inhibition, working memory, cognitive flexibility) and supplemented by the BRIEF-2 parent questionnaire for everyday EF. Results showed significantly better accuracy in the MMA group compared to controls post-intervention (congruent block $d = 0.83$, mixed block $d = 1.01$). Parent-reported behavioral regulation ($d = -0.67$), emotional regulation ($d = -0.88$), and global EF ($d = -0.81$) showed moderate to large improvements. No significant group differences were found in reaction time. The authors suggested that behavioral inhibition might have shown the least improvement among the three EF domains, and the intervention may have successfully targeted core EF but not fully challenged complex EF (e.g., planning and organization). No follow-up assessment was conducted.

Multiple studies have validated the effectiveness of karate training. [Greco & De Ronzi \(2020\)](#) used an RCT design with 28 children with ASD aged 8 - 11 years, matched by age, sex, and ASD severity and randomly assigned to an intervention group ($n = 14$) or control group ($n = 14$). The 12-week intervention (2 sessions/week, 45 min/session) used traditional Shotokan Karate training, primarily involving Heian Shodan Kata techniques, with typically developing peers assisting to promote social skills. Activities specifically targeted EF domains (inhibition, working memory, cognitive flexibility) and had high cognitive demand (requiring memorization of sequence order, movement control, sustained attention, supplemented by meditation and breathing exercises for emotional regulation). Social skills were assessed using the Social Skills Improvement System Rating Scales (SSIS-RS), and EF using the BRIEF parent version. Results showed significant improvements in the intervention group compared to controls in social-emotional skills ($d = 2.85$) and reduction in problem behaviors ($d = 2.64$). Behavioral regulation ($d = 1.36$), emotional regulation ($d = 1.63$), and cognitive regulation ($d = 1.54$) indices all improved, with significant improvement in the global EF composite score ($\Delta -3.2 \pm 3.3$, $p = 0.003$, $d = 0.97$). No follow-up assessment was conducted, and parents were not blinded, potentially introducing reporting bias.

[Kurniawan et al. \(2022\)](#) used an A-B single-subject design with 4 boys with mild-to-moderate ASD aged 8 - 12 years, who underwent 6 weeks of karate training (3 sessions/week, 30 - 45 min/session, total 18 sessions). Content progressed weekly: Week 1 basic punching (oi-zuki-chudan), Week 2 upper-level punching (oi-zuki-jodan), Week 3 lower-level blocking (gedan-barai), Week 4 upper-level blocking (agi-uke), Week 5 inner blocking (uchi-ude-uke), Week 6 outer blocking (soto-ude-uke). Cognitive demand was moderate, requiring memorization of technique sequences, control of movement accuracy, and sustained attention. Social, emotional, and executive dysfunction were assessed weekly by parents using a ques-

tionnaire adapted from ICD-10 and DSM-IV. Results showed stable scores for social, emotional, and executive dysfunction during the 2-week baseline period (mean scores approximately 9 - 10). After 6 weeks of intervention, mean scores for social dysfunction decreased from 10 to 7, emotional dysfunction from 10 to 7, and executive dysfunction from 10 to 7, with all three showing sustained downward trends. However, the small sample size and lack of a control group limit the strength of the evidence.

In summary, combat sports interventions for EF in children with ASD share several common characteristics. In terms of intervention design, cognitive demands are generally moderate to high: MMA training progressively increases movement sequences from 2 - 3 to 4 - 13 steps, while karate requires memorization of sequence order and techniques. Regarding intervention effects, existing studies provide preliminary evidence supporting EF improvements in school-age children with ASD. MMA training yielded large effect sizes on direct EF measures (congruent block $d = 0.83$, mixed block $d = 1.01$), with moderate to large effects on parent-reported behavioral regulation ($d = -0.67$), emotional regulation ($d = -0.88$), and global EF ($d = -0.81$). Karate training showed significant improvements in social-emotional skills ($d = 2.85$), reduction in problem behaviors ($d = 2.64$), and various EF dimensions (behavioral regulation $d = 1.36$, emotional regulation $d = 1.63$, cognitive regulation $d = 1.54$, global composite $d = 0.97$). However, the evidence base remains limited due to the small number of studies, small sample sizes, potential reporting bias from parent reports, and lack of follow-up data. Furthermore, participants are predominantly school-age males, with no studies in preschool children or adolescents.

3.4. Acute Exercise Interventions

Acute exercise interventions, characterized by short duration and operational flexibility, offer a unique perspective for exploring the immediate relationship between exercise and EF. Existing research encompasses treadmill walking, circuit-based interval training, cycling skill acquisition, figure skating, and square-stepping exercise, primarily targeting school-age children, with limited exploration in preschool children and adolescents.

Bremer et al. (2020) used a within-subject crossover design to compare the immediate effects of three 20-minute exercise conditions on EF in 12 boys with ASD aged 8 - 12 years: steady-state treadmill walking (target heart rate 120 - 160 bpm), circuit-based interval training (including jumping jacks, medicine ball chest press, squat jumps, seated rows with resistance band, alternating step-ups; each exercise 45 sec with 20 sec rest intervals; 3 sets), and a sedentary control condition (watching age-appropriate movies). Both exercise conditions had similar intensity (circuit training heart rate 131.5 ± 8.7 bpm; treadmill 128.8 ± 10.4 bpm) but differed in cognitive demand: circuit training required switching between exercises (higher cognitive demand), while treadmill walking had lower cognitive demand. Inhibitory control was assessed using the Leiter International Performance Scale-Third

Edition (Leiter-3) cancellation task pre- and post-exercise, with fNIRS measuring prefrontal oxygenation changes. Results showed a significant main effect of time ($F(1, 11) = 13.2, p = 0.004, \eta^2 = 0.546$) and a condition \times time interaction with moderate to large effect size ($F(2, 22) = 1.5, p = 0.251, \eta^2 = 0.118$). Post-hoc analysis indicated a small to moderate effect of circuit training on inhibitory control ($d = 0.37$), with smaller effects for treadmill walking ($d = 0.23$) and sedentary control ($d = 0.23$). fNIRS data showed a large effect size for prefrontal oxygenation changes following circuit training ($d = 0.85$), compared to smaller effects for treadmill ($d = 0.14$) and sedentary control ($d = 0.39$). However, study limitations included small sample size (only able to detect large effects), use of only one EF measure, and lack of follow-up assessment. The authors suggested that circuit training, requiring higher cognitive engagement (exercise switching, dynamic movements), may confer greater benefits for inhibitory control.

Tse and colleagues have conducted systematic research in the area of cycling skill acquisition. Tse et al. (2021) used a three-group RCT design with 62 children with ASD aged 8 - 12 years, randomly assigned to a learn-to-cycle group ($n = 22$), stationary cycling group ($n = 20$), or control group ($n = 20$). The learn-to-cycle group received 2 weeks of cycling skill acquisition training (5 sessions/week, 60 min/session, total 10 sessions), with high cognitive demand (requiring learning balance, coordination, route planning, memory of movement sequences). The stationary cycling group performed repetitive pedaling with low cognitive demand. Results showed significant improvements in the learn-to-cycle group in planning ($d = 0.45$), visuospatial working memory ($d = 0.27$), cognitive flexibility ($d = 0.33$), and inhibitory control ($d = 0.22$), while the stationary cycling and control groups showed no significant changes.

Building on this, Tse et al. (2024) conducted a mediation analysis using the same 2-week intervention protocol with 64 children with ASD aged 8 - 12 years (learn-to-cycle $n = 23$, stationary cycling $n = 19$, active control $n = 22$). Unlike the 2021 study, this study measured only cognitive flexibility and inhibitory control and used PROCESS Macro Model 4 with 5000 bootstrap samples for mediation analysis. Results showed that physical self-efficacy significantly mediated the relationship between exercise and cognitive flexibility (indirect effect = 1.25, 95% CI: 0.13 - 3.90, accounting for 78.13% of total effect). Perceived physical competence significantly mediated the relationship between exercise and inhibitory control (indirect effect = 2.15, 95% CI: 0.06 - 4.65, accounting for 38.74% of total effect). Perceived social support significantly mediated the relationship between exercise and self-regulation (indirect effect = 10.29, 95% CI: 1.07 - 22.36, accounting for 53.96% of total effect).

In figure skating, Lin & Chang (2022) used a single-subject experimental design with 2 children with high-functioning ASD aged 8-10 years, who underwent 6 weeks of figure skating training (12 sessions, 2 sessions/week, 60 min/session) conducted by a certified figure skating coach according to the International Skating Union training system. A multiple baseline design was used, with assessment

tools including the Traditional-Chinese Childhood Executive Functioning Inventory from the Taiwan Region and the Repetitive Behavior Scale-Revised, with social validity verified through maternal interviews. Results showed that both children improved their figure skating skills over the 12 sessions, with improvements in inhibitory control and reductions in repetitive behaviors associated with the training, with positive effects possibly transferring to daily life. This study provides preliminary empirical support for figure skating interventions in improving EF and reducing repetitive behaviors in children with ASD.

In summary, acute exercise interventions demonstrate immediate effects on EF in children with ASD. Regarding intervention design, cognitive demands vary across exercise modalities: cycling skill acquisition and figure skating have high cognitive demands (requiring learning balance, coordination, memory of movement sequences, route planning); circuit-based interval training has relatively high cognitive demand (requiring switching between exercises and performing dynamic movements); treadmill walking has low cognitive demand (repetitive movements). Regarding exercise intensity, [Bremer et al. \(2020\)](#) reported similar intensities for circuit training and treadmill walking (heart rate 131.5 ± 8.7 bpm vs. 128.8 ± 10.4 bpm). [Tse et al. \(2021\)](#) used RPE, with similar ratings for the learn-to-cycle and stationary cycling groups (RPE = 4.0 vs. 4.60). [Lin & Chang \(2022\)](#) did not report objective intensity data. Regarding effect sizes, [Bremer et al. \(2020\)](#) found immediate effects on inhibitory control of $d_{rm} = 0.37$ for circuit training and $d_{rm} = 0.23$ for treadmill walking. [Tse et al. \(2021\)](#) reported effect sizes of $d = 0.22 - 0.45$ for various EF components in the learn-to-cycle group. Beyond behavioral improvements, [Tse et al. \(2024\)](#) explored psychological mechanisms (physical self-efficacy, perceived physical competence, perceived social support) mediating the relationship between exercise and EF improvements. Common limitations across studies include small sample sizes, short intervention durations, lack of objective intensity measurement in some studies, and absence of long-term follow-up assessments.

3.5. Game-Based Exercise Interventions

Integrating game elements into exercise interventions has become an important direction in recent research on EF in ASD. Existing studies encompass the Makoto arena, Xbox Kinect, SPARK program, and social game integration, primarily targeting school-age children, with limited exploration in adolescents and preschool children.

[Hilton et al. \(2014\)](#) used a single-group pre-posttest design with 7 children with ASD aged 6.41 - 13.9 years (5 boys, 2 girls) who underwent an exergaming intervention. Participants were required to complete at least three 2-minute sessions in the Makoto arena weekly until completing 30 sessions (approximately 10 weeks). The Makoto arena is an interactive audiovisual exergame consisting of three ~6-foot towers arranged in a triangle, each with 10 lights. Participants needed to identify the location of illuminated lights and hit the target with a ball as quickly as

possible, with reaction time requirements progressively increasing (11 speed levels, from 3 sec to 0.95 sec). Cognitively, participants needed to simultaneously process audiovisual information, react quickly, attend to multiple targets, and remember game rules. EF was assessed using the BRIEF parent report, and motor skills using the BOT-2. Results showed significant improvement in reaction speed (from session 6 to 30, $d = 1.18$, $p = 0.018$). For EF, only working memory ($d = -1.01$, $p = 0.027$) and the metacognition index ($d = -0.53$, $p = 0.027$) showed significant improvement, with no significant changes in inhibition, shifting, emotional control, planning/organization, materials organization, or monitoring. No follow-up assessment was conducted.

Regarding active video games (AVG), Rafiei Milajerdi et al. (2021) used a three-group RCT design with 60 children with ASD aged 6 - 10 years, randomly assigned to a SPARK group ($n = 20$), Kinect group ($n = 20$), or control group ($n = 20$). The SPARK and Kinect groups received 8 weeks of intervention (3 sessions/week, ~35 min/session, total 14 hours), while the control group received treatment as usual. Intention-to-treat repeated measures ANOVA was used. For EF, there was a significant main effect of group for correct responses [$F(2, 53) = 5.43$, $P < 0.01$], with the Kinect group showing significantly better correct responses than the SPARK and control groups. Significant main effects of time were found for conceptual responses [$F(1, 53) = 10.61$, $P < 0.01$] and perseverative errors [$F(1, 53) = 14.31$, $P < 0.01$]. This study indicates that structured PA interventions can improve motor function in children with ASD, and AVG can effectively improve EF.

For social game integration, Greco (2020) used a matched-pairs RCT design to examine the effects of 12 weeks of multilateral training on EF and motor skills in 24 children with ASD aged 8 - 11 years. Children were randomly assigned to an intervention group ($n = 12$) or control group ($n = 12$). The intervention group received multilateral training twice weekly for 70 min/session, integrating EF-related motor skill training (40 min) with social games (20 min). Activities involved task manipulations (color, direction, interval, speed) and social interactions (peer cooperation, instructor guidance), with high cognitive demand requiring visual information processing, response planning, rule memory, and adaptation to new information. Motor skills were assessed using the BOT-2, and EF using the BRIEF parent report. Results showed significant improvements in the intervention group in behavioral regulation ($\eta^2 p = 0.47$, $d = 1.18$), emotional regulation ($\eta^2 p = 0.71$, $d = 2.68$), cognitive regulation ($\eta^2 p = 0.22$, $d = 1.78$), and global EF ($\eta^2 p = 0.32$, $d = 0.84$), with a 91% adherence rate. No significant changes were observed in the control group. This study suggests that multilateral training integrating social elements can effectively improve EF and motor skills in children with ASD, indicating that combining social interaction with motor training may be an important pathway for enhancing intervention effects.

Su et al. (2025) used an RCT design to examine the differential effects of whole-body movement play and sedentary fine motor play on inhibitory control and behavioral problems in school-age children with ASD. Forty children with ASD

(mean age 8.6 ± 0.4 years) were matched by age and ability and randomly assigned to two groups. The Movement Play group received a game-based whole-body movement intervention requiring processing of audiovisual information, quick reactions, and coordinated whole-body movements (high cognitive demand). The Sedentary Play group performed seated fine motor activities (relatively low cognitive demand). Inhibitory control was assessed using the Flanker task, and sensory behaviors, repetitive behaviors, and negative behaviors during the intervention were coded. Results showed significant improvements in inhibitory control and significant reductions in sensory and negative behaviors in the Movement Play group, with no significant changes in the Sedentary Play group. Moreover, negative behaviors during the intervention were significantly correlated with inhibitory control performance ($r = 0.3 - 0.4$). This study indicates that whole-body movement interventions are superior to sedentary fine motor activities in improving EF and reducing problem behaviors in children with ASD, suggesting that cognitive demand may be a key factor influencing intervention effectiveness.

For preschool children, [Chen et al. \(2024\)](#) used an RCT design to examine the effects of an 8-week sports game intervention on EF and neural mechanisms in 30 children with ASD aged 3 - 6 years. The intervention group ($n = 15$) received moderate-intensity sports games (track and field, basketball, soccer) 6 times/week for 30 min/session, with heart rate controlled at 60% - 69% of maximum heart rate. The control group ($n = 15$) maintained routine intervention. The sports games had high cognitive demand, involving complex skill learning, instruction processing in dynamic environments, working memory updating, response inhibition, and task switching. Behavioral results showed significant improvements in inhibitory control and cognitive flexibility in the intervention group ($\eta^2 = 0.300 - 0.406$), but no significant change in working memory ($\eta^2 = 0.073$), suggesting selective effects of exercise intervention on different EF components. Regarding neural mechanisms, fNIRS monitoring revealed increased activation in multiple prefrontal regions post-intervention (dorsolateral prefrontal cortex, frontopolar area, orbitofrontal cortex, etc.), and the degree of brain activation was positively correlated with behavioral performance. This study provides neurophysiological evidence for sports game interventions improving EF in children with ASD and suggests that the preschool period may be a critical window for exercise intervention.

[Zhang et al. \(2025\)](#) used a three-group design to examine the effects of different game interventions on EF in 24 preschool children with ASD aged 2.58 - 4.5 years. Children were matched at baseline and assigned to a physical play group, pretend play group, or combined play group ($n = 8$ per group), receiving 8 weeks of intervention (4 days/week, 30 - 40 min/session). The physical play group primarily engaged in moderate-intensity physical activities, the pretend play group in role-play activities, and the combined play group integrated both features, combining moderate exercise intensity with high cognitive demand. Working memory, cognitive flexibility, and inhibitory control were assessed using digit span backward,

dimensional change card sort, and day/night tasks at pre-intervention, 4 weeks, and 8 weeks post-intervention. Results showed that all three groups significantly improved working memory and cognitive flexibility, but the combined play group showed earlier effects (significant at mid-test) and overall superior effects, with marginally significant improvement in inhibitory control. This study suggests that combined play interventions integrating motor and cognitive-social elements are more effective than single game formats in promoting EF in preschool children with ASD, indicating that synergistic activation of motor and cognitive demands may be a key mechanism for enhancing intervention effects.

Research in adolescents is limited. [Anderson-Hanley et al. \(2011\)](#) used two pilot study designs to examine the effects of single-session exergaming on EF and repetitive behaviors in adolescents with ASD. Twenty-two participants with ASD (Pilot I: 10 - 18 years, $n = 12$; Pilot II: 8 - 21 years, $n = 10$) completed single 20-minute sessions of Dance Dance Revolution (DDR) or cybercycling, with moderate exercise intensity and cognitive demand, and a video-watching control condition. EF was assessed using digit span backward, Color Trails, and Stroop tasks, with repetitive behaviors coded from video. Results showed significant reductions in repetitive behaviors in the DDR group ($\eta^2 = 0.47$) and significant improvements in working memory ($\eta^2 = 0.20$) and cognitive flexibility ($\eta^2 = 0.19$) in the cybercycling group. Although the Stroop task showed a significant interaction, the control group showed greater improvement. This study suggests that single-session exergaming can have immediate beneficial effects on EF and repetitive behaviors in adolescents with ASD, indicating that combining motor and cognitive elements may be a key factor influencing intervention effectiveness.

In recent years, researchers have also expanded intervention modalities to include gymnastics and fundamental movement skills training. These interventions, similar to the SPARK program in game-based interventions, emphasize the acquisition and consolidation of basic movements with similar motor development goals. [Deng et al. \(2025\)](#) used an RCT design to examine the effects of a 12-week structured gymnastics intervention on EF in 24 children with ASD aged 6 - 9 years. Children were randomly assigned to an experimental group ($n = 12$) or control group ($n = 12$). The experimental group received structured gymnastics intervention (covering walking, running, crawling, rolling, jumping, etc.) 3 times/week for 40 min/session, with moderate intensity (mean heart rate 100 - 120 bpm). The control group maintained regular daily activities. Inhibitory control, working memory, and cognitive flexibility were assessed using the Day-Night Stroop task, self-ordered pointing task, and WCST at pre- and post-intervention. Results showed significant within-group improvements in the experimental group for inhibitory control ($p < 0.01$), working memory ($p < 0.001$), and cognitive flexibility ($p < 0.05$). The control group showed significant improvement only in working memory ($p < 0.05$). However, between-group comparisons did not reach statistical significance ($p > 0.05$). This study indicates that 12 weeks of structured gymnastics intervention can positively promote EF in children with ASD, but the limited sample size

may have prevented detection of significant between-group advantages, warranting further validation in larger studies.

Wang et al. (2025) used an RCT design to examine the effects of an 18-week fundamental movement skills intervention on EF and social interaction in 25 children with moderate ASD aged 6 - 9 years. Children were randomly assigned to an experimental group ($n = 12$) or control group ($n = 10$). The experimental group received fundamental movement skills intervention (covering 13 skills including walking, running, jumping, crawling, throwing) 4 times/week for 45 min/session, with moderate intensity (heart rate maintained at 60 - 90% of maximum). The control group maintained regular daily activities. EF was assessed using the BRIEF at pre- and post-intervention, measuring eight dimensions: inhibit, shift, emotional control, working memory, initiate, plan/organize, organization of materials, and monitor. Results showed significant improvements in the experimental group for inhibit ($d = -3.201$), shift ($d = -2.829$), emotional control ($d = -2.876$), and working memory ($d = -1.085$) ($P < 0.05$), but no significant changes in initiate, plan/organize, organization of materials, or monitor ($P > 0.05$). This study indicates that 18 weeks of fundamental movement skills intervention has selective promoting effects on EF in children with ASD, suggesting that imitative learning may primarily activate habitual behavioral systems, while higher-order EF may require integration of autonomous decision-making tasks to enhance intervention effects.

In summary, the advantage of game-based exercise interventions lies in maintaining sustained participant engagement through engaging design, with adherence rates reaching 91% (Greco, 2020). Regarding intervention parameters, game-based exercise intensity is generally moderate (heart rate maintained at 60 - 90% of maximum or 100 - 120 bpm), with single session durations ranging from 20 - 70 minutes, frequencies of 2 - 6 times weekly, and durations of 8 - 18 weeks. Cognitive demand varies: Makoto arena, Xbox Kinect, whole-body movement games, and combined games have high cognitive demand (requiring processing of audiovisual information, quick reactions, rule memory, and task switching), while SPARK, gymnastics, and fundamental movement skills have relatively low cognitive demand. Regarding effect direction, improvements in EF components are selective: inhibitory control and cognitive flexibility show significant improvement in most studies (Chen et al., 2024; Su et al., 2025; Wang et al., 2025), findings for working memory are inconsistent (Hilton et al., 2014; Deng et al., 2025), and evidence for higher-order EF improvements (e.g., planning, organization, monitoring) is limited (Wang et al., 2025). Neural mechanism studies (Chen et al., 2024) have found positive correlations between post-intervention prefrontal activation and behavioral performance, providing neurophysiological evidence for understanding intervention effects. Regarding age distribution, current research primarily targets school-age children (6 - 12 years), with preliminary exploration in preschool children (Chen et al., 2024; Zhang et al., 2025). Adolescent research is limited to two pilot studies by Anderson-Hanley et al. (2011) published over a

decade ago, urgently requiring updated evidence. Additionally, effect size reporting standards are inconsistent (some studies report Cohen's d , others report η^2 or only p -values), and some studies have small sample sizes ($n = 7 - 25$) with non-significant between-group comparisons (Deng et al., 2025). Future research should standardize effect size reporting in large-sample RCTs to enhance evidence comparability and reliability.

3.6. Neurophysiological Mechanisms of Exercise-Induced EF Improvements in ASD

The preceding sections have reviewed empirical evidence for five types of exercise interventions, demonstrating that behavioral-level improvements in executive function (EF) for children with autism spectrum disorder (ASD) are well-established across different exercise modalities. Concurrently, some studies have employed neuroimaging techniques to explore the neurophysiological changes underlying these intervention effects, providing direct evidence to address the core question of "how exercise promotes EF." The multi-path theoretical model proposed by Chen et al. (2021) suggests that physical exercise can promote cognitive development in children and adolescents through four pathways: optimizing exercise load (physiological states), enhancing motor skills, increasing situational interaction, and improving psychological states. Based on this theoretical framework, Wang (2020) provided preliminary neuroimaging evidence for exercise-induced EF improvements in children with ASD, finding that increased regional homogeneity (ReHo) in the right inferior temporal gyrus was significantly correlated with changes in inhibitory ability ($r = 0.49$, $p = 0.048$), suggesting that temporal lobe functional plasticity may be one neural mechanism of exercise intervention. The neurophysiological and psychological mediation evidence accumulated in recent years provides preliminary but diverse empirical support for the multi-path theoretical model. Integrating these mechanism findings scattered across different intervention studies can facilitate deeper understanding of the pathways through which exercise interventions operate and provide theoretical foundations for developing precise intervention protocols.

The exercise load pathway focuses on the direct modulation of brain activation and oxygen supply by exercise, and currently has direct evidence supported by functional near-infrared spectroscopy (fNIRS). Chen et al. (2024) using fNIRS to examine the effects of an 8-week sports game intervention on prefrontal cortex activation in children with ASD, found increased activation in the dorsolateral prefrontal cortex, frontopolar area, and orbitofrontal cortex, along with improved short-range functional connectivity post-intervention. Correlation analysis revealed that changes in left dorsolateral prefrontal cortex activation were significantly correlated with improvements in inhibitory control ($r = 0.60$, $p = 0.018$). Bremer et al. (2020) using fNIRS to examine the effects of a single session of moderate-intensity circuit training on prefrontal oxygenation in children with ASD, found that prefrontal oxygenation levels during cognitive tasks significantly in-

creased post-exercise ($\eta^2 = 0.237$), concurrent with immediate improvements in inhibitory control ($\eta^2 = 0.118$). Both studies employed fNIRS to directly measure prefrontal neural activity, providing relatively robust neuroimaging evidence for the exercise load pathway.

The situational interaction pathway is rooted in the complex social interaction demands within exercise contexts, and currently has direct evidence supported by electroencephalography (EEG) combined with source localization techniques. [Chan et al. \(2013\)](#) using a randomized controlled trial design with EEG and sLORETA source localization to examine the effects of a 4-week Qigong intervention on brain function in children with ASD, found significantly enhanced theta (4 - 7.5 Hz) activity in the anterior cingulate cortex (ACC) during inhibitory control tasks post-intervention ($t = 0.30$, $p = 0.02$), concurrent with improvements in self-control behavior. The ACC is a key brain region for conflict monitoring, error detection, and social cognition, and its enhanced function may reflect the training effects of interactive tasks such as rule understanding, role-playing, and social decision-making during exercise on EF. This study provides direct neuroelectrophysiological evidence for the situational interaction pathway, although the evidence source is limited, with only one study currently supporting it.

The motor skill pathway and psychological state pathway currently lack direct neuroimaging evidence. Some behavioral-level studies (e.g., [Wang et al., 2025](#); [Deng et al., 2025](#); [Pan et al., 2017](#); [Tse et al., 2024](#)) have demonstrated EF improvements, but these studies did not employ neuroimaging techniques to directly measure brain function changes, and their neural mechanism hypotheses await direct validation in future research.

In summary, to date, among studies on the neural mechanisms underlying exercise-induced EF improvements in children with ASD, only two pathways have received direct validation from neuroimaging techniques: the exercise load pathway is supported by two fNIRS studies, confirming that enhanced prefrontal activation and improved functional connectivity are important neural bases for exercise intervention; the situational interaction pathway is supported by one EEG study, demonstrating that enhanced ACC theta activity is associated with improvements in self-control behavior. The motor skill pathway and psychological state pathway await direct validation through neuroimaging evidence. Future research should employ multimodal neuroimaging techniques (e.g., fNIRS, EEG, fMRI) and conduct large-sample longitudinal follow-up studies to reveal the neuroplastic mechanisms underlying EF improvements across different exercise types and developmental stages in children with ASD, while strengthening interaction analyses among pathways to provide scientific bases for developing precise intervention protocols.

4. Strengths of Current Physical Exercise Interventions

The studies included in this review demonstrate that exercise interventions for improving EF in children and adolescents with ASD exhibit multidimensional

positive characteristics, primarily reflected in the following three aspects.

4.1. Diverse and Rich Intervention Modalities

The research has identified five main categories of intervention formats, each encompassing numerous specific intervention types. This richness is first reflected in the broad coverage of different developmental stages: preschool children have access to engaging interventions such as mini-basketball and combined games; school-age children have the most diverse options, covering all five categories including ball sports, martial arts, combat sports, acute exercise, and game-based exercise; adolescents have some exploration in martial arts and game-based exercise. Second, different intervention formats exhibit differentiated characteristic orientations: some interventions (e.g., game-based exercise, adapted physical education) place greater emphasis on engagingness and ecological validity, highlighting participants' active engagement; other interventions (e.g., martial arts, combat sports) emphasize standardization and systematicity, focusing on precise acquisition of motor skills and deep embedding of cognitive demands. This diverse research landscape provides a rich practical foundation for subsequent exploration of the applicability and optimization pathways of different exercise types.

4.2. Developmentally Appropriate Intervention Design

Most interventions demonstrate consideration of the developmental characteristics of children with ASD in their design, primarily reflected in progressive task difficulty and diverse embedding of interactive formats. Regarding task progression, interventions generally employ a progression from simple to complex: preschool children begin with single movement imitation, school-age children progressively learn skill combinations and rule applications, and adolescents face more complex tactical coordination and social interaction tasks. Regarding interactive design, interventions focus on maintaining participants' sustained engagement through human-human interaction (e.g., teacher feedback, peer collaboration) and human-machine/object interaction (e.g., virtual games, exercise sensors). Some studies have also established systematic incentive mechanisms and professional guidance procedures, providing safeguards for smooth intervention implementation. This person-context interaction design approach aligns with the context-dependent characteristics of EF development.

4.3. Significant Short-Term Intervention Effects

Overall, the vast majority of studies observed significant EF improvements at post-intervention. Evidence is most abundant for school-age children: basketball, table tennis, soccer, martial arts, combat sports, acute exercise, and game-based exercise all demonstrated improvement effects on inhibitory control, working memory, or cognitive flexibility in this age group. Preschool interventions such as mini-basketball and combined games, as well as adolescent martial arts and game-

based interventions, though limited in number, showed preliminary positive results. This indicates that exercise intervention has broad applicability as a means of improving EF in ASD and provides a reference baseline for future exploration of effect differences across exercise types.

5. Limitations of Physical Exercise Interventions

5.1. High Intervention Burden and Limited Ecological Validity

Current intervention protocols generally exhibit resource-intensive characteristics: intervention durations typically range from 8 to 20 weeks, single session durations from 30 to 120 minutes, frequencies from 2 to 5 times weekly, and most require delivery in specific settings by professional instructors. This issue manifests differently across age groups: for preschool children, parents must accompany throughout, increasing family care burden; for school-age children, intervention time conflicts with academic schedules; for adolescents, it encroaches on already limited autonomous activity time. This high-burden model not only leads to participant dropout, causing resource waste and research bias, but also makes intervention protocols difficult to generalize in real-life settings, thus limiting their ecological validity.

5.2. Unclear Long-Term Benefits and Lack of Follow-Up Evidence

Follow-up assessments of intervention effects are severely lacking in existing research. Among included studies, only a few conducted post-intervention follow-ups, with inconsistent results: table tennis training effects were maintained for 12 weeks (Pan et al., 2017), while soccer intervention effects significantly declined within 3 weeks of intervention cessation. More critically, long-term benefits across different age groups lack comparative follow-up: can preschool intervention effects persist into school age? Can school-age improvements be maintained into adolescence? These questions currently remain unanswered. The attenuation of effects after intervention cessation and the unknown continuity of benefits across different age groups limit the ability of existing conclusions to support judgments about the long-term value of interventions.

5.3. Homogeneous Task Design and Difficulty Maintaining Participant Motivation

Some intervention protocols overemphasize psychological experimental paradigms in design, with tasks exhibiting fragmented, discontinuous characteristics, lacking overall contextual coherence and meaning construction. This “task fragmentation” tendency manifests as easily distracted attention and short interest duration in preschool children; in school-age children, it appears as reduced participation motivation due to repetitive tasks; in adolescents, simple movement drills are even more difficult to elicit emotional resonance without challenge and social significance. Diminished participation motivation directly affects the achievement of intervention effects, becoming a key bottleneck restricting intervention

efficacy.

5.4. Imbalanced Age Distribution and Fragmented Developmental Continuity

Through age-stratified analysis of research evidence within each exercise type, this review found that current research is highly concentrated in school-age children, with severely insufficient attention to preschool and particularly adolescent stages. In ball sports, preschool has only preliminary exploration in basketball, and adolescents lack dedicated studies across all ball sport types. In martial arts, school-age research is most abundant, adolescents have only a few case studies, and preschool remains unexplored. In combat sports, all studies focus on school-age children. In acute exercise, school-age studies predominate. In game-based exercise, school-age studies are most abundant, preschool has the most recent explorations, and adolescents have only sporadic studies from over a decade ago. This imbalanced age distribution makes it difficult to verify the developmental appropriateness of existing intervention protocols and limits understanding of EF improvement effects across the entire developmental continuum.

6. Future Directions

6.1. Developing Portable and Efficient Intervention Approaches

Current research on exercise interventions for EF in children and adolescents with ASD, while rich and diverse in intervention formats and content, remains generally constrained by traditional experimental paradigms in implementation, exhibiting high dependence on time, space, human resources, and professional guidance. Most intervention protocols have relatively long durations (typically 8 - 20 weeks) and require delivery in specific settings (e.g., schools, laboratories, or training centers) by trained professionals. This “resource-intensive” intervention model not only increases economic and time burdens for families of children with ASD (especially for preschool children requiring parental participation throughout) but also poses challenges to sample maintenance and ecological validity. More critically, existing protocols mostly adopt “one-size-fits-all” fixed durations and frequencies (e.g., 3 times weekly, 60 minutes per session), failing to adequately consider individual differences and family accessibility, leading to participant dropout due to academic pressure, time conflicts, or declining interest, resulting in resource waste and research bias.

Addressing these limitations, future research urgently needs to promote the transformation of exercise interventions from “resource-intensive” to “precision-efficient” models, developing more flexible and accessible portable intervention protocols. First, systematic large-sample network meta-analyses should be conducted to rank effect sizes and perform cost-effectiveness analyses across different exercise types (e.g., ball sports, martial arts, combat sports, game-based exercise), identifying the most efficient and stable core intervention elements for EF improvement. Building on this, effective interventions could be modularized and

miniaturized, such as designing “10 - 15 minute high-cognitive-demand micro-exercise sessions” that can be integrated into daily school breaks or evening family activities, reducing implementation barriers. Second, with the rapid development of wearable devices, 5G communication, and artificial intelligence (AI), future research could explore “online guidance + offline practice” blended intervention models. For example, using smart wristbands or motion sensors to monitor heart rate, exercise intensity, and movement accuracy in real time, and delivering personalized training tasks and immediate feedback through mobile applications. Simultaneously, incorporating augmented reality or virtual reality technologies to create immersive exercise contexts (e.g., virtual table tennis matches, social game scenarios) can enhance engagement while reducing dependence on professional venues and instructors. [Chen et al. \(2024\)](#) have preliminarily demonstrated that sports game interventions combined with fNIRS monitoring of prefrontal activity can effectively improve EF in children with ASD and provide evidence for understanding neuroplastic changes. Future research could further integrate multi-modal physiological signal monitoring with adaptive algorithms to achieve dynamic optimization and closed-loop feedback of intervention protocols.

Furthermore, differentiated portable protocols should be developed for different age groups: for preschool children, portable exercise game kits integrating parent-child interaction (e.g., simple ball games, balance training tools) could be designed; for school-age children, “micro-curriculum” interventions based on school breaks could be explored; for adolescents, elements such as social media check-ins and peer competition could be incorporated to enhance autonomous participation motivation. It should be emphasized that AI and digital tools should serve as “assistance” rather than “replacement,” and their algorithm transparency, data privacy protection, and applicability across different ASD subtypes require continuous validation. The ultimate goal is to, through technological empowerment, bring scientifically effective exercise interventions out of the laboratory and truly integrate them into the daily life contexts of children with ASD, maximizing and sustaining intervention benefits.

6.2. Focusing on the Daily Living Needs of Children with ASD

The ultimate goal of intervention research should not be limited to improvements in EF scores in laboratories or standardized tests, but rather whether these improvements can effectively transfer to the daily lives of children with ASD, truly addressing the practical challenges they face. Therefore, future research must strengthen attention to “ecological validity,” clearly defining and measuring functional outcome indicators that best reflect the transfer of intervention effects. Based on literature review, this paper considers the following three categories of indicators crucial for assessing transfer effects: classroom behaviors (e.g., following classroom rules, task attention and persistence, ability to follow instructions), adaptive functioning (e.g., daily self-care, social interaction, communication quality), and participation (e.g., engagement in school activities, peer play, community

activities). However, systematic review of studies included in this review reveals severely insufficient attention to these transfer indicators, exhibiting a tendency of “emphasizing cognitive measurement, neglecting life assessment.”

First, the vast majority of studies in this review relied entirely on standardized cognitive neuropsychological tests such as Flanker tasks, Stroop tasks, digit span tasks, and n-back tasks. These tools precisely measure specific EF subcomponents (e.g., inhibitory control, working memory), but their results only represent cognitive potential under laboratory conditions and do not directly equate to children’s performance in real-life settings. For example, reduced reaction time on a Stroop task does not necessarily imply better ability to inhibit distracting behaviors in the classroom. These studies failed to provide any direct evidence of intervention effects transferring to classroom, home, or community settings.

Second, although a few studies employed assessment tools with greater ecological validity, their assessment content still gaps from genuine “life needs.” For instance, [Chan et al. \(2013\)](#) used parent questionnaires (ATEC and self-control behavior questionnaire) to assess behavioral changes, [Greco & De Ronzi \(2020\)](#), [Wang et al. \(2025\)](#), and [Hilton et al. \(2014\)](#) used the BRIEF (parent/teacher report) to assess EF performance in natural settings, and [Phung & Goldberg \(2019\)](#) used the BRIEF-2 parent questionnaire to track pre-post intervention behavioral changes. These tools represent a significant advancement compared to laboratory cognitive tasks (e.g., Flanker, Stroop, n-back) as they can reflect children’s behavioral performance in natural contexts. However, such assessments still focus on “EF-related behaviors” themselves rather than broader “adaptive functioning” outcomes (e.g., ability for independent dressing, ability to initiate peer conversations, quality of classroom task completion) or “participation” indicators (e.g., frequency of school activity participation, degree of community integration). Taking the BRIEF as an example, although its dimensions of “planning,” “organization,” and “working memory” have life relevance, they remain subjective ratings of EF behaviors and do not directly assess intervention effects on children’s actual life functioning.

Notably, some studies have begun attempting to connect cognitive improvements with broader developmental outcomes. For example, [Greco \(2020\)](#), while measuring EF (BRIEF), also assessed children’s motor skill proficiency using the BOT-2, which directly relates to children’s ability to participate in physical activities and games, serving as an indirect assessment of “participation.” [Tse et al. \(2024\)](#), through mediation analysis, revealed the mediating role of physical self-efficacy between exercise intervention and EF improvements, providing mechanism explanations for how cognitive improvements may affect daily behaviors through psychological pathways.

Particularly regrettably, almost no study included in this review used tools such as classroom observation scales (e.g., classroom behavior records), adaptive behavior scales (e.g., Vineland Adaptive Behavior Scales), or participation measures (e.g., school engagement questionnaires) to directly assess intervention effects on

children's lives. For instance, although the introduction repeatedly emphasizes the importance of EF for "school readiness" and "academic achievement," included preschool studies (e.g., Wang, 2020; Zhang et al., 2025) used only parent questionnaires (CHEXI) or laboratory cognitive tasks (e.g., Day/Night task, digit span backward, dimensional change card sort) for assessment, without measuring children's actual school adaptation or classroom behavior upon school entry. Similarly, numerous school-age studies (e.g., Greco & De Ronzi, 2020; Tse et al., 2024) did not report intervention effects on academically related behaviors such as homework completion ability or class listening attention.

In summary, future research must fundamentally shift perspective, taking "life needs" as the starting point for intervention design and the ultimate measure of intervention effectiveness. Researchers should prioritize selecting or developing tools capable of assessing classroom behaviors, adaptive functioning, and participation, and include these as core outcome indicators. It is recommended that future intervention protocols, from the design stage, collaborate with parents, teachers, and clinicians to clearly define the most critical "life needs" for children with ASD at specific developmental stages (e.g., school readiness behaviors for preschool children, peer interaction quality for school-age children, independent living skills for adolescents) and systematically assess changes in these indicators pre- and post-intervention. Only through such approaches can we ensure that exercise interventions are not merely effective means of "improving EF" but powerful pathways to "improving the lives of children with ASD."

6.3. Enhancing Intervention Engagement and Coherence

The long-term effectiveness of exercise interventions heavily depends on participants' sustained engagement and intrinsic motivation. However, the studies included in this review indicate that some intervention protocols overemphasize psychological experimental paradigms in design, with tasks exhibiting fragmented, discontinuous characteristics, lacking overall contextual coherence and meaning construction. This "task fragmentation" tendency manifests as easily distracted attention and short interest duration in preschool children; in school-age children, it appears as reduced participation motivation due to repetitive tasks; in adolescents, simple movement drills are even more difficult to elicit emotional resonance without challenge and social significance. Therefore, how to enhance task engagement and coherence while ensuring intervention scientificity becomes a methodological challenge urgently needing resolution in future research.

Enhancing intervention engagement, the primary pathway is systematic integration of gamification elements into exercise intervention design. Gamification is not simply "packaging" exercise content as games, but designing activity contexts with clear goals, immediate feedback, appropriate challenges, and autonomous choice based on the cognitive characteristics and interest preferences of children with ASD. For example, for preschool children, multisensory experiences, story contexts, and role-playing combined with game-based exercise (e.g., "little

animal sports meet,” “forest adventure”) can be used, embedding inhibitory control, working memory, and other EF training tasks in natural contexts. For school-age children, challenging goals, point rewards, peer collaboration, or moderate competition elements (e.g., “unlock new skills upon task completion,” “team challenges”) can be introduced to stimulate social comparison and achievement motivation. For adolescents, elements can be combined with social issues (e.g., “sports expert challenge,” “public welfare exercise check-in”) or self-challenge tasks (e.g., personal best record breakthrough) to enhance the intrinsic value and identity recognition of activities. Existing research shows that AVG interventions based on exergames, due to their immediate visual feedback and interactive challenge, have relatively good improvement effects on EF (Rafiei Milajerdi et al., 2021; Su et al., 2025), suggesting that gamification design has potential value-enhancing effects.

While enhancing engagement, the coherence of intervention tasks is equally crucial. Some current intervention protocols lack logical connections and contextual continuity between tasks, making it difficult for participants to form an overall understanding and expectation of activities, thereby affecting the depth of cognitive engagement. Future research should draw on “narrative intervention” or “situated learning” theories, integrating a series of exercise tasks into a continuous thematic story or goal achievement pathway, forming a complete closed loop of “context introduction → skill learning → integrated application → outcome demonstration.” For example, centering around themes such as “little firefighters” or “space exploration team,” training tasks such as balance, coordination, and response inhibition could be designed as continuous episodes like “traversing obstacles,” “rescuing companions,” and “material transport,” making each intervention both a consolidation of previous skills and a starting point for new challenges. Simultaneously, a “monitoring → feedback → adjustment” dynamic regulation mechanism should be established, continuously collecting participants’ behavioral performance (e.g., task completion time, error rate, heart rate changes) and subjective experiences (e.g., enjoyment, self-efficacy) during intervention, and providing immediate feedback through visual charts or voice prompts to help children perceive their own progress and enhance self-regulation abilities. If monitoring reveals declining interest or dropout risk, task difficulty should be adjusted promptly, game themes changed, or new social interaction elements introduced to maintain intervention freshness and adaptability. Notably, intervention coherence should be reflected not only in the internal logic of single sessions but also throughout the entire intervention cycle, forming a complete closed loop of “baseline assessment → staged goal setting → mid-term feedback → final outcome demonstration → effect tracking.” Only through an organic combination of engagement and coherence can we effectively sustain the long-term participation motivation of children with ASD, ensuring the accumulation and transfer of intervention effects.

Funding

This work was supported by the Postgraduate Research & Practice Innovation

Program of Jiangsu Province (Grant No. KYCX24_3000).

Conflicts of Interest

The author reports there are no competing interests to declare.

References

- Ameis, S. H., Blumberger, D. M., Croarkin, P. E., Mabbott, D. J., Lai, M., Desarkar, P. et al. (2020). Treatment of Executive Function Deficits in Autism Spectrum Disorder with Repetitive Transcranial Magnetic Stimulation: A Double-Blind, Sham-Controlled, Pilot Trial. *Brain Stimulation*, *13*, 539-547. <https://doi.org/10.1016/j.brs.2020.01.007>
- American Psychiatric Association (2013). *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.). American Psychiatric Association.
- Anderson-Hanley, C., Tureck, K., & Schneiderman, (2011). Autism and Exergaming: Effects on Repetitive Behaviors and Cognition. *Psychology Research and Behavior Management*, *4*, 129-137. <https://doi.org/10.2147/prbm.s24016>
- Bremer, E., Graham, J. D., Heisz, J. J., & Cairney, J. (2020). Effect of Acute Exercise on Prefrontal Oxygenation and Inhibitory Control among Male Children with Autism Spectrum Disorder: An Exploratory Study. *Frontiers in Behavioral Neuroscience*, *14*, Article ID: 84. <https://doi.org/10.3389/fnbeh.2020.00084>
- Chan, A. S., & Sze, S. L. (2008). Traditional Chinese Mind-Body Exercises Improve Self-Control Ability of an Adolescent with Asperger's Disorder. *Journal of Psychology in Chinese Societies*, *9*, 225-239.
- Chan, A. S., Sze, S. L., Cheung, M., Han, Y. M. Y., Leung, W. W. M., & Shi, D. (2011). Dejian Mind-Body Intervention Improves the Cognitive Functions of a Child with Autism. *Evidence-Based Complementary and Alternative Medicine*, *2011*, Article ID: 549254. <https://doi.org/10.1155/2011/549254>
- Chan, A. S., Sze, S. L., Siu, N. Y., Lau, E. M., & Cheung, M. (2013). A Chinese Mind-Body Exercise Improves Self-Control of Children with Autism: A Randomized Controlled Trial. *PLOS ONE*, *8*, e68184. <https://doi.org/10.1371/journal.pone.0068184>
- Chen, A., Xiong, X., Zhu, L., Dong, X., & Wang, W. (2021). Physical Exercise and Development of Brain and Mind in Children and Adolescents: Evidence and Theory. *China Sport Science*, *41*, 3-12.
- Chen, H., Liang, Q., Wang, B., Liu, H., Dong, G., & Li, K. (2024). Sports Game Intervention Aids Executive Function Enhancement in Children with Autism—An fNIRS Study. *Neuroscience Letters*, *822*, 137647. <https://doi.org/10.1016/j.neulet.2024.137647>
- Cirino, P. T., Child, A. E., & Macdonald, K. T. (2018). Longitudinal Predictors of the Overlap between Reading and Math Skills. *Contemporary Educational Psychology*, *54*, 99-111. <https://doi.org/10.1016/j.cedpsych.2018.06.002>
- Demetriou, E. A., Lampit, A., Quintana, D. S., Naismith, S. L., Song, Y. J. C., Pye, J. E. et al. (2018). Autism Spectrum Disorders: A Meta-Analysis of Executive Function. *Molecular Psychiatry*, *23*, 1198-1204. <https://doi.org/10.1038/mp.2017.75>
- Deng, C., Zhu, Z., Luo, G., Zeng, H., Jiang, X., Yu, Q. et al. (2025). Effects of Gymnastics Exercises on Executive Function in Children with Autism Spectrum Disorder Aged 6 to 9 Years: A Pilot Study of a Randomized Controlled Trial. *Frontiers in Psychology*, *16*, Article ID: 1660305. <https://doi.org/10.3389/fpsyg.2025.1660305>
- Diamond, A. (2013). Executive Functions. *Annual Review of Psychology*, *64*, 135-168.

- <https://doi.org/10.1146/annurev-psych-113011-143750>
- Diamond, A., & Ling, D. S. (2019). Aerobic-Exercise and Resistance-Training Interventions Have Been among the Least Effective Ways to Improve Executive Functions of Any Method Tried Thus Far. *Developmental Cognitive Neuroscience*, 37, Article 100572. <https://doi.org/10.1016/j.dcn.2018.05.001>
- Dijkhuis, R. R., Ziermans, T., & Swaab, H. (2021). The Relationship between Executive Functioning and Quality of Life in Children with Autism Spectrum Disorder. *Autism*, 25, 1905-1917.
- Ezema, J. U., Ugwu, J. C., & Udeh, C. V. (2023). Executive Function Deficits in Autism Spectrum Disorder: A Systematic Review. *Medicina*, 59, Article 1442.
- Fang, Q., Aiken, C. A., Fang, C., & Pan, Z. (2019). Effects of Exergaming on Physical and Cognitive Functions in Individuals with Autism Spectrum Disorder: A Systematic Review. *Games for Health Journal*, 8, 74-84. <https://doi.org/10.1089/g4h.2018.0032>
- Fernandez-Prieto, M., Moreira, C., Cruz, S., Campos, V., Martínez-Regueiro, R., Taboada, M. et al. (2021). Executive Functioning: A Mediator between Sensory Processing and Behaviour in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, 51, 2091-2103. <https://doi.org/10.1007/s10803-020-04648-4>
- Greco, G. (2020). Multilateral Training Using Physical Activity and Social Games Improves Motor Skills and Executive Function in Children with Autism Spectrum Disorder. *European Journal of Special Education Research*, 5, 26-41.
- Greco, G., & De Ronzi, R. (2020). Effect of Karate Training on Social, Emotional, and Executive Functioning in Children with Autism Spectrum Disorder. *Journal of Physical Education and Sport*, 20, 1637-1645.
- Gunnell, K. E., Poitras, V. J., LeBlanc, A., Schibli, K., Barbeau, K., Hedayati, N. et al. (2019). Physical Activity and Brain Structure, Brain Function, and Cognition in Children and Youth: A Systematic Review of Randomized Controlled Trials. *Mental Health and Physical Activity*, 16, 105-127. <https://doi.org/10.1016/j.mhpa.2018.11.002>
- Hill, E. L. (2004). Executive Dysfunction in Autism. *Trends in Cognitive Sciences*, 8, 26-32. <https://doi.org/10.1016/j.tics.2003.11.003>
- Hilton, C. L., Cumpata, K., Klohr, C., Gaetke, S., Artner, A., Johnson, H. et al. (2014). Effects of Exergaming on Executive Function and Motor Skills in Children with Autism Spectrum Disorder: A Pilot Study. *American Journal of Occupational Therapy*, 68, 57-65. <https://doi.org/10.5014/ajot.2014.008664>
- Hodgdon, L. A., Chu, K. A., & Caskey, C. R. (2022). Social Communication and Executive Function in Autism Spectrum Disorder: A Meta-Analysis. *Clinical Psychology Review*, 93, Article 102144.
- Ji, C., Yang, J., Lin, L., & Chen, S. (2022). Executive Function Improvement for Children with Autism Spectrum Disorder: A Comparative Study between Virtual Training and Physical Exercise Methods. *Children*, 9, Article 507. <https://doi.org/10.3390/children9040507>
- Kurniawan, R., Yusti Sianti, E., Annisaa, A., & Rohana, S. (2022). Karate: Effective Tools to Improve Social, Emotional, and Executive Functions of Students with Autism. *Jurnal SPORTIF: Jurnal Penelitian Pembelajaran*, 8, 29-43. https://doi.org/10.29407/js_unpgri.v8i1.17684
- Lai, C. L. E., Lau, Z., Lui, S. S. Y., Lok, E., Tam, V., Chan, Q. et al. (2017). Meta-Analysis of Neuropsychological Measures of Executive Functioning in Children and Adolescents with High-Functioning Autism Spectrum Disorder. *Autism Research*, 10, 911-939. <https://doi.org/10.1002/aur.1723>

- Liang, X., Li, R., Wong, S. H. S., Sum, R. K. W., Wang, P., Yang, B. et al. (2022). The Effects of Exercise Interventions on Executive Functions in Children and Adolescents with Autism Spectrum Disorder: A Systematic Review and Meta-Analysis. *Sports Medicine*, *52*, 75-88. <https://doi.org/10.1007/s40279-021-01545-3>
- Lin, H., & Chang, T. (2022). Improving Executive Functions in Two Children with High-Functioning Autism Spectrum Disorder through Figure Skating Experiences: Focusing on Inhibiting Repetitive Behaviors. *Fu-Jen Journal of Medicine*, *20*, 32-43.
- Ludyga, S., Pühse, U., Gerber, M., & Mücke, M. (2021). Muscle Strength and Executive Function in Children and Adolescents with Autism Spectrum Disorder. *Autism Research*, *14*, 2555-2563. <https://doi.org/10.1002/aur.2587>
- Macoun, S. J., Schneider, I., Bedir, B., Sheehan, J., & Sung, A. (2021). Pilot Study of an Attention and Executive Function Cognitive Intervention in Children with Autism Spectrum Disorders. *Journal of Autism and Developmental Disorders*, *51*, 2600-2610. <https://doi.org/10.1007/s10803-020-04723-w>
- Pan, C., Chu, C., Tsai, C., Sung, M., Huang, C., & Ma, W. (2017). The Impacts of Physical Activity Intervention on Physical and Cognitive Outcomes in Children with Autism Spectrum Disorder. *Autism*, *21*, 190-202. <https://doi.org/10.1177/1362361316633562>
- Patrick, K. E., Schultheis, M. T., Agate, F. T., McCurdy, M. D., Daly, B. P., Tarazi, R. A. et al. (2020). Executive Function “Drives” Differences in Simulated Driving Performance between Young Adults with and without Autism Spectrum Disorder. *Child Neuropsychology*, *26*, 649-665. <https://doi.org/10.1080/09297049.2020.1713311>
- Pellicano, E., Kenny, L., Brede, J., Klaric, E., Lichwa, H., & McMillin, R. (2017). Executive Function Predicts School Readiness in Autistic and Typical Preschool Children. *Cognitive Development*, *43*, 1-13. <https://doi.org/10.1016/j.cogdev.2017.02.003>
- Phung, J. N., & Goldberg, W. A. (2019). Promoting Executive Functioning in Children with Autism Spectrum Disorder through Mixed Martial Arts Training. *Journal of Autism and Developmental Disorders*, *49*, 3669-3684. <https://doi.org/10.1007/s10803-019-04072-3>
- Rafiei Milajerdi, H., Sheikh, M., Najafabadi, M. G., Saghaei, B., Naghdi, N., & Dewey, D. (2021). The Effects of Physical Activity and Exergaming on Motor Skills and Executive Functions in Children with Autism Spectrum Disorder. *Games for Health Journal*, *10*, 33-42. <https://doi.org/10.1089/g4h.2019.0180>
- Rodger, M., Boussefard, M., & Gibb, R. (2022). Interventions for Executive Function Deficits in Children and Adolescents with Autism Spectrum Disorder: A Systematic Review. *Research in Autism Spectrum Disorders*, *93*, Article 101932.
- Ruggeri, A., Cellerino, A., & Lametti, D. C. (2021). Decision-Making, Reversal Learning, and Cognitive Flexibility in Autism Spectrum Disorder. *Journal of Autism and Developmental Disorders*, *51*, 3477-3485.
- Su, W. C., Srinivasan, S., & Bhat, A. N. (2025). Effects of Movement and Sedentary Play Interventions on Executive Functioning and Their Relationships with Sensory, Repetitive, and Negative Behaviors of Children with ASD—A Pilot Rct. *Disability and Rehabilitation*, *47*, 4999-5007. <https://doi.org/10.1080/09638288.2025.2465600>
- Torske, T., Nærland, T., Øie, M. G., Stenberg, N., & Andreassen, O. A. (2018). Metacognitive Aspects of Executive Function Are Highly Associated with Social Functioning on Parent-Rated Measures in Children with Autism Spectrum Disorder. *Frontiers in Behavioral Neuroscience*, *11*, Article ID: 258. <https://doi.org/10.3389/fnbeh.2017.00258>
- Trott, M., Driscoll, R., Iorio, E., & Puleo, E. (2022). A Meta-Analysis and Systematic Review

- of the Association between Physical Activity and Executive Function in Children with Autism Spectrum Disorder. *Autism*, *26*, 2078-2090.
- Tse, A. C. Y., Anderson, D. I., Liu, V. H. L., & Tsui, S. S. L. (2021). Improving Executive Function of Children with Autism Spectrum Disorder through Cycling Skill Acquisition. *Medicine & Science in Sports & Exercise*, *53*, 1417-1424. <https://doi.org/10.1249/mss.0000000000002609>
- Tse, A. C., Liu, V. H., Lee, P. H., Anderson, D. I., & Lakes, K. D. (2024). The Relationships among Executive Functions, Self-Regulation, and Physical Exercise in Children with Autism Spectrum Disorder. *Autism*, *28*, 327-341. <https://doi.org/10.1177/13623613231168944>
- Tse, C. Y. A., Lee, H. P., Chan, K. S. K., Edgar, V. B., Wilkinson-Smith, A., & Lai, W. H. E. (2019). Examining the Impact of Physical Activity on Sleep Quality and Executive Functions in Children with Autism Spectrum Disorder: A Randomized Controlled Trial. *Autism*, *23*, 1699-1710. <https://doi.org/10.1177/1362361318823910>
- Varigonda, A., B. Edgcomb, J., & T. Zima, B. (2020). The Impact of Exercise in Improving Executive Function Impairments among Children and Adolescents with ADHD, Autism Spectrum Disorder, and Fetal Alcohol Spectrum Disorder: A Systematic Review and Meta-Analysis. *Archives of Clinical Psychiatry (São Paulo)*, *47*, 146-156. <https://doi.org/10.15761/0101-608300000000251>
- Wang, J. (2020). *Effects of Small Basketball on Executive Function and Resting-State Brain Functional Regional Homogeneity in Preschool Children with Autism Spectrum Disorder*. Doctoral Dissertation, Yangzhou University.
- Wang, Q., Jia, S., Ding, F., Wang, X., Si, Y., Wang, X. et al. (2025). Effect of Fundamental Movement Skills Practice on Executive Function and Social Interaction Ability in Children with Moderate Autism: A Randomized Controlled Trial. *BMC Complementary Medicine and Therapies*, *25*, Article No. 354. <https://doi.org/10.1186/s12906-025-05107-2>
- Wang, Y., Zhang, Y. B., Liu, L. T., Wang, Y. J., & Wang, Y. (2022). Heterogeneity of Executive Function in Children with Autism Spectrum Disorder: A Systematic Review and Meta-Analysis. *World Journal of Clinical Cases*, *10*, 3071-3081.
- Wu, Q., Cai, W., Du, J., & Chang, F. (2025). The Effect of Basketball Intervention on Executive Function in Children with Autism Spectrum Disorders. *Frontiers in Psychiatry*, *16*, Article ID: 1720218. <https://doi.org/10.3389/fpsy.2025.1720218>
- Zeidan, J., Fombonne, E., Scora, J., Ibrahim, A., Durkin, M. S., Saxena, S. et al. (2022). Global Prevalence of Autism: A Systematic Review Update. *Autism Research*, *15*, 778-790. <https://doi.org/10.1002/aur.2696>
- Zelazo, P. D. (2015). Executive Function: Reflection, Iterative Reprocessing, Complexity, and the Developing Brain. *Developmental Review*, *38*, 55-68. <https://doi.org/10.1016/j.dr.2015.07.001>
- Zhang, Y., Tian, H., Tao, Y., Li, Y., Wang, D., & Qin, L. (2025). A Study on the Effects of Three Game Intervention Programs on Executive Functions of Preschool Autistic Children. *International Journal of Developmental Disabilities*, *71*, 168-178. <https://doi.org/10.1080/20473869.2023.2215606>
- Zhao, Y., Lu, F., Ding, R., Zhu, D., Zhang, R., Sun, S. et al. (2025). Prevalence, Incidence, and Characteristics of Autism Spectrum Disorder among Children in Beijing, China. *Autism*, *29*, 884-895. <https://doi.org/10.1177/13623613241290388>
- Zhu, Y., Xu, C., Wan, Q., Guo, L., & Cai, S. X. (2017). Effects of Adapted Physical Exercise Intervention on Visual Working Memory in Children with Autism Spectrum Disorder. *China Sport Science and Technology*, *53*, 55-62.

Zimmerman, D., Owsnworth, T., O'Donovan, A., Roberts, J., & Gullo, M. J. (2020). A Meta-Analysis of the Relationship between Repetitive Behaviors and Executive Function in Autism Spectrum Disorder. *Autism Research, 13*, 2053-2067.