BMC Psychology

RESEARCH

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Comparative effectiveness of physical exercise interventions on sociability and communication in children and adolescents with autism: a systematic review and network meta-analysis

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Abstract

Objective To investigate the efficacy of physical activity as a crucial intervention for Autism spectrum disorder (ASD) in clinical settings, we conducted a network meta-analysis to evaluate the effect of various exercise interventions on sociability and communication in individuals with ASD. Our aim was to identify the exercise modalities most conducive to enhancing these essential skills.

Methods We searched Web of Science, PubMed, Cochrane Library, Scopus, Embase, and searched Chinese databases from inception to April 2024. We included randomized controlled trials that assessed the effects of different exercise types on sociability and communication in individuals with ASD. Network meta-analysis (NMA) was performed using a frequentist approach, and the node-splitting method was applied to assess inconsistency.

Results We included 38 original studies published between 2009 and 2024, with a total of 1,382 participants analyzed for sociability outcomes. Results indicated that sports games [SMD = 1.12, 95%CI (0.51, 1.73)], combination therapy [SMD = 1.11, 95%CI (0.13, 2.09)], group ball sports [SMD = 1.06, 95%CI (0.37, 1.75)], and outdoor exercise [SMD = 1.02, 95%CI (0.50, 1.55)] were more effective than passive controls. A total of 25 original literatures were included in the analysis of communication ability, involving 904 subjects, and the results showed that combination therapy [SMD = 1.57, 95% CI (0.74, 2.40)], sports games [SMD = 1.01, 95% CI (0.45, 1.56)], group ball games [SMD = 0.85, 95% CI (0.45, 1.26)], outdoor exercise [SMD = 0.79, 95% CI (0.48, 1.11)], and mind-body exercise [SMD = 0.79, 95% CI (0.29, 1.30)], all of which were more effective than passive controls.

Conclusion Physical exercise plays a significant role in alleviating symptoms and enhancing sociability and communication in individuals with ASD. Our findings highlight that sports games, combination therapy, team ball sports, and outdoor exercise are particularly effective in improving sociability. In terms of communication skills, combination therapy, sports games, team ball sports, outdoor exercise, and mind-body exercise demonstrated the

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most substantial benefits. These results provide a robust foundation for future interventions aimed at improving the quality of life for individuals with ASD.

Keywords Autism, Adolescents, Children, Network meta-analysis, Physical exercise interventions

Introduction

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects the neurobiological development of individuals and their interactions with the world, leading to social challenges [1, 2]. "Persistent social communication and interaction deficits" are core symptoms of ASD and serve as primary diagnostic criteria for ASD. Individuals with autism exhibit differences in social communication, including difficulties with nonverbal communication and atypical conversational styles. They also demonstrate restricted, repetitive patterns of behavior [3]. Baron proposed that autistic children exhibit a wide range of social skills deficits. Some children isolate themselves and avoid interacting with others [4], while others actively engage in group social activities but struggle to initiate and maintain communication, resulting in inappropriate social behavior. Consequently, individuals with ASD frequently encounter peer rejection and bullying [5–7], which subsequently can lead to poor attachment and intimate relationships. It also may delay the learning process, reduces self-esteem and self-confidence, and has a negative impact on all aspects of their future lives and careers [8, 9].

Studies have demonstrated that ASD is associated with social impairments in cognition, perception, and attention [10]. Specifically, individuals with autism have difficulty using and understanding basic social cues, including eye contact, facial expressions, body language, and variations in voice tone, during communication [1]. Furthermore, children with ASD experience challenges in reading the thoughts and feelings of others (especially the expression of nonverbal information), initiating and maintaining interactive, fluent dialogue, exchanging information, and responding to requests. These challenges can hinder friendly cooperative activities [11–13].

Various interventions have been used to improve the social functioning of children with autism, including drug therapy [14], sensory integration training [15], music therapy [16], and critical response training [17]. Notably, compared with traditional psychotherapy and drug therapy, physical exercise has the advantages of rich forms, individual and group (including team communication and cooperation), unrestricted places, easy to implement, and no side effects of drugs, which has gradually attracted the attention of clinicians [15, 18].

Psychotherapy and medications may be supplemented or replaced by exercise [19]. The World Health Organization (WHO) and the National Institute for Health and Care Excellence (NICE) report that physical activity positively impacts mental health [20]. Physical activity refers to any movement involving the skeletal muscles that require energy expenditure, including work, play, housework, exercise, and sports. To increase physical activity levels, these activities were grouped into various non-sleep categories, including leisure, occupation, transportation, and family activities. Physical activity is considered a transdiagnostic, effective, and inexpensive intervention strategy [21] because physical inactivity is a risk factor for many mental disorders. Several studies have investigated the relationship between physical activity and mental health [22]. Social cognitive theory posits that motivation for behavioral change arises from external environmental stimuli and internal cognitive processes [23]. Physical activity has been demonstrated to improve a patient's quality of life and alleviate symptoms of disease, as it improves cognitive function and is associated with brain plasticity [24].

Physical activity is an important intervention for ASD patients. Through clinical experiments, Smith and Merwin demonstrated a positive correlation between exercise and the prognosis of various psychiatric disorders [25], including mood and neurocognitive disorders. Coffey et al. investigated the effects of a comprehensive exercise intervention on the behavior of children with ASD and whether these behaviors are influenced by the severity of ASD symptoms. The results demonstrated that the intervention significantly improved the behavior of all the children ($p<0.05$) [26]. Furthermore, participants with severe ASD exhibited a significant improvement in social withdrawal ($p<0.05$). Studies have revealed that exercise interventions can improve social communication and white matter integrity in children with autism [8]. Previous studies have demonstrated that physical exercises, such as equestrian training, swimming, fighting, and basketball interventions, can positively affect spinal cord injury in children with ASD [27].

Given the critical importance of social functioning in children with autism, it is imperative to investigate accessible and effective interventions such as exercise. Previous meta-analyses have primarily compared exercise with various psychological interventions [28]. However, few studies have compared the effects of different types of exercise intervention on social function in children with autism.

Recent meta-analyses have demonstrated that physical activity interventions can enhance social

functioning and communication in children and adolescents with autism [29–32]. Chan et al. found that physical activity provides small to moderate improvements in communication and social functioning, with younger participants benefiting the most. This highlights the potential of early intervention in achieving better outcomes for children with autism [29]. Sempl et al. also noted that interventions such as yoga, positive thinking, or meditation can foster various pro-social behaviors in children with autism, including enhanced communication and imitative behaviors [33]. Moreover, Morris et al. emphasized the benefits of coordinated movement interventions, suggesting that Dance Movement Therapy could be particularly effective in improving sociability and communication among autistic children [34].

Despite these findings, few studies have compared the effects of different types of exercise interventions on social function in children with autism [35, 36]. Our study conducted a network meta-analysis to address this gap by evaluating the relative effectiveness of various exercise interventions on social functioning and communication.

Network meta-analysis is an appropriate methodology for achieving research goals. It is also known as multitreatment meta-analysis or mixed-treatment comparison. This methodology is designed to compare evidence from multiple studies (usually randomized trials) of multiple treatments (or other interventions) by combining direct evidence with circumstantial evidence [37]. For instance, network meta-analysis can either use studies that directly compare experimental groups A and B (direct evidence) or computationally analyze the differences between groups A and B by comparing experimental groups A and C and B and C (indirect evidence) [38, 39].

Which specific types of physical activities provide the most significant benefits for improving sociability and communication in children and adolescents with autism? Given the critical role of social functioning in the lives of children with autism, identifying the most effective and practical interventions is essential. Such research has the potential to significantly advance child health and positively influence public health and education. To this end, we conducted a systematic review and network meta-analysis to explore these questions.

Methods

Protocol

This study followed the guidelines outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses of Network Meta-Analyses (PRISMA-NMA) [40]. The protocol was registered with the International Platform of Registered Systematic Review and Meta-analysis Protocols (INPLASY) (INPLASY202460105).

Search strategy

We searched several English databases (Web of Science, PubMed, Cochrane Library, Scopus, and Embase) and Chinese databases (Wan Fang Data and CNKI) using the same Chinese terminology published from inception to April 2024, focusing on identifying studies that examined the effects of various physical exercise interventions on sociability and communication in children and adolescents with autism. We used Medical Subject Headings (MeSH) terms, keywords, and related terms in our search strategy, including "Autism Spectrum Disorder," "child," "adolescent," "sports," "exercise," "physical activity," "social skills," "communication," and "randomized controlled trial." We also manually searched the references of the included studies to ensure completeness of the literature. The details of the search strategy are provided in Appendix 1 S1.

Criteria for inclusion and exclusion

The inclusion criteria were based on the PICOS framework as follows: (a) Population: children or adolescents under 18 years of age with any subtype of ASD; (b) Intervention: various physical exercises with no restrictions on frequency, intensity, duration, and type; (c) Comparison: the comparators involved were controlled and included options such as no intervention, placement on a waiting list, conventional exercise, and other types of physical activity; (d) Outcome: sociability or communication measured using multiple scales and tests; (e) Study design: the type of experiment was a randomized controlled trial (RCT) or quasi-RCT.

The exclusion criteria were as follows: (a) studies where physical exercise was combined with other non-exercise treatments, such as pharmacotherapy or dietary interventions, without separate analysis of exercise effects; (b) non-interventional clinical trials, such as protocol reviews, cohort studies, case-control studies, book chapters, and conference articles; (c) studies with missing, incomplete, or missing data points; (d) the language of the article is not in English or Chinese.

Study selection and data extraction

Studies identified through the search strategy and inclusion and exclusion criteria were independently reviewed by two authors for title and abstract. The full papers were scrutinized following the preliminary screening process. Two authors extracted data separately, and in case of discrepancies, a third author was consulted until a consensus was reached. The data extraction form included study characteristics (author names, year, country, and study design), sample characteristics (sample size, age, and sex ratio), interventions (type, frequency, intensity, duration of each session, and duration of intervention), control information, and outcomes.

Data classification and management

Exercise interventions were categorized as follows: (1) Sports games (exercise activities with fun games, such as running games and spark programs [41]); (2) aquatic exercise; (3) team ball sports; (4) combination therapy (combining physical activity with other non-pharmacological therapies, such as music [42] and social story therapies [43]); (5) outdoor exercise (mainly consisting of horse riding and adventure activities close to nature); (6) fundamental motor skills (including basic motor skills, such as walking, running, jumping, and throwing); (7) mind-body exercise (physical activities that focus on both the physical and mental aspects of health, including tai chi and yoga [44]). We differentiated between control groups categorized as active control (participants in this group engaged in some form of organized physical activity, such as low-intensity stretching exercises, Progressive Muscle Relaxation, or other structured exercises that did not involve the specific interventions being tested); and passive control (participants did not participate in any form of physical activity intervention; this group often included a waiting list or routine care control, where participants received standard care without additional exercise interventions).

Study quality assessment and quality of evidence

The methodological quality of the included studies was assessed by two authors using the Physiotherapy Evidence Database Scale (PEDro) [45], and disagreements were resolved through discussion. The PEDro tool is well known for its reliability and validity in assessing the quality of clinical trials in physical therapy and related disciplines. The scale consists of 11 items, including eligibility criteria, random allocation, concealed allocation, baseline comparability, blind subjects, blind therapists, blind assessors, adequate follow-up, intention-to-treat analysis, between-group comparisons, and estimates and variability. For studies that were already listed in the PEDro online database, we directly retrieved their scores. For studies not listed in the PEDro database, we performed a manual assessment based on the same criteria. This approach ensured accuracy and consistency in evaluating the methodological quality across all included studies. The studies were then classified according to their PEDro scores as follows: < 4 points: poor, 4–5 points: fair quality, 6–8 points: good, and 9–10 points: excellent quality.

The degree of evidence supporting each outcome was assessed using Grading of Recommendations, Assessment, Development, and Evaluation (GRADE). Determine whether to downgrade the quality of evidence based on GRADE's five subtraction items: risk of bias, inconsistency, indirectness, imprecision, and publication bias [46]. Four categories (very low, low, moderate, and high-quality evidence) were used to group the results.

Statistical analysis

A paired meta-analysis was used to compare the effects of various physical exercise interventions with those of the control group. To combine outcomes measured on different scales, we calculated the standardized mean differences (SMD) and 95% confidence intervals (CIs) for continuous variables. Statistical heterogeneity was assessed using the I^2 statistic, with values exceeding 50% indicating significant heterogeneity [47]. A random-effects model was used in the presence of significant heterogeneity; otherwise, a fixed-effects model [48].

This network meta-analysis followed the recommendations of PRISMA-NMA [49], and we analyzed the data using a frequentist approach to estimate the relative treatment effects using STATA (version 17.0) and R (version 4.4.0). We used the node-splitting method to assess inconsistency, which occurs when different sources of evidence (direct and indirect) provide conflicting estimates of the same treatment effect [50]. This method comparing direct evidence from pairwise trials with indirect evidence derived from the network meta-analysis. By "splitting" the evidence at a specific node, we can evaluate whether the direct and indirect evidence are in agreement [51, 52]. We performed pairwise comparisons at each node in the network, assessing the p-values for each comparison. Specifically, a p-value greater than 0.05 indicates that the direct and indirect evidence are consistent, meaning there is no statistically significant inconsistency in the network. Conversely, a p-value of 0.05 or less indicates potential inconsistency that warrants further investigation.

This network meta-analysis combined direct evidence from RCTs with head-to-head comparison and indirect evidence, where each of the two interventions was individually compared against a common comparator. The data were analyzed using the 'Network' package to create a visual network structure graph. Each node in the graph represents a distinct intervention or control condition, where the size of the node is proportional to the number of participants receiving that intervention, and the lines connecting the nodes indicate direct comparisons made in the included studies. The thickness of each line was proportional to the number of studies comparing two connected interventions. Thicker edges indicate more direct comparisons, highlighting the robustness and frequency of certain intervention comparisons in the network [53]. We used the surface under the cumulative ranking curve (SUCRA) to rank the interventions and plotted the probability rankings in the table. SUCRA values vary from 0 to 1 and indicate the likelihood of an intervention being the best treatment, with higher values indicating better intervention outcomes [54]. Finally, the funnel plot was plotted and checked for publication bias using a symmetry criterion check [53].

Results

Selection process

Based on the search strategy, the preliminary search identified 3843 articles. After removing duplicates and screening titles and abstracts, 196 articles remained. After applying the inclusion and exclusion criteria, 38 trials were included in the network meta-analysis. A flow chart of the search and the included studies is presented in Fig. 1.

Characteristics of included studies

These studies (published between 2009 and 2024) included 1454 children and adolescents between the ages of 3 and 15 years, with 740 in the experimental group and 714 in the control group. In these studies, the experimental group performed various physical exercise interventions. The interventions included sports games (eight studies), aquatic exercise (three studies), team ball sports (mini-basketball and soccer) (six studies), combination therapy (exercise with music and social stories therapy) (three studies), outdoor exercise (horseback riding and

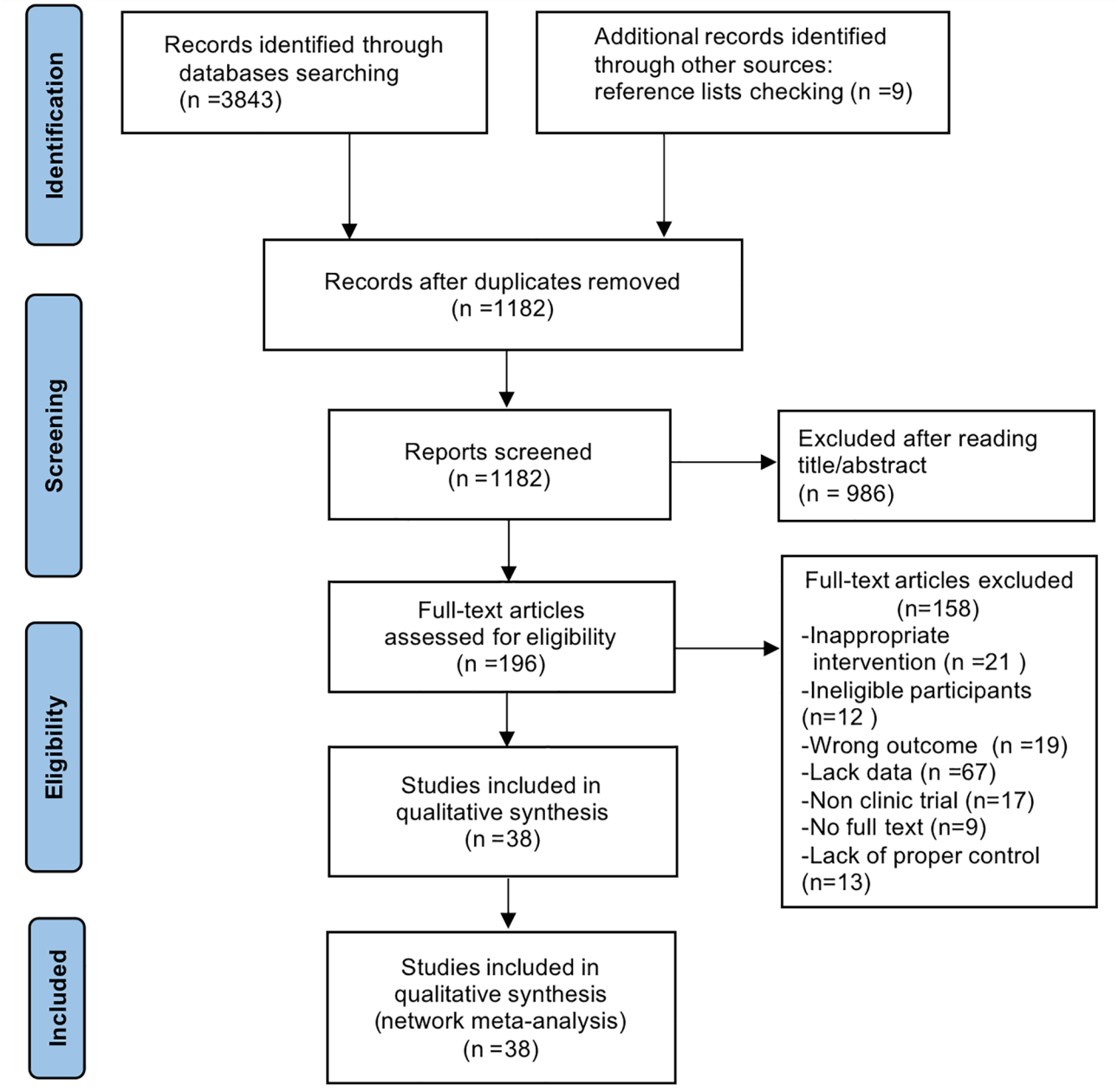

Fig. 1 PRISMA flow diagram of the study selection

outdoor rehabilitation activities) (10 studies), fundamental motor skill (two studies), and mind-body exercise (six studies). The median length of therapy was 14 weeks, and each session lasted 45 min. The physical exercise intensity was mostly moderate or moderate-to-vigorous. Three studies did not report the sex of the participants, with a male-to-female ratio of approximately 4:1. Further details are presented in Table 1.

MVPA, Moderate-to-Vigorous Physical Activity. N/A, Not Applicable.

Risk of bias assessment

The methodological quality of the included studies was evaluated using the PEDro Scale. The quality scores for the studies ranged from 4 to 7, reflecting a spectrum of fair (36%) to good (63.2%) quality. (Appendix 1, S2, Table S1). Most studies demonstrated adequate randomization and baseline comparability, indicating that the groups were well-matched at the start of the trials. However, blinding in exercise trials is particularly challenging because of the nature of the interventions, where it is difficult to blind providers, patients, and outcome assessors. This lack of blinding can introduce various biases that can potentially affect the reliability of the outcomes.

Outcome-sociability

For sociability, 38 studies and 1,382 subjects were included, involving seven interventions. Pairwise meta-analyses were conducted to compare the efficacy of various physical exercise interventions and control groups (Appendix 1, S3, Table S2). The inconsistency test after network analysis did not reveal any significant inconsistencies (Appendix 1, S4, Figure S1).

All physical activity interventions, except combination therapy, were directly compared with the non-physical activity control group (Fig. 2). Direct comparisons were also made between the different physical activity interventions. However, there is still a lack of studies directly comparing aquatic exercise, outdoor exercise, and team ball sports with other physical activity interventions.

The network meta-analysis revealed the following statistically significant results: sports games [SMD = 1.12, 95% CI (0.51, 1.73)], combination therapy [SMD = 1.11, 95% CI (0.13, 2.09)], group ball sports [SMD = 1.06, 95% CI (0.37, 1.75)], and outdoor exercise [SMD = 1.02, 95% CI (0.50, 1.55)] were more effective than passive controls (Fig. 3).

The rankings of physical exercise interventions based on cumulative probability plots and SUCRA are presented in Appendix 1, S4, Figure S2. In SUCRA, sports games were the most effective type of physical exercise intervention, with an SUCRA value of 80.4%, followed by combination therapy (77.6%), group ball sports (77.1%), and outdoor exercise (75.3%).

Furthermore, the results comparing the adjusted funnel plots are provided in the Supplementary Figures (Appendix 1, S5, Figure S4). No significant asymmetry was observed between groups. Based on the meta-regression analyses, no significant effects were identified for participant age, exercise intervention intensity, session duration, or total weeks of intervention, indicating that these factors did not significantly modify the overall effect size. The Meta-regression analysis results are presented in Appendix 1, S6, Figure S5. Overall, the quality of evidence was judged to be moderate to very low (Appendix 1, S7, Table S4).

Outcome-communication

For communication, 25 studies with 904 subjects were included, involving seven interventions. Pairwise meta-analyses compared the efficacy of various physical exercise interventions and the control groups (Appendix 1, S2, Table S3). After the network analysis, the inconsistency test revealed no significant inconsistencies (Appendix 1, S8, Figure S6).

Fundamental motor skills and combination therapy were not directly compared with non-sporting controls but with other physical activity interventions (sports games, mind-body exercises) (Fig. 4). Additionally, there is a lack of studies directly comparing aquatic and outdoor exercises and team ball sports with other physical exercise interventions.

Figure 5 demonstrates the statistically significant results of the network meta-analysis: combination therapy [SMD = 1.57, 95% CI (0.74, 2.40)], sports games [SMD = 1.01, 95% CI (0.45, 1.56)], group ball games [SMD = 0.85, 95% CI (0.45, 1.26)], outdoor exercise [SMD = 0.79, 95% CI (0.48, 1.11)], and mind-body exercise [SMD = 0.79, 95% CI (0.29, 1.30)], all of which were more effective than passive controls.

Rankings of physical exercise interventions based on cumulative probability plots and SUCRA are presented in Appendix 1, S8, Figure S7. According to the SUCRA, combination therapy was the most effective physical exercise intervention with an SUCRA value of 97.5%, followed by sports games (77.9%), group ball games (67.2%), outdoor exercise (62.5%), and physical and mental exercise (62.3%).

Finally, the results comparing the adjusted funnel plots are provided in Supplementary Figures (Appendix 1, S9, Figure S9), no significant asymmetry was observed. Meta-regression analyses were conducted to explore the potential influence of participant age, intensity of physical exercise interventions, duration per session, and total weeks of intervention on the overall effect size. The results indicated that none of these factors showed a statistically significant impact on the outcomes. Meta-regression analysis results are presented in Appendix

Table 1 Characteristics of included study

Study	Country	Participants (intervention vs. control)			Interventions		Comparator	Outcomes
		Sample size	Age (year)	Female/male	Type	Time, frequency, period, intensity		
Bahrami et al. (2016) [55]	Iran	15 vs. 15	9.20 ± 3.32 vs. 9.06 ± 3.33	2/13 vs. 2/13	Karate techniques training	90 min, 4 weekly, 14 weeks, MVPA	Routine care	Social interaction
Bass et al. (2009) [56]	USA	19 vs. 15	6.95 ± 1.67 vs. 7.73 ± 1.65	2/17 vs. 3/12	Therapeutic horseback riding	60 min, 1weekly, 12 weeks, Moderate	Routine care	Social cognition; Social communication
Borgi et al. (2016) [57]	Italy	15 vs. 13	9.2 ± 1.8 vs. 8.0 ± 1.5	0/15 vs. 0/13	Therapeutic riding	60 min, 1 weekly, 25 weeks, Moderate	Routine care	Socialization
Caputo et al. (2018) [58]	Italy	13 vs. 13	8.3 ± 2.3 vs. 7.7 ± 2.0	2/11 vs. 7/6	Multisystem aquatic therapy	45 min, 1–2 weekly, 40 weeks, MVPA	Routine care	Social interaction; Communication
Chan et al. (2013) [59]	China	20 vs. 20	11.28 ± 3.90 vs. 12.42 ± 3.25	1/19 vs. 3/17	Mind-body exercise (Nei Yang Gong)	60 min, 2 weekly, 4 weeks, Moderate	Progressive muscle relaxation	Social interaction; Communication
Gabriels et al. (2015) [60]	USA	58 vs. 58	10.5 ± 3.2 vs. 10 ± 2.7	9/49 vs. 6/52	Therapeutic horseback riding	45 min, 1 weekly, 10 weeks, Moderate	No sports activities	Socialization; Social communication
Howells et al. (2020) [61]	Australia	19 vs. 21	7.98 ± 1.71 vs. 8.62 ± 2.26	3/17 vs. 1/20	Australian rules football	60 min, 1 weekly, 4–21 weeks, MVPA	Organized physical activity	Socialization; Communication
Movahedi et al. (2013) [62]	Iran	15 vs. 15	9.54 ± 3.43 vs. 9.06 ± 3.33	2/13 vs. 2/13	Kata techniques training	20 min, 4 weekly, 14 weeks, MVPA	No sports activities	Social interaction
Najafabadi et al. (2018) [41]	Iran	12 vs. 14	7.08 ± 2.06 vs. 8.07 ± 2.23	N/A	SPARK games: stability and displacement movements	40 min, 3 weekly, 12 weeks, Moderate	No sports activities	Social interaction; Sociability
Zachor et al. (2017) [63]	Israel	30 vs. 21	5.6 ± 0.9 vs. 5.0 ± 1.0	4/26 vs. 7/14	Outdoor adventure programme	30 min, 1 weekly, 13 weeks, MVPA	No sports activities	Social communication
Zhao et al. (2018) [18]	China	21 vs. 20	6.14 ± 0.96 vs. 6.1 ± 0.98	7/14 vs. 5/15	Structured physical activity program	30 min, 2 weekly, 12 weeks, MVPA	Regular sports activities	Social interaction; Communication
Cai et al. (a) [8]	China	15 vs. 14	5.13 ± 0.61 vs. 4.68 ± 0.72	3/12 vs. 1/13	Mini-Basketball training program	40 min, 5 weekly, 12 weeks, MVPA	Routine activities	Social communication
Cai et al. (b) [64]	China	15 vs. 15	5.03 ± 0.64 vs. 4.56 ± 0.84	3/12 vs. 1/14	Mini-Basketball training program	40 min, 5 weekly, 12 weeks, MVPA	Routine care	Social communication
Pan et al. (2010) [65]	China	8 vs. 8	7.27 ± 1.25 vs. 7.20 ± 0.89	N/A	Water exercise swimming program	90 min, 2 weekly, 10 weeks, Moderate	No sports activities	Social competence
Sansi et al. (2021) [66]	Turkey	13 vs. 9	8.69 ± 0.86 vs. 8.26 ± 0.78	1/12 vs. 1/8	Inclusive physical activity program	60 min, 2 weekly, 12 weeks, Moderate	No sports activities	Co-operation
Silva et al. (2009) [67]	USA	25 vs. 21	5.43 ± 1.73 vs. 4.44 ± 1.56	6/19 vs. 3/18	Qigong sensory training	60 min, 3 weekly, 16 weeks, Moderate	No sports activities	Social competence

Table 1 (continued)

Study	Country	Participants (intervention vs. control)			Interventions		Comparator	Outcomes
		Sample size	Age (year)	Female/male	Type	Time, frequency, period, intensity		
Steiner (2015) [68]	Hungary	13 vs. 13	10–13 vs. 10–13	7/6 vs. 7/6	Therapeutic horse riding	30 min, 1 weekly, 8 weeks, Low	No sports activities	Social interaction; Communication
Yang (2021) [69]	China	15 vs. 15	4.67 ± 0.7 vs. 5.03 ± 0.55	3/12 vs. 2/13	Mini-Basketball training program	40 min, 5 weekly, 12 weeks, MVPA	No sports activities	Social communication
Zhao (2021) [70]	China	31 vs. 30	7.06 ± 1.5 vs. 7.13 ± 1.36	10/21 vs. 7/23	Therapeutic horseback riding	60 min, 2 weekly, 16 weeks, Moderate	Regular activities	Social skills; Communication
Liu (2021)(a) [71]	China	13 vs. 10	8.23 ± 1.30 vs. 8.10 ± 1.37	2/11 vs. 3/7	Gross motor intervention	60 min, 4 weekly, 6 weeks, MVPA	No sports activities	Social communication
Liu (2024) [72]	China	36 vs. 36	5.08 ± 1.17 vs. 4.83 ± 1.22	9/27 vs. 12/24	Sports games	60 min, 5 weekly, 12 weeks, Moderate	FMS	Social communication
Liu (2021)(b) [73]	China	30 vs. 30	3.24 ± 0.94 vs. 3.15 ± 0.96	13/17 vs. 12/18	Adaptive exercise	40 min, 5 weekly, 26 weeks, Moderate	Language training, Sensory training	Sociability
Zhang (2017) [74]	China	30 vs. 30	7.62 ± 3.14 vs. 7.54 ± 2.96	13/17 vs. 12/18	Motor functional skills	40 min, 5 weekly, 26 weeks, Moderate	No sports activities	Sociability; Language
Özyurt (2017) [75]	Turkey	12 vs. 12	6.81 ± 2.46 vs. 6.76 ± 2.25	5/7 vs. 5/7	Therapeutic horseback riding	60 min, 1 weekly, 8 weeks, Moderate	No training	Social interaction
Zanobini (2019) [76]	Italy	13 vs. 12	5.69 ± 1.27 vs. 5.42 ± 1.54	3/10 vs. 3/9	Swimming program	30 min, 1 weekly, 12 weeks, Moderate	Regular sports activities	Social communication
Xu (2018) [77]	China	52 vs. 54	14.8 ± 6.1 vs. 15.5 ± 5.1	12/40 vs. 12/42	Outdoor rehabilitation activities	90 min, 3 weekly, 12 weeks, MVPA	Traditional education model	Socialization
Pan (2019) [78]	USA	8 vs. 8	11.88 ± 2.45 vs. 9.80 ± 2.82	2/6 vs. 1/7	Therapeutic horseback riding	45 min, 1 weekly, 10 weeks, Low	Regular activities	Social communication
Wang (2023) [79]	China	15 vs. 15	6.93 ± 1.08 vs. 6.93 ± 1.19	6/9 vs. 7/8	Horseback riding	45 min, 3 weekly, 16 weeks, Moderate	Traditional physical education classes	Sociability; Social communication
Lei (2022) [42]	China	15 vs. 15	10.46 ± 2.69 vs. 10.53 ± 2.79	10/5 vs. 9/6	Orff music and sports games	60 min, 3 weekly, 9 weeks, Moderate	Simple sports games	Social communication
Luan (2023) [80]	China	15 vs. 15	11.07 ± 2.37 vs. 11.33 ± 2.19	7/8 vs. 7/8	Light equipment rhythmic exercise	60 min, 3 weekly, 8 weeks, Moderate	Unarmed rhythmic gymnastics	Social communication
Zhao (2022) [81]	China	6 vs. 6	4–6 vs. 4–6	2/4 vs. 2/4	Small basketball training	60 min, 2 weekly, 16 weeks, Moderate	Normal routine	Social communication
Yan (2021) [82]	China	20 vs. 20	5.86 ± 0.9 vs. 6.00 ± 0.82	6/14 vs. 7/13	Fun track and field sports	45 min, 3 weekly, 10 weeks, Moderate	Routine exercise	Sociability; Communication
Zhai (2022) [83]	China	8 vs. 8 vs. 8	3–6 vs. 3–6 vs. 3–6	N/A	Sports games	60 min, 5 weekly, 12 weeks, Moderate	Functional motor skills; General education	Sociability; Communication
Pan (2023) [84]	China	4 vs. 4	7–8 vs. 7–8	1/3 vs. 1/3	Fun track and field sports	35 min, 3 weekly, 16 weeks, Moderate	Traditional track and field training	Sociability; Communication
Zheng (2022) [85]	China	10 vs. 10	5–8 vs. 5–8	2/8 vs. 2/8	Sports games	45 min, 3 weekly, 12 weeks, Moderate	Traditional physical education	Sociability

Table 1 (continued)

Study	Country	Participants (intervention vs. control)			Interventions		Comparator	Outcomes
		Sample size	Age (year)	Female/male	Type	Time, frequency, period, intensity		
Wang (2020) [43]	China	41 vs. 41	8.27 ± 2.53 vs. 8.02 ± 2.73	14/27 vs. 18/23	Social storise combined with sports	60 min, 3 weekly, 15 weeks, Moderate	Regular sports activities	Sociability; Language
Ma (2020) [86]	China	17 vs. 11	13.29 ± 1.80 vs. 13.18 ± 1.60	5/12 vs. 1/10	Dance therapy	60 min, 2 weekly, 44 weeks, MVPA	Non-intervention	Sociability; Communication
Shanker (2023) [87]	China	23 vs. 20	9.77 ± 2.63 vs. 9.61 ± 1.93	4/19 vs. 4/16	Yoga	45 min, 5 weekly, 12 weeks, Moderate	Regular sports activities	Social communication

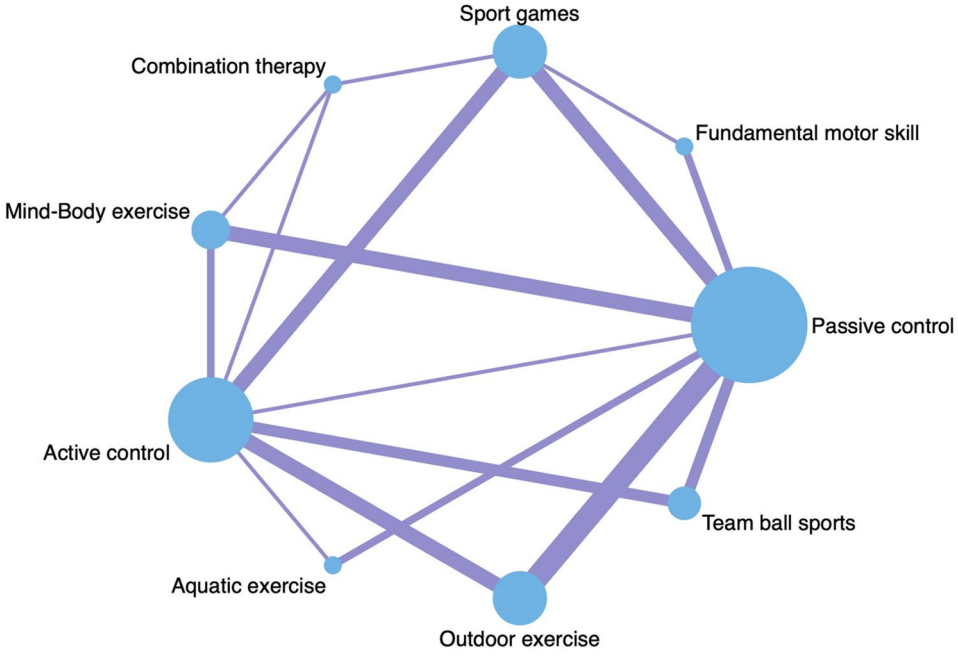

Fig. 2 Network plot for sociability

Sport games								
0.01 (-0.97,1.00)	**Combination therapy**							
0.06 (-0.80,0.92)	0.05 (-1.07,1.17)	**Team ball sports**						
0.10 (-0.65,0.84)	0.09 (-0.96,1.13)	0.04 (-0.76,0.84)	**Outdoor exercise**					
0.59 (-0.21,1.39)	0.58 (-0.43,1.58)	0.53 (-0.33,1.40)	0.49 (-0.27,1.25)	**Mind-Body exercise**				
0.71 (-0.36,1.78)	0.70 (-0.60,2.00)	0.65 (-0.46,1.76)	0.61 (-0.42,1.64)	0.12 (-0.96,1.20)	**Aquatic exercise**			
1.11 (0.02,2.19)	1.10 (-0.31,2.50)	1.05 (-0.23,2.33)	1.01 (-0.19,2.21)	0.52 (-0.72,1.76)	0.40 (-1.03,1.82)	**Fundamental motor skill**		
1.05 (0.40,1.71)	**1.04 (0.10,1.98)**	**0.99 (0.31,1.67)**	**0.95 (0.37,1.54)**	0.46 (-0.21,1.13)	0.34 (-0.63,1.31)	-0.06 (-1.23,1.12)	**Active control**	
1.12 (0.51,1.73)	**1.11 (0.13,2.09)**	**1.06 (0.37,1.75)**	**1.02 (0.50,1.55)**	0.53 (-0.09,1.15)	0.41 (-0.52,1.34)	0.01 (-1.09,1.11)	0.07 (-0.46,0.60)	**Passive control**

Fig. 3 League table for sociability

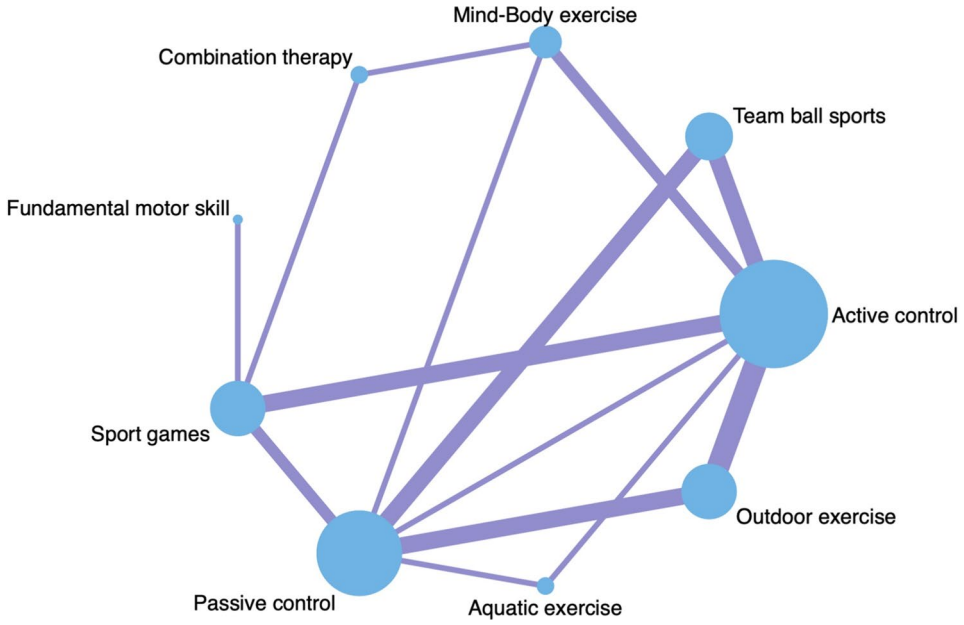

Fig. 4 Network plot for communication

Combination therapy							
0.56 (-0.19,1.32)	Sport games						
0.72 (-0.15,1.58)	0.15 (-0.47,0.78)	Team ball sports					
0.78 (-0.06,1.61)	0.21 (-0.37,0.80)	0.06 (-0.36,0.48)	Outdoor exercise				
0.78 (-0.03,1.58)	0.21 (-0.43,0.86)	0.06 (-0.49,0.61)	-0.00 (-0.51,0.50)	Mind-Body exercise			
1.12 (0.11,2.12)	0.56 (-0.25,1.36)	0.40 (-0.29,1.10)	0.34 (-0.32,1.00)	0.34 (-0.41,1.09)	Aquatic exercise		
1.46 (0.65,2.26)	**0.89 (0.35,1.44)**	**0.74 (0.37,1.10)**	**0.68 (0.38,0.98)**	**0.68 (0.25,1.11)**	0.34 (-0.30,0.97)	Active control	
1.57 (0.74,2.40)	**1.01 (0.45,1.56)**	**0.85 (0.45,1.26)**	**0.79 (0.48,1.11)**	**0.79 (0.29,1.30)**	0.45 (-0.18,1.08)	0.12 (-0.23,0.47)	Passive control
1.69 (0.72,2.66)	**1.13 (0.52,1.73)**	**0.97 (0.10,1.84)**	**0.91 (0.07,1.75)**	**0.91 (0.03,1.80)**	0.57 (-0.44,1.57)	0.23 (-0.58,1.05)	0.12 (-0.71,0.94)	Fundamental motor skill

Fig. 5 League table for communication

1, S10, Figure S10. Overall, the quality of evidence was assessed as moderate to very low (Appendix 1, S11, Table S5).

Discussion

ASD is a neurodevelopmental disorder that significantly affects a child's social interaction skills [88]. This network meta-analysis compared the relative efficacy of various exercise interventions in terms of their impact on the sociability and communication abilities of children diagnosed with ASD. This is the first network meta-analysis of sociability and communication in children with autism that integrates a more comprehensive literature. This study categorized the types of exercise into sports games, combination therapies, outdoor exercise, and mind-body exercise. Our findings confirmed the effect of various physical exercise interventions on improving sociability and communication in children with ASD. They revealed that sports games are most likely to be an exercise therapy to improve the sociability of children with ASD. The best exercise intervention to improve communication is combination therapy (sports games combined with music therapy or mind-body therapy combined with music therapy). Our findings should be interpreted with circumspection given the significant presence of studies with limited quality and direct evidence in our analysis.

Effect of sports games on sociability and cognitive development in children with ASD

Previous research suggests that physical activity positively impacts cognitive, behavioral, and motor skills in individuals with ASD [89, 90]. Our results revealed that sports games had a significant effect on the sociability of children with ASD, consistent with the findings of Liu et al. [72]. The sports games we discussed here are an intervention method different from the one-to-one treatment but carried out in the form of a group. This type of intervention enhances the enthusiasm of patients during

training and helps them return to society and integrate into the environment of collective life [91, 92]. During exercise, the regulation of myosin-irisin can promote the expression of brain-derived sports nutrition factor protein (BDNF) in the prefrontal cortex of patients [93]. At the same time, IL-6 released by muscles binds to its corresponding receptors after passing the blood-brain barrier, inducing BDNF-mediated cell expression, thus improving cognition and brain plasticity mechanism [94].

Fun exercise improves the metabolism of neurotransmitters involved in social communication, which also enhances the social skills of patients by regulating their levels of oxytocin and serotonin [41, 95]. Oxytocin is primarily involved in the early life activities of mammalian neurodevelopment and relieves tension in patients with autism [96]. Compared to healthy humans, children with ASD have lower levels of oxytocin, which affects normal development of the nervous system [97]. Serotonin, an inhibitory neurotransmitter, is mainly involved in the regulation of cognitive function, and ASD is closely associated with increased dependence on serotonin signaling [98–100].

Combination exercise shows positive effects on communication skills

Consistent with the results of Wang, we believe that the combination of exercise and sports games exhibited a positive effect on the communication ability of children with ASD, and this effect may be associated with the severity of the condition, cognitive ability, and duration of the intervention [79]. However, in terms of the most effective interventions, combination exercise was more effective than playing sports games [101, 102]. Combination exercise refers to music therapy combined with sports games or mind-body therapy as an intervention. Music therapy in combined movement increases the interest in training based on movement games and improves patient compliance and cooperation [42, 103]. Adolescents with ASD have poor hypoconnectivity in the sensorimotor network; therefore, sensory integration often does not function well [104, 105]. Specific movements in music therapy, such as following music, can be directly linked to brain activity, helping improve the symptoms of multimodal functional separation of brain areas often seen in autistic patients and improving sensory integration in patients [106, 107]. The intervention site of the social story method is casual, the operation is simple, and it has a good intervention effect on the development of language and social participation in ASD [108]. The social story method combined with sports intervention can improve the intervention effect of children with ASD and has positive significance for improving autistic behavior, self-care, and emotions [43, 109].

The effect of team ball games on sociability and communication

Team ball games improved sociability and communication equally in children with ASD, but to a lesser extent than the two previous studies. Group sports involve small-group training with several individuals and are consistent with the recommended physical activity for children with ASD [110]. Structural abnormalities in the limbic system, such as the amygdala, may be linked to social difficulties in patients [111]. Team ball games delayed the degeneration of the limbic system, which was sufficient to establish a correlation between ASD and the nervous system, particularly the callosum and white matter microstructures of the brain [69]. Long-term exercise intervention is widely used in treating ASD because of its safety and low cost [27]. When teachers teach children with ASD in this way, nonverbal communication, such as touch, stimulates the sensory and perceptual systems of the patients, thereby improving their social initiative [112].

The effect of team ball games on social communication skills

Outdoor adventures are important leisure activities that enhance the social and communication skills of people with ASD. Outdoor adventure programs allow patients to collaborate with their peers and may improve their missing social communication skills [113, 114]. Gabriels et al. suggested therapeutic horseback riding uses ASD and horse interaction to change patients' stress levels and improve their social communication and communication skills [78]. The unique stimulation of horse-riding activity increases the patient's motivation to participate, which may improve motor control in the cerebellum [115, 116]. In addition to exercise interventions, the hormone levels of individuals with ASD themselves can also affect their social and communication skills. Viau's team demonstrated a link between cortisol and autism using changes in hormone levels produced after interactions between children with ASD and dogs. They measured cortisol levels in 42 ASD patients during daily life, interaction with the dog, and after the dog left, and found that cortisol levels decreased significantly during the patient's interaction with the dog, and the hormone levels returned to baseline values after the dog left [117]. Cortisol is a hormone associated with stress, and lower levels of cortisol can help relieve stress and promote physical and mental relaxation [118]. Therefore, lowering cortisol levels can help improve the situation in which patients have deficits in social and communication skills.

FMS intervention has weak effects on communication skills

The intervention effect on Fundamental Motor Skills (FMS) was unsatisfactory, which is inconsistent with the

findings of Li et al. [35]. This discrepancy may be attributed to the inclusion of ball games in the FMS category'in Li's study, whereas our study distinguished ball games from FMS to better explore the specific intervention effects of group ball games. In our context, FMS encompasses individual activities, such as walking, running, jumping, and throwing, which have been reported to improve cardiorespiratory fitness, physical activity, and flexibility [119, 120]. Our results indicated that the intervention effect of the FMS was even lower than that of the general control group in terms of communication. This outcome suggests that repetitive, monotonous exercises may negatively affect children with autism. Given the limited literature on FMS interventions, further research is required to investigate whether such single-type exercises can adversely affect this population.

Future directions

The findings of our network meta-analysis have profound implications for the future development of clinical practice and scientific research. In clinical practice, sports games should be used as a complementary treatment for ASD because they significantly improve patients' social and communication skills. However, more scientific research is required to determine how exercise affects social and communication functioning.

Limitations

Our network meta-analysis has several limitations. First, the effect sizes reported for some interventions, particularly those based on smaller sample sizes or with significant heterogeneity, should be interpreted with caution. The confidence intervals for these effect sizes were often wide, indicating a degree of uncertainty in the estimated effects. This variability suggests that the true effect could differ substantially, and future studies with larger, more homogenous samples are needed to confirm these findings. Second, some studies included in the network meta-analysis were of poor methodological quality, particularly due to the lack of double-blind design, which may introduce bias. This issue is especially relevant in exercise interventions, where implementing blinding for both participants and assessors is inherently challenging. Such limitations introduce potential biases and weaken the strength of the evidence presented. Third, the generalizability of our results to all children with ASD is limited. The interventions included in this meta-analysis were diverse, with varying types, intensities, and durations of exercise, as well as differences in participant characteristics, such as age, severity of ASD symptoms, and cognitive abilities. Although meta-regression was conducted, future studies should explore the optimal exercise dose and adequately apply the frequency, intensity, type, and time principle [121] to develop standardized exercise prescriptions for therapeutic use. Finally, most studies focused geographically on a few countries. Future studies should aim for a more geographically diverse sample to better capture worldwide practices and cultural differences in ASD treatment.

Conclusion

Our findings indicate that sports games have the most beneficial effect on the sociability of children with autism, followed by combination therapy, team ball sports, and outdoor exercise. Regarding communication, combination therapy appears to be the most effective, followed by sports games, team ball sports, outdoor exercise, and mind-body exercise. Future research should prioritize the study of these interventions, and these findings should be integrated into physical exercise interventions and programs specifically designed for children with autism.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40359-024-02210-w.

Supplementary Material 1

Supplementary Material 2

Acknowledgements
Not applicable.

Author contributions
Conceptualization, R.K. and J.Z.; methodology, R.Z. and W.R.; software, R.K. and F.Z.; writing—original draft preparation, R.K. and Z.L.; writing—review and editing, R.K., M.L and J.Z. All authors have read and agreed to the published version of the manuscript.

Funding
Fundamental Research Funds for the Central Universities (2024CDJSKXYTY03).

Data availability
The corresponding author can provide the datasets used and/or analyzed for this work upon reasonable request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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Received: 27 June 2024 / Accepted: 19 November 2024
Published online: 30 November 2024

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