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Effect of intervention programs to promote fundamental motor skills among typically developing children: A systematic review and meta-analysis

Dong Zhang [a,*], Kim Geok Soh [a,*], Yoke Mun Chan [b], Zeinab Zaremohzzabieh [c]

[a] Department of Sports Studies, Faculty of Educational Studies, Universiti Putra, Malaysia
[b] Department of Dietetics and Nutrition, Faculty of Medicine and Health Sciences, Universiti Putra, Malaysia
[c] Institute for Social Science Studies, Universiti Putra, Malaysia

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ABSTRACT

Background: Proficiency in fundamental motor skills (FMS) is associated with children's overall development and long-term physical literacy. However, FMS is not acquired naturally, but needs to be trained.
Objective: This study aims to evaluate and provide up-to-date evidence on the effectiveness of intervention programs focused on promoting FMS among typically developing children between 2010 and 2022.
Methods: Following Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, a search was conducted in four databases (PubMed, Scopus, Web of Science, and SPORT Discus) from January 2010 to December 2022. Studies included any interventions in preschools and primary schools that aimed to improve fundamental motor skills in typically developing children aged 3 to 12, and reported fundamental motor skills outcomes and statistics.
Results: Thirty-six articles (21 randomized controlled trials, 11 pre-post trials, and four quasi-experimental trials) satisfied all inclusion and exclusion criteria. Outcomes were primarily demonstrated in composite fundamental motor skills (n = 32) and its three primary parts: locomotor skills (n = 26), object control skills (n = 26), and balance skills (n = 4). A *meta*-analysis was conducted on 16 of these publications, revealing significant intervention effects for overall FMS proficiency (Std diff in means = 0.928, 95 % confidence interval 0.744–1.112, P = 0.001), locomotor skills (Std diff in means = 0.636, 95 % confidence interval 0.508–0.765, P = 0.001) and object control skills (Std diff in means = 0.871, 95 % confidence interval 0.660–1.081, P = 0.001).
Discussion and Conclusions: The results indicate that implementing FMS development intervention programs in preschools and primary schools can be effective in promoting typically developing children's fundamental motor skills. The interventions on object control skills had a more significant effect size than locomotor skills. However, existing evidence cannot conclude which types of interventions are most effective.

1. Introduction

Fundamental motor skills (FMS) are the foundation of children's movement. Numerous studies in recent years have highlighted the critical importance of mastering fundamental motor skills for children's overall development and long-term physical literacy (Whitebread and Coltman, 2015). These skills serve as the foundational movements or precursor patterns for more advanced sports techniques (Barnett et al., 2016), as many motor skills used in athletics and daily activities are advanced versions of FMS. For example, javelin and baseball throwing are advanced forms of overhand throwing (Walkley et al., 1996). Consequently, developing proficiency in FMS is necessary to achieve excellence in a sport or game and to become an elite athlete. Moreover, FMS provides children with the skills to explore their environment and learn the world around them, which promotes physical activity (Wick et al., 2017), while supporting cognitive and social development during childhood (Goodway et al., 2019). However, the reality is that children worldwide have insufficient FMS, and several types of research conducted on children in various nations have come to the same conclusions (Aye et al., 2018; Hardy et al., 2010; Kit et al., 2017). According to a comprehensive systematic review of 65 separate studies on children's FMS levels, children have "below average" to "average" FMS levels

* Corresponding authors at: Jalan Universiti 1, 43400 Serdang, Selangor, Malaysia.
E-mail addresses: brandondong001@gmail.com, gs60862@student.upm.edu.my (D. Zhang), kims@upm.edu.my (K.G. Soh), cym@upm.edu.my (Y.M. Chan), z_zienab@upm.edu.my (Z. Zaremohzzabieh).

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when compared to the Test of Gross Motor Development, second edition (TGMD-2) normative data (Bolger et al., 2021). Low levels of FMS can inhibit a child's positive development in various aspects (Jones et al., 2020). Growing evidence indicates that insufficient FMS competence in childhood may cause insufficient physical activity and correlate to obesity, leading to health risk factors for children (Wibowo et al., 2021).

Considering the short- and long-term effects of inadequate FMS, one effective strategy is ha focus on the development of these skills through targeted interventions and instructional approaches. Numerous studies indicate that FMS should be taught, and children need more opportunities to practice FMS through guidance and specific interventions (Logan et al., 2012). Many nations have now implemented effective strategies for the development of FMS in youth physical education and community sports (Wu, et al., 2014). One such example is Hong Kong, where it has improved fundamental movement skills among students through an assessment-for-learning intervention that places emphasis on fun, mastery, and support (Chan et al., 2016). However, the existence of certain misconceptions and a limited understanding also indirectly hinder the development of FMS, specifically due to the lack of a clear comprehension of the effects of FMS interventions. Consequently, educators, policymakers, and those involved in promoting youth physical education and community sports programs encounter challenges in selecting the appropriate intervention methods and determining the most effective programs. These specific objectives revolve around improving FMS in children and youth, encompassing goals such as enhancing physical literacy, sports performance, and overall physical well-being.

A few reviews have evaluated and summarized the effects of FMS interventions. All these evaluations reported substantial improvements in FMS (Wick et al., 2017; Logan et al., 2012). However, they significantly differ by targeting specific populations and interventions. For example, some focus on the effects on children with autism and cerebral palsy (Colombo-Dougovito and Block, 2019). Two of these reviews have a similar scope to this study. One was published in 2013, analyzed obese children, and included family, school, and community-based interventions. These variables resulted in a significant heterogeneity, which affected the *meta*-analysis outcomes (Morgan et al., 2013). Another article had methodological limitations, selecting only randomized and case-controlled studies, and did not do a *meta*-analysis. Therefore, the quantitative analytical evidence is insufficient (Eddy et al., 2019). Many research findings have since been published.

Due to the increased focus on FMS in recent years, many research findings have since been published. Further review is required to gather more evidence and support for the practical development of these skills. Therefore, the primary purpose of this review is to evaluate and provide up-to-date evidence on the effect of interventions to promote FMS in typically developing children ranging in age from 3 to 12 years old.

2. 2.Methods

This review adheres to the reporting standards outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The present work has been registered in the PROSPERO database, CRD42023393517.

2.1. Search strategy

Studies were identified through electronic databases and Google Scholar and by reviewing the reference lists of all included studies. The literature search was done through four databases: PubMed, Scopus, Web of Science, and SPORT Discus, including the literature of recent years from January 2010 to December 2022. This period is suitable for observing the latest changes and developments in the field and updating and incorporating new research. The following keywords were utilized to search: ("fundamental movement skill" or "basic motor skill" or "motor competence" or "gross motor skill" or "fundamental motor skill") and ("intervention" or "training" or "training method" or "training approach" or "training program*") and ("children" or "adolescent" or "preschoolers" or "kid" or "youth" or "teen*" or "child*" or "student*").

2.2. Eligibility criteria

The review employed PICOS (population, intervention, comparison, outcome, and study design) principles to establish the inclusion criteria (McKenzie et al., 2019). Studies had to meet the following criteria: (1) The population involved healthy children in preschool and primary school aged 3–12 years as subjects; (2) study design involved RCTs or non-RCTs with two or more groups, and one-group design with pre-posttest; (3) intervention in preschool or primary school is designed to promote the development of FMS; (4) the primary outcomes had to be measured with standardized assessment scales of FMS, and the analysis of at least one component of FMS had to be reported; (5) all articles must be published in English.

Studies meeting the following criteria were excluded: (1) Reviewed articles, conference papers, notes, and abstract; (2) the subjects with diseases, disorders, and obesity; (3) family- and community-based intervention programs; (4) studies that did not conduct any training interventions or experiment; (5) studies that did not report any outcomes or detailed data of FMS.

2.3. Study selection

After the systematic search, all articles were imported into Mendeley and checked for duplicates. Two independent reviewers examined the titles and abstracts of the remaining articles. Articles agreed to be included will be reviewed in full text, and data extracted. The articles not be identified by title and abstract will also reviewed in full text. If any disagreement occurs, a consensus will be reached through discussion. When necessary, a third reviewer will be included to resolve the dispute.

2.4. Quality assessment of included studies

Two independent reviewers utilized the PEDro scale to evaluate the general quality of the experimental procedures. The scale has good validity and reliability. It includes 11 items that evaluate four aspects of the research method: randomization process, blinding procedure, group comparison, and data analysis (Maher et al., 2003). The score determines the results: Yes (1 point) or No (0 points). The higher the score, the more reliable the research. A 9–10 is excellent, 6–8 is good, 4–5 is acceptable, and 1–4 is poor quality. Discussion or evaluation by a third author resolved any disagreements.

2.5. Data extraction

Two independent reviewers extracted and recorded the articles' specific information and data in a standardized form. The information and data include (1) Authors, year, and country; (2) study design and setting; (3) sample characteristics (sample size, gender, age); (4) intervention (content, duration, intensity, and frequency) (5) type of FMS evaluation scale (6) outcomes and results (FMS total score, GMQ, subtest raw /standard score, and percentile).

2.6. Data synthesis and analysis

Comprehensive Meta-Analysis (CMA) software was employed to synthesize the results of the FMS tests (Borenstein, 2022). Articles eligible for *meta*-analysis included data on groups' sample sizes and the mean score (SD or SE) of the pre-and post-intervention test value. For the *meta*-analysis, post-intervention values were utilized. These data were employed to calculate the standardized mean difference (SMD) and 95 % confidence interval (CI). The total SMD of the studies was obtained by random effects analysis pooling. The effect sizes were small (SMD = 0.2), medium (SMD = 0.5), and big (SMD = 0.8) (Takeshima et al., 2014).

Most studies have employed the Test of Gross Motor Development (TGMD) (second or third edition) to evaluate FMS. The primary test data of the TGMD are the FMS total and subtests of locomotor and object control skills (Maeng et al., 2016). In light of this, a *meta*-analysis was conducted on the three data sets. However, studies that did not qualify for the *meta*-analysis but fulfilled the inclusion criteria were systematically analyzed.

3. Investigation of heterogeneity and subgroup analyses

The I^2 statistic was employed to examine the heterogeneity of the study (Higgins and Thompson, 2002). It was explored through subgroup analysis and sensitivity analysis. Two priori hypotheses were utilized to explore the reasons for heterogeneity based on the features of gender and age differences in FMS. The first hypothesis was that differences FMS performances between boys and girls would influence the results. Secondly, it was hypothesized that interventions applied to different ages would have different effects. The subgroup analysis was carried out according to gender and type of experiment object to verify these hypotheses. Since the settings of the intervention programs that were implemented differed in most studies, further exploratory analyses are required.

4. Results

4.1. Overview of studies

A preliminary search revealed a total of 11,908 studies. A reference check produced an additional seven studies After deleting duplicates (n = 3980) and screening the titles and abstracts (n = 7868), 60 remained. These articles were thoroughly reviewed in full-text, yielding 36 studies that met the inclusion criteria. The Fig. 1 showed a detailed process.

4.2. Study quality assessment

All included studies were assessed according to the PEDro scale. The results revealed that there are no articles with a score lower than 4 points. Of the 17 articles with acceptable quality, six were included in the *meta*-analysis. Eight of 18 good-quality articles were included in the *meta*-analysis, as was one remaining article of excellent quality. The mean score of the articles in the *meta*-analysis was 6.05, indicating good

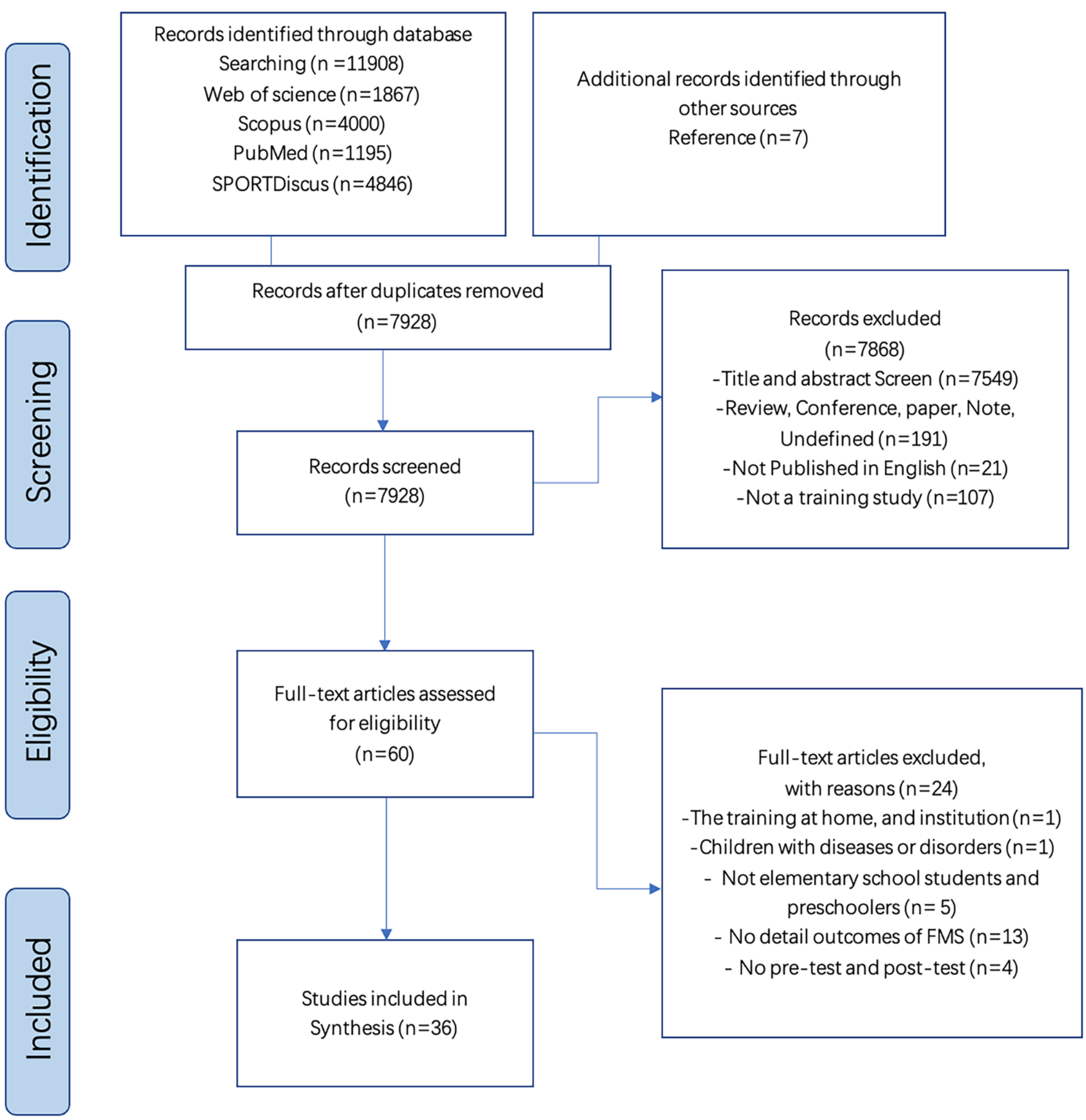

Fig. 1. Article identified process (PRISMA).

quality and the credibility of the findings. However, no study met all the quality assessment criteria, although all followed the three assessment criteria: similar at baseline, between-group comparisons, and point measurements and variability. Additionally, no studies blinded the experimenters, one blinded the subjects, and seven blinded the data assessor. Table 2 provides a summary of the specific scores.

4.3. Participant characteristics

The participants can be categorized into two age categories: preschoolers (n = 17 articles) and primary school children (n = 19 articles). The total number of participants was 7256, with 3582 boys and 3358 girls in all studies. Four articles did not indicate the subjects' gender (Johnson et al., 2019; Jones et al., 2011; Mostafavi et al., 2013; Rocha et al., 2016), while ten studies addressed gender differences (Costello and Warne, 2020; Duncan et al., 2021; Engel et al., 2021; Foulkes et al., 2017; Kelly et al., 2021; Lee et al., 2020; Rudd et al., 2017; Skowroński et al., 2019; Zhang and Cheung, 2019; Zoran et al., 2014). Additionally, five studies reported separate data on FMS for boys and girls, but no sex differences were analyzed (Abdullah et al., 2013; Burns, et al., 2017a; Burns, et al., 2017b; Chan, et al., 2019; Gu et al., 2021). From the data, girls seem to acquire better locomotor skills than boys. However, boys develop superior object control skills. Understanding gender differences in FMS development could lead to more effective interventions in future studies.

The age range for this review was restricted. The mean age of the experimental group ranged from 4.2 ± 0.7 to 11.3 ± 0.3, whereas that in the control group ranged from 3.62 ± 0.41 to 10.4 ± 0.3. The children in the research were all healthy, and no study included children with medical issues or who were overweight. Table 1 presents the characteristics of the study.

4.4. Intervention characteristics

Most studies adopted a parallel group design, whereas just three employed a one-group design. There were 21 randomized controlled trials (RCTs), 11 pre–post controlled trials, and four quasi-experimental trials.

Almost all interventions were conducted in preschool and primary school settings, and most were administered by trained PE teachers. The interventions were classified into five groups to acquire a comprehensive understanding of the interventions and to allow meaningful comparisons: (1) Eight articles utilized interventions based on games and active play programs, such as the SPARK program (Mostafavi et al., 2013), and the BRAINball games (Pham et al., 2021); (2) Nine studies utilized structured physical activity; (3) Eight articles focused on skills development, such as skill-station-based intervention (Roach and Keats, 2018) and the A + FMS program (Chan et al., 2019); (4) Six articles developed FMS by introducing specific sports training. This training is evident in the case of badminton training (Duncan et al., 2020) and gymnastics training (Rudd et al., 2017); and (5) Five articles employed novel and unique training methods, such as CHAMP (Palmer et al., 2019), novel rhythmic activity (Hu, 2020), music + exercise (Marinšek and Denac, 2020), and neuromuscular training (Duncan et al., 2021). Some of the intervention programs also provide guidance and support for teachers (Chan et al., 2019; Jones et al., 2016), making the interventions more effective and beneficial for children's long-term development. In contrast to the experiment group, the control group intervened with the participants through regular PE classes and free play.

The duration, frequency, and intensity of intervention implementation are important. The intervention lengths in the reviewed literature ranged from 4 to 36 weeks. The frequency of most studies was two to three times per week, with each session lasting from 20 to 80 min and the majority lasting 40 to 60 min. These frequencies suggest that both short- and long-term interventions effectively enhance FMS. However, most trials did not report on the intensity of the interventions.

4.5. Outcome and measures

The effects of intervention programs on FMS proficiency and locomotor, object control, and balance skills were examined and analyzed.

4.5.1. Effects on overall FMS proficiency

FMS proficiency is the primary measure of children's competence in FMS. In the reviewed literature, 32 studies published data on overall FMS proficiency, and 29 of those studies demonstrated a significant improvement following the intervention. However, two studies employing active play reported no significant difference between groups and only had a small effect size (p = 0.11, 95 % CI −0.22–2.24) within the group (Foulkes et al., 2017; Johnstone, et al., 2019). These results may be due to unstructured training content. Other studies produced exceptional results. In several cases, FMS development may be associated with the age of children, as younger children developing more quickly than older ones in primary school (Rudd et al., 2017; Hu, 2020; Jones et al., 2016). Additionally, according to Engel et al. (2022) (Engel et al., 2021), improvements cannot be maintained when practice opportunities are not continued.

When pooling the appropriate studies, the *meta*-analyses revealed big effect sizes for overall FMS proficiency (SMD = 0.928, 95 % [CI] 0.744–1.112, P = 0.001) (Fig. 2). Similarly, the subgroup analysis revealed that intervention programs had moderate effect sizes on FMS for both boys (SMD = 0.795, 95 % [CI] 0.368–1.223, P = 0.001) and girls (SMD = 0.789, 95 % [CI] 0.363–1.214, P = 0.001). Boys tended to perform better than girls (Table 4). The next section of the subgroup analysis addressed age. The intervention for preschoolers (SMD = 0.900, 95 % [CI] 0.615–1.185, P = 0.001), and primary school children (SMD = 0.965, 95 % [CI] 0.701–1.1228, P = 0.001) had big effect sizes. These results provide important insights into the significant positive correlation between intervention programs and overall FMS.

4.5.2. Effects on locomotor skills

One of the most significant FMS is locomotor skills. A total of 26 articles reported locomotor skills test data, and all but four studies demonstrated significant differences (Foulkes et al., 2017; Rudd et al., 2017; Johnstone et al., 2019; Hamilton and Liu, 2018). Two studies on active play interventions with unstructured training projects identified no statistically significant results (Foulkes et al., 2017; Johnstone et al., 2019). In another study utilizing gymnastics, Rudd et al. (2017) (Rudd et al., 2017) found that the intervention did not affect the locomotor skills of the lower-age children (F = 1.3, P = 0.24). However, there was an effect on upper-age children, and the findings were statistically significant. These findings have appeared in just a few studies. Therefore, the reasons cannot be generalized.

When pooling the appropriate studies, the *meta*-analysis revealed moderate effect sizes for locomotor skills (SMD = 0.636, 95 % [CI] 0.508–0.765, P = 0.000) (Fig. 3). The subgroup analyses displayed no significant difference in locomotor skills between preschool and primary school children after the intervention, both with moderate effect sizes (preschool: SMD = 0.691, 95 % [CI] 0.350–1.032, P = 0.000; primary school: SMD = 0.604, 95 % [CI] 0.470–0.738, P = 0.000) (Table 4). The effect sizes were different when considering gender factors. The intervention for boys had moderate effect sizes (SMD = 0.620, 95 % [CI] 0.223–1.017, P = 0.002), whereas contrary to expectations, for girls had a small effect size and was not statistically significant (SMD = 0.327, 95 % [CI] −0.053–0.706, P = 0.092) (Table 4). It is unclear whether gender differences caused.

4.5.3. Effects on object control skills

All FMS evaluations employed the standard TGMD scale version 2 or version 3, which measures locomotor and object control skills. There also had 26 articles reported on the test data of object control skills.

Table 1
Research specific information.

Study	Design	Participant	Experimental	Control	Measurement	Result
Johnstone et al. (2019) Scotland (Johnstone et al., 2019)	CRCT 10 weeks	Primary school children SS:137EG:73 Gender: 34 boy/ 39 girl; Age:7.1 ± 03 yr; CG:64 Gender:24 boy/ 40 girl; Age:7.1 ± 03 yr;	IV: The active play intervention INT: Moderate-to-vigorous Freq: 1/ weekTime: 60 min	No details	TGMD-2 (GMQ, standard score)	Both EG and CG Sedentary% ↓; EG: GMQ Score; percentile ↑; LM Score ↑; percentile ↑; OC Score ↑; percentile ↑. CG: GMQ Score ~; percentile↓; LM Score ↓; LM percentile ↓; OC Score ↑; OC percentile ↑.
Engel et al. (2022) Australia (Engel et al., 2021)	CRCT 12 weeks	Preschool children SS:66 Gender: 36 boy/ 30 girl; EG:49 Gender: 26 boy/ 23 girl; Age:4.2 ± 0.7 yr; CG:17 Gender: 10 boy/ 7 girl; Age:4.2 ± 0.6 yr;	IV: Game-based PLAYFunProgram Freq: 1–5 / weekTime: 40 min with 30 min specific skill instruction + 10 min set up free game	IV: Normal preschool PE class	TGMD-2 (GMQ percentile)	EG: GMQ percentile ↑; LM percentile ↑; OC percentile ↑.CG: GMQ percentile ↑; LM percentile ↑; OC percentile ↑.
Melvin Chung et al. (2022) Malaysia (Melvin Chung et al., 2022)	QE pre-post study 24 weeks	Preschool children SS:153 Gender: 83 boy/ 70 girl;Age:4.5 ± 0.5 yr; EG:85 Gender: 48 boy/ 37 girl; Age:4.6 ± 0.50 yr; CG:68 Gender: 35 boy/ 33 girl; Age:4.4 ± 0.50 yr;	IV: Physical activity (PA) program Freq: 3 / weekTime: 30 min	IV: Normal preschool PE class	TGMD-2 (GMQ)	PA ↑ in EG by time and between groups, large ES, P < 0.001;FMS ↑ in EG by time and between groups, large ES, P < 0.001;
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Roach et al. (2018) Canada (Roach and Keats, 2018)	CRCT 8 weeks	Preschool children SS:51 Gender: 26 boy/ 25 girl; EG1:16 Gender: 10 boy/ 6 girl; Age:4.0 ± 0.53yr; EG2:16 Gender: 6 boy/ 10 girl; Age:4.29± 0.78yr; CG:19 Gender: 10 boy/ 9 girl; Age:3.62 ± 0.41yr;	IV1: Skill-station based intervention Freq: 2 / week Time: 45 min IV2: The active play intervention INT: No details Freq: 2 / weekTime: 45 min	IV: Free-play Freq: 2 / weekTime: 45 min	TGMD-2 (GMQ, standard score)	EG: GMQ effect by time, p < 0.05; type X time, p <0.005 difference between EG and free-play.
Ali et a. (2021) New Zealand (Ali et al., 2021)	pre-post study 10 weeks	Preschool children SS:66 Gender: 36 boy/ 30 girl; EG:46 Gender: 24 boy/ 22 girl; Age:4.1 ± 0.6yr; PA class attended:7.0 ± 1.7 CG:20 Gender: 10 boy/ 9 girl; Age:3.8 ± 0.5yr; PA class attended: None	IV: physical activity (PA) program Freq: 1 / weekTime: 45 min	IV: Received no PA classes	TGMD-2 (Standard score)	EG:LC ↑ SS, OC ↑ SS. CG: no change in LC, OC
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Costello et al. (2019) Ireland (Costello and Warne, 2020)	pre-post study 4 weeks	Primary School children Third- and fourth-class SS:100 58 boys; Age:8.6 ± 0.7yr; 42 girls; Age: 8.8 ± 0.7yr EG:51 Gender: 31 boy/ 20 girl;CG:49 Gender: 27 boy/ 22 girl;	IV: FMS intervention Freq: 2 / weekTime: 30 min	IV: Normal Primary School PE class Freq: 2 / weekTime: 30 min	Fundamental Motor Skills Quotient (FMSQ) 4 skills	EG: P=0.003l, (time*group*gender) for FMS; group by intervention and control, time by Pre - Post on FMS. CG: no change in LC, OC
Lee et al. (2020) USA (Lee et al., 2020)	pre/post study 8 weeks	Primary school children SS:36 Gender: 13 boy/ 23 girl; Age:6.53 ± 0.97yr; EG:25 Gender: 8 boy/ 17 girl; girl, Age:6.41 ± 0.79yr; boy, Age:6.37 ± 0.91yr; CG:11 Gender: 5 boy/ 6 girl; girl, Age:6.66 ± 1.63yr; boy, Age:7.00 ± 0.70yr;	IV: FMS-based afterschool program Freq: 3 / weekTime: 60 min	IV: Regular afterschool programTime: 3 h	TGMD-2 (Raw score)	(Intervention & Control) significant differences LC, OC EG: FMS, medium effect size. CG, not significant improvements
Kelly et al. (2020) Ireland (Kelly et al., 2021)	CRCT 8 weeks	Primary school children SS:255 Gender: 127 boy/ 128 girl;Age:7.4 ± 0.6yr;	IV: FMS-based PE class Freq: 2 / week Time: 45 min	IV: Normal Primary School PE class Freq: 2 / weekTime: 45 min	TGMD-3 (Raw score)	Group I-C: phase 1medium effect size significant ↑ LC; a large significant ↑ OC and FMS (p <

(continued on next page)

Table 1 (*continued*)

Study	Design	Participant	Experimental	Control	Measurement	Result
		EG:134 Gender: 64 boy/ 70 girl; Age:7.5 ± 0.7yr; CG:121 Gender: 63 boy/ 58 girl; Age:7.4 ± 0.6yr;				0.001).Group C-I: FMS has little change.
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Pranotoa et al. (2021) Indonesia (Pranotoa et al., 2021)	pre/post study 6 weeks	Preschool children SS:80 Gender: 45 boy/ 35 girl; EG:40 Gender: 23 boy/ 17 girl;CG:40 Gender: 22 boy/ 18 girl;	IV: FMS intervention Freq: 2 / week Time: 60 min	IV: Regular FMS learning	(GMQ)	EG: FMS ↑ CG: FMS ↑. FMS score in EG is better than CG
Jones et al. (2011) Australia (Jones et al., 2011)	'CRCT 20 weeks	Preschool children SS:97 Age:4.64 ± 0.5yr; EG:52 CG:45	IV1: Movement skill program Freq: 3 / weekTime: 20 min	IV: Normal preschool PE class-Usual care	TGMD-2 (Raw score)	Greater improvements in the EG compared with the CG A medium-to-large ES d=0.75;EG: Statistically significant difference for jump and sum of the five skills.
Bolger et al. (2019) Ireland (Bolger et al., 2019)	pre/post study 26 weeks	Primary school childrenSS:544 PA intervention: 187 Gender: 103 boy/ 84 girl; EG:96 Gender: 51 boy/ 45 girl; 6yr: Age:5.9 ± 0.4yr; 10yr: Age:9.9 ± 0.4yr; CG: 91 Gender: 52 boy/ 39 girl; 6yr: Age:6.1 ± 0.3yr; 10yr: Age:10.0 ± 0.4yr;	IV1: Physical activity (PA) intervention IV2: Multicomponent FMS Intervention	IV: Normal Primary School PE class	TGMD-2 (GMQ)	EG:LC SS ↑ (p = 0.041), OC SS, GMQ no change. CG:LC SS, OC SS, GMQ no change. EG:LC standard score, OC standard score, GMQ ↑ significant change. CG: LC SS, OC SS, GMQ no change.
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Foulkes et al. (2017) UK (Foulkes et al., 2017)	CRCT 6 weeks	Preschool children SS:162 Gender: 86 boy/ 76 girl; Age:4.64 ± 0.58yr; EG:71 Gender: 33 boy/ 38 girl; boy, Age:4.7 ± 0.7yr; girl, Age:4.7 ± 0.6yr; CG:91 Gender: 53 boy/ 38 girl; boy, Age:4.7 ± 0.6yr; girl, Age:4.5 ± 0.6yr;	IV1: The active play intervention Freq: 1 / weekTime: 60 min	IV: Physical activity curriculum	TGMD-2 (Raw score, standard score)	No significant intervention effects on FMS, OC, LC between pre - post-test or pre - follow-up.
Zhang et al. (2019) China (Zhang and Cheung, 2019)	CRCT 12 weeks	Primary school children SS:560 Gender: 321boy/ 239 girl; Age: 7.54 ± 0.94yr; EG:282 CG:278	IV1:PE-based low organized games approach Freq: 2 / weekTime: 40 min	IV: Normal Primary School PE classTime: 40 min	TGMD-2 (Standard score)	significant difference in the changes FMS, LC, OC between EG and CG; EG exhibited greater score than CG.
Gu et al. (2021) China (Gu et al., 2021)	RCT 12 weeks	Preschool children SS:104 Gender: 50 boy/ 54 girl;EG:52 Gender: 25 boy/ 27 girl; Age (month): 55.190 ± 8.702yr; CG:52 Gender: 25 boy/ 27 girl; Age (month): 55.190 ± 8.997yr;	IV1: A table tennis physical activity (PA) program Freq: 3 / weekTime: 50 min	IV: Normal preschool PE class	TGMD-2 (Raw score)	EG: Both the boy and girl in EG had significantly improved scores GMS, LC subtest, OC subtest. EG exhibited greater score than CG.
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Johnstone et al. (2017) Scotland (Johnstone et al., 2017)	pre/post study 20 weeks	Primary school children SS:196 Gender: 90 boy/ 106 girl;EG:172 Gender: 82 boy/ 90 girl; Age: 7.0 ± 1.1yr; CG:24 Gender: 8 boy/ 16 girl; Age: 7.4 ± 0.9yr;	IV1: The active play intervention-Go2Play Freq: 2 / weekTime: 60 min	IV: Normal Primary School PE class Freq: 1 / weekTime: 50 min	TGMD-2 (GMQ, standard score)	EG: Sedentary ↓ (- 18.6%), GMQ, GMQ percentile, LC, OC↑ CG: Sedentary ↑ (0.1%, p=1.0),
Chan et al. (2019) Hong Kong (Chan et al., 2019)	CRCT 13 weeks	Primary school childrenSS:276 Gender: 88 boy/ 188 girl; Age: 8.4 ± 0.56yr; EG:147 CG:129	IV1: A + FMS intervention Freq: 1–2 / weekTime: 40–70 min	IV: Normal Primary School PE class	TGMD-3 (Standard score)	LC (d = 0.76), FMS (d = 0.93), between EG and CG from baseline to post, OC no difference EG and CG
Palmer et al. (2018) USA (Palmer et al., 2019)	RCT 5 weeks	Preschool children SS:102 Gender: 63 boy/ 39 girl; Age:4.40 ± 0.43yr; EG:64 Gender: 40 boy/ 24 girl;	IV1: A Movement skill development intervention-CHAMP Freq: 3 / weekTime: 40 min	IV: Free-play Freq: 5 / weekTime: 40–45 min	TGMD-3 (Raw score)	CHAMP outscored for LC, OC than CG.Total FMS, LC and OC both improved CHAMP and CG.

(*continued on next page*)

Table 1 (*continued*)

Study	Design	Participant	Experimental	Control	Measurement	Result
		Age:4.40 ± 0.44yr; CG:38 Gender: 23 boy/ 15 girl; Age:4.40 ± 0.41yr;				
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Mostafavi et al. (2013) Iran (Mostafavi et al., 2013)	RCT 8 weeks	Preschool children SS:90 EG1: 30 Age (month): 59.7 ± 9.0yr; EG2: 30 Age (month): 58.1 ± 7.8yr; CG: 30 Age (month): 59.0 ± 7.9yr;	IV1: SPARK Freq: 3 / week IV2: GymnasticsFreq: 3 / week	IV: Routine activity	TGMD-2	Difference before and after only significant in SPARK.
Rudd et al. (2017) Australia (Rudd et al., 2017)	RCT 8 weeks	Primary school children SS:113 Gender: 61 boy/ 52 girl; Age: 9.4 ± 1.8yr; EG: 56CG: 57	IV1: A gymnastics program Freq: 2 / weekTime: 60 min	IV: Normal Primary School PE class Freq: 2 / weekTime: 60 min	TGMD-2/KTK (Raw score)	EG: 2-4yr, KTK show no effect. FMS score, OC show a significant main effect, but not LC.6yr, KTK show no effect. FMS score, LC show a significant main effect, but OC
Johnson et al. (2019) USA (Johnson et al., 2019)	RCT 36 weeks	Preschool childrenSS:96 EG: 58CG: 38	IV1: PE-based Motivational climates (MMC) Freq: 2 / weekTime: 30 min	IV: Normal preschool PE class Freq: 2 / weekTime: 30 min	TGMD-3 (Raw score)	EG: higher scores at post-test.
Duncan et al. (2021) UK (Duncan et al., 2021)	CRCT 10 weeks	Primary school children SS:158 Gender: 83 boy/ 75 girl; Age: 7.6 ± 0.97yr; EG1: No detail EG2: No detailCG: No detail	IV1: Shuttle Time 2Xweek Freq: 2 / week Time: 60 min IV2: Shuttle Time 1Xweek Freq: 1 / weekTime: 60 min	IV: Normal Primary School PE class Freq: 2 / weekTime: 60 min	TGMD-2 (Raw score)	Shuttle 2Xweek, Shuttle 1Xweek (P 1⁄4 0.007), Shuttle 2Xweek, control (P 1⁄4 0.0001) and Shuttle 1Xweek and control (P 1⁄4 0.007)
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Result**
Hu et al. (2020) China (Hu, 2020)	RCT No details	Preschool children SS:289 Gender: 135 boy/ 154 girl; EG:142 Age 3: 52 Age 4: 67 Age 5: 23 CG:147 Age 3: 56 Age 4: 64 Age 5: 27	IV1: Novel rhythmic physical activity (PA) program	IV: Rhythmic physical activities	TGMD-2 (Raw score)	EG:LC, OC, and GMQ ↑ ($P < 0.01$) CG:LC, OC, and GMQ ↑ ($P < 0.01$)
Zoran et al. (2013) Croatia (Zoran et al., 2014)	pre/post study 18 weeks	Primary school childrenSS:75 Gender:30 boy/ 45 girl; Age: 7± 0.6yr	IV1: A gymnastics program Freq: 3 / weekTime: 45 min	NO	FMS-polygon (time)	Significant improved FMS-polygon
Branje et al. (2021) Canada (Branje et al., 2022)	CRCT 24 weeks	Preschool childrenSS:197 Gender:109 boy/ 88 girl; Age: 3.8 yr; EG:104 Gender: 63 boy/ 41 girl; CG:93 Gender: 46 boy/ 47 girl;	IV1: Integrating outdoor loose program	IV: Planned outdoor play schedule and activities	TGMD-3 (Raw score)	EG: FMS Significant improved no significant between groups.
Grainger et al. (2020) UK (Grainger et al., 2020)	CRCT 4 weeks	Primary school children SS:72 Gender: 34 boy/ 38 girl; EG1: 18 Gender: 9 boy/ 9 girl; Age: 11.3± 0.3yr; EG2: 20 Gender: 8 boy/ 12 girl; Age: 11.2± 0.2yr;CG: 21 Gender: 11 boy/ 10 girl; Age: 10.4± 0.3yr;	IV1: FMS intervention Freq: 2 / week Time: 60 min IV2: FMS + strength intervention Freq: 2 / weekTime: 60 min	IV: No interventionFreq: 2 / week Time: 60 min	CAMSA	CG: No change at CAMSA across. EG: CAMSA ↑.
Study	**Design**	**Participant**	**Experimental**	**Control**	**Measurement**	**Results**
Marinšek et al. (2020) Slovenia (Marinšek and Denac, 2020)	pre/post study 5 weeks	Preschool childrenSS:62 Gender: 33 boy/ 29 girl; Age: 5.60± 0.40yrEG: 35 Movement: 17; Music and movment:18CG: 27	IV1: Movement Freq: 4 / week Time: 40 min IV1: Music and movement Freq: 4 / weekTime: 40 min	IV:Normal preschool PE class	TGMD-2 (Raw score)	Movement ↑ between the CG, MG, and MMG. EG: All skills ↑ among MMG, two skills among MG, and no improved among CG.
Burns et al. (2017) USA (Burns et al., 2017a)	pre/post study 12 weeks	Primary school children SS:1460 Gender: 730 boy/ 730 girl; Age:8.4 ± 1.8yr	IV: Comprehensive School Physical Activity Program (PE class, activity during leisure times) Freq: 1 / weekTime: 50min	NO	TGMD-2 (Raw score)	TGMD-2 ↑, medium-sized effect; 7/8/9yr ↑ greater than 10/11/12yr, medium-sized effect; 7-12yr ↑ greater than 6yr, medium to large-sized effect
Burns et al. (2017) USA (Burns et al., 2017b)	QE pre/post study 36 weeks	Primary school children SS:959 Gender: 533 boy/ 406 girl;Age:9.1 ± 1.5yr;	IV: A comprehensive school physical activity program Freq: 3/ weekTime: 30 min	NO	TGMD-3 (Raw score)	LC scores, coefficients for time ↑, age x time ↑; OC scores, coefficients for time ↑, age x time ↑; FMS scores, coefficients for time↑, age x time ↑;

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Table 1 (*continued*)

Study	Design	Participant	Experimental	Control	Measurement	Result
Study	Design	Participant	Experimental	Control	Measurement	Result
Jones et al. (2016) Australia (Jones et al., 2016)	RCT 24 weeks	Preschool children SS:150 Gender: 85 boy/ 65 girl; EG:77 Gender: 43 boy/ 34 girl; Age:4.0 ± 0.6yr; CG:73 Gender: 42 boy/ 31 girl; Age:4.0 ± 0.62yr;	IV: A teacher-led early program (Jump Start) Freq: 3 / weekTime: 20min	IV: Free-play	TGMD-2 (Raw score)	Small to medium ES, Catch, medium ES: run, d=058; sedentary behavior, d=0.39; small ES: jump, d=0.19; kick, d=0.22; total GMS, d=0.23between group: No differences were found.
Hamilton et al. (2017) USA (Hamilton and Liu, 2018)	RCT 16 weeks	Preschool children SS:149 Gender: 75 boy/ 74 girl;EG:74 37 boy/ 37 girl; Age(month):54.32 ± 3.07yr; CG:75 38 boy/ 37 girl; Age(month):55.05 ± 3.67yr;	IV1: A gross and fine motor intervention Freq: 1 / weekTime: 50 min	IV: Play-based lessons and center-based activities Freq: 1 / weekTime: 50 mins	Peabody Developmental Motor Scales-2 (PDMS)	significant difference in the EG and CG on GMQ, TMQ; stationary subtest. no difference in LC and OC.
Skowroński et al. (2019) Poland (Skowroński et al., 2019)	QE pre/post study No details	Primary school chidren SS: 31 Gender: 15 boy/ 16 girl; EG:20 Gender: 11 boy/ 9 girl; boy, Age:7.30 ± 0.25yr; girl, Age:7.19 ± 0.28yr; CG:11 Gender: 4 boy/ 7 girl; boy, Age:7.34 ± 0.23yr; girl, Age:7.24 ± 0.32yr;	IV1: Additional 45-minute physical activity program (also take the regular PE) Freq: 1 / weekTime: 45 min	IV: Normal Primary School PE class	TGMD-2 (Raw scores)	EG: large effects FMS ↑. significant differences in GMDQ, p =0.036, OC, p =0042.
Study	Design	Participant	Experimental	Control	Measurement	Result
Abdullah et al. (2013) Malaysia (Abdullah et al., 2013)	QE pre/post study 10 weeks	Primary school children SS:64 Gender: 33 boy/ 31 girl; EG:32 16boy/ 16 girl; Age:8.28yr; CG:32 17 boy/ 15 girl; Age:8.55yr	IV1: Traditional games Freq: 2 / weekTime: 35 min	IV: Normal Primary School PE class Freq: 2 / weekTime: 35 mins	TGMD (GMQ, standard score)	EG: SLS, AEL, SMS, AEM and GMDQ is higher compared to CG.Traditional games towards subject gross motor development is vital
Pham et al. (2020) Vietnam (Pham et al., 2021)	pre/post study 20 weeks	Primary School children SS:55 Gender: 23 boy/ 32 girl; EG:28 12boy/ 16 girl; CG:27 11 boy/ 16 girl;	IV1: BRAINball games Freq: 2 / weekTime: 35 min	IV: Normal Primary School PE class Freq: 2 / weekTime: 35 mins	TGMD-2 (Raw scores)	FMS in the EG and CG ↑.differences in the LC (F = 18.88, p = 0.000) and OC (F = 20.74, p = 0.000) between EG and CG. In EG had better performance.
Rocha et al. (2016) Portugal (Rocha et al., 2016)	pre/post study 5–10 month	Preschool children boysSS:33 Age:4.80 ± 0.5yr; EG1:11 Age:4.60 ± 0.4yr; EG2:11 Age:4.80 ± 0.5yr; CG:11 Age:5.3 ± 0.2yr;	IV1: Swimming Freq: 2 / week Time: 45min IV1: soccer Freq: 2 / weekTime: 45min	IV: Normal preschool PE class	TGMD-2 (GMQ, standard score)	Both EG ↑ between T5 and T10 FMS quotient and in the SS of both subtests.
Duncan et al. (2018) UK (Duncan et al., 2018)	CRCT 10 weeks	Primary School children SS:94 Gender: 49 boy/ 45 girl; EG:53 Age: 6.43 ± 0.5yr; CG:41 Age: 6.23 ± 0.7yr;	IV1: Integrated neuromuscular training Freq: 2 / week 1INT and1 PETime: 30-40min	IV: Normal Primary School PE classFreq: 2 / week	TGMD-2	Higher total FMS in EG than CG (P = 0.001). Both total FMS pre to post in EG and the CG ↑ (both P = 0.001)
Study	Design	Participant	Experimental	Control	Measurement	Result
Duncan et al. (2020) UK (Duncan et al., 2020)	CRCT 6 weeks	Primary School childrenSS:124 Gender: 67 boy/ 57 girl; Age:8.5 ± 1.9yr EG:63 Age:6.43 ± 0.5yr; CG:61 Age:6.23 ± 0.7yr;	IV1: Shuttle Time intervention Freq: 2 / week 1INT and 1 PETime: 60min	IV: Normal Primary School PE class Freq: 2 / week Time: No details	TGMD-2	6–7 yr in the EG had higher total FMS compared to children in the CG. 10–11yr no differences in total FMS scores in EG and CG.

CRCT: cluster randomized controlled trial; RCT: randomized controlled trial; QE: quasi-experimental; EG: experimental group；CG: control group; IV: intervention; Freq: frequency; INT: intensity; SS: sample size.

However, six studies revealed insignificant improvement after the intervention (Foulkes et al., 2017; Chan et al., 2019; Johnstone et al., 2019; Hamilton and Liu, 2018; Bolger et al., 2019; Johnstone et al., 2017).

When pooling the appropriate studies, the *meta*-analyses revealed big effect sizes for object control skills (SMD = 0.871, 95 % [CI] 0.660–1.081, P = 0.000) (Fig. 4). The results of the subgroup analysis were also similar to those of locomotor skills. Preschoolers and primary school students had no significant difference in object control skills, and both groups had big effect sizes. (Preschool: SMD = 0.889, 95 % [CI]

Table 2
PEDro assessment results.

	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10	Part 11	Score
Johnstone et al. (2019)	√	√	–	√	–	–	–	√	–	√	√	6
Engel et al. (2022)	√	√	–	√	–	–	√	√	–	√	√	7
Melvin Chung et al. (2022)	√	–	–	√	–	–	–	√	–	√	√	5
Roach et al. (2018)	√	√	–	√	–	–	–	√	–	√	√	6
Ali et a. (2021)	√	–	–	√	–	–	–	√	–	√	√	5
Costello et al. (2019)	√	–	–	√	–	–	–	√	–	√	√	6
Lee et al. (2020)	√	–	–	√	–	–	–	√	–	√	√	5
Kelly et al. (2020)	√	√	–	√	–	–	–	√	–	√	√	6
Pranoto et al. (2021)	√	–	–	√	–	–	–	√	√	√	√	6
Bolger et al. (2019)	√	–	–	√	–	–	–	√	–	√	√	5
Jones et al. (2011)	√	√	–	√	–	–	√	√	–	√	√	7
Foulkes et al. (2017)	√	√	–	√	–	–	√	√	–	√	√	7
	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10	Part 11	Score
Zhang et al. (2019)	√	√	–	√	–	–	–	√	√	√	√	6
Gu et al. (2021)	√	√	–	√	–	–	–	√	√	√	√	7
Johnstone et al. (2019)	√	–	–	√	–	–	–	√	–	√	√	5
Chan et al. (2019)	√	√	√	√	√	–	√	√	√	√	√	10
Palmer et al. (2018)	√	√	–	√	–	–	√	√	–	√	√	7
Mostafavi et al. (2013)	√	√	–	√	–	–	–	–	–	√	√	5
Rudd et al. (2017)	√	√	–	√	–	–	–	√	–	√	√	6
Johnson et al. (2019)	√	√	–	√	–	–	√	√	–	√	√	7
Duncan et al. (2021)	√	√	–	√	–	–	√	–	–	√	√	6
Hu et al. (2020)	√	√	–	√	–	–	–	√	√	√	√	7
Zoran et al. (2013)	√	–	–	√	–	–	–	–	–	√	√	4
Branje et al. (2021)	√	√	–	√	–	–	–	√	–	√	√	6
Grainger et al. (2020)	√	√	–	√	–	–	–	√	–	√	√	6
	Part 1	Part 2	Part 3	Part 4	Part 5	Part 6	Part 7	Part 8	Part 9	Part 10	Part 11	Score
Marinšek et al. (2020)	√	–	–	√	–	–	–	–	–	√	√	4
Burns et al. (2017a)	√	–	–	√	–	–	–	√	–	√	√	5
Burns et al. (2017b)	√	–	–	√	–	–	–	√	–	√	√	5
Jones et al. (2016)	√	√	–	√	–	–	√	√	–	√	√	7
Hamilton et al. (2017)	√	√	–	√	–	–	–	–	–	√	√	5
Skowroński et al. (2019)	√	–	–	√	–	–	–	√	–	√	√	5
Abdullah et al. (2013)	√	–	–	√	–	–	–	√	–	√	√	5
Pham et al. (2020)	√	–	–	√	–	–	–	–	–	√	√	4
Rocha et al. (2016)	√	–	–	√	–	–	–	–	–	√	√	4
Duncan et al. (2021)	√	√	–	√	–	–	–	–	–	√	√	5
Duncan et al. (2020)	√	√	–	√	–	–	–	–	–	√	√	5

Item 1, eligibility criteria specified; item 2, random allocation; item 3, concealed allocation; item 4, groups similar at baseline; item 5, participant blinding; item 6, therapist blinding; item 7, assessor blinding; item 8, fewer than 15% dropouts; item 9, intention-to-treat analysis; item 10, between-group statistical comparisons; item 11, point measures and variability data.

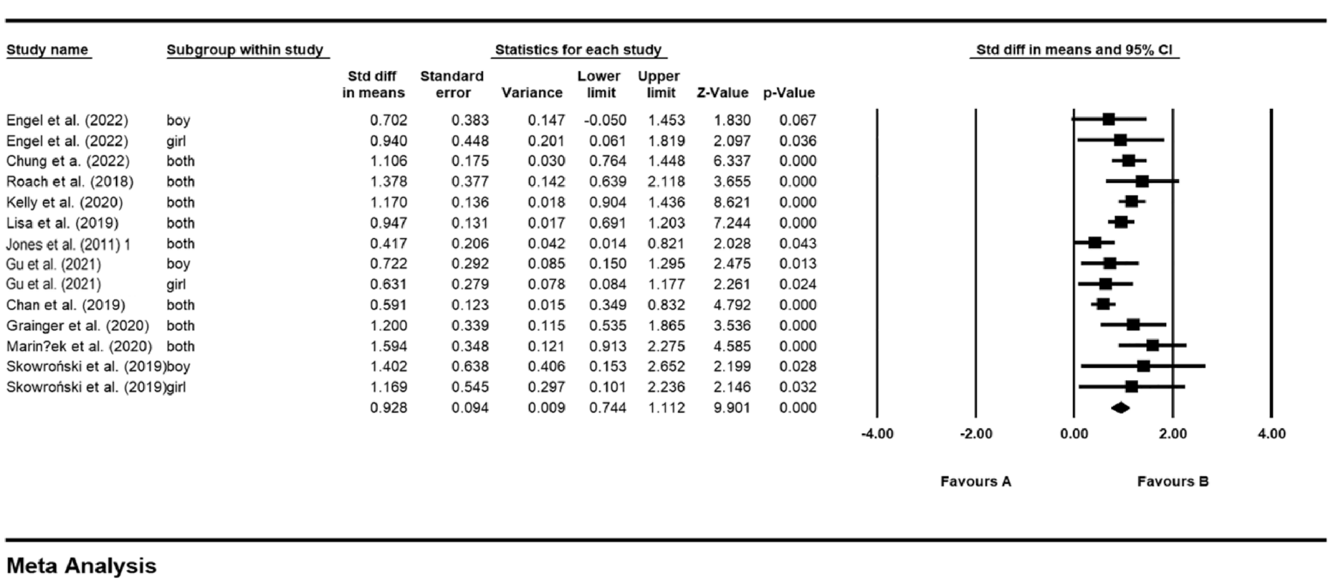

Fig. 2. Random effect size of FMS proficiency.

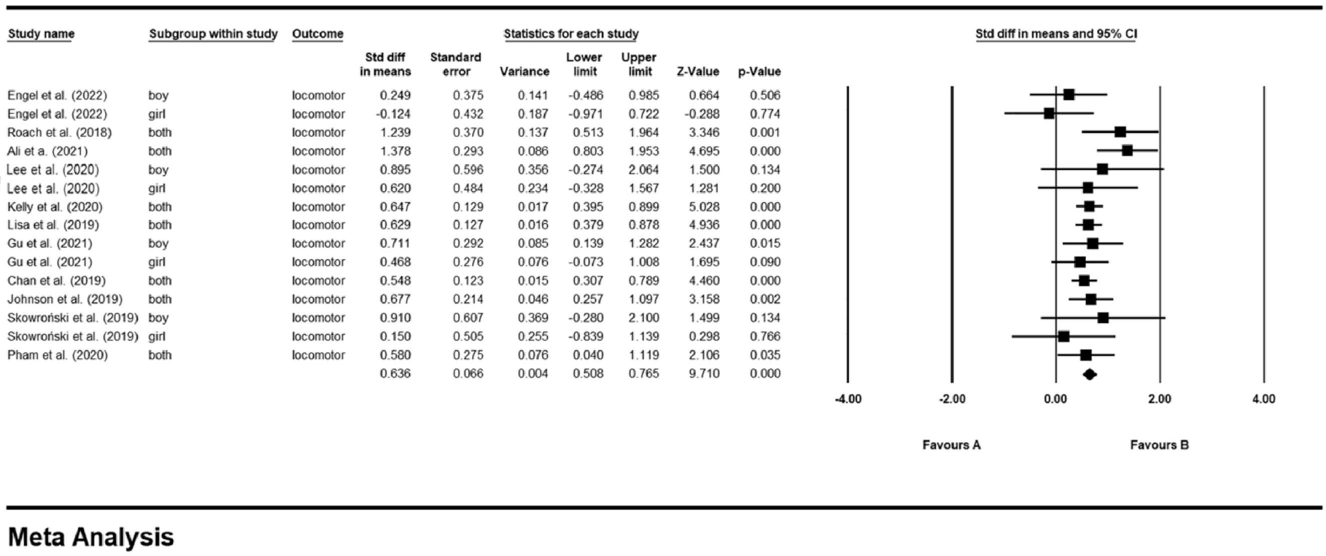

Fig. 3. Random effect size of locomotor skills.

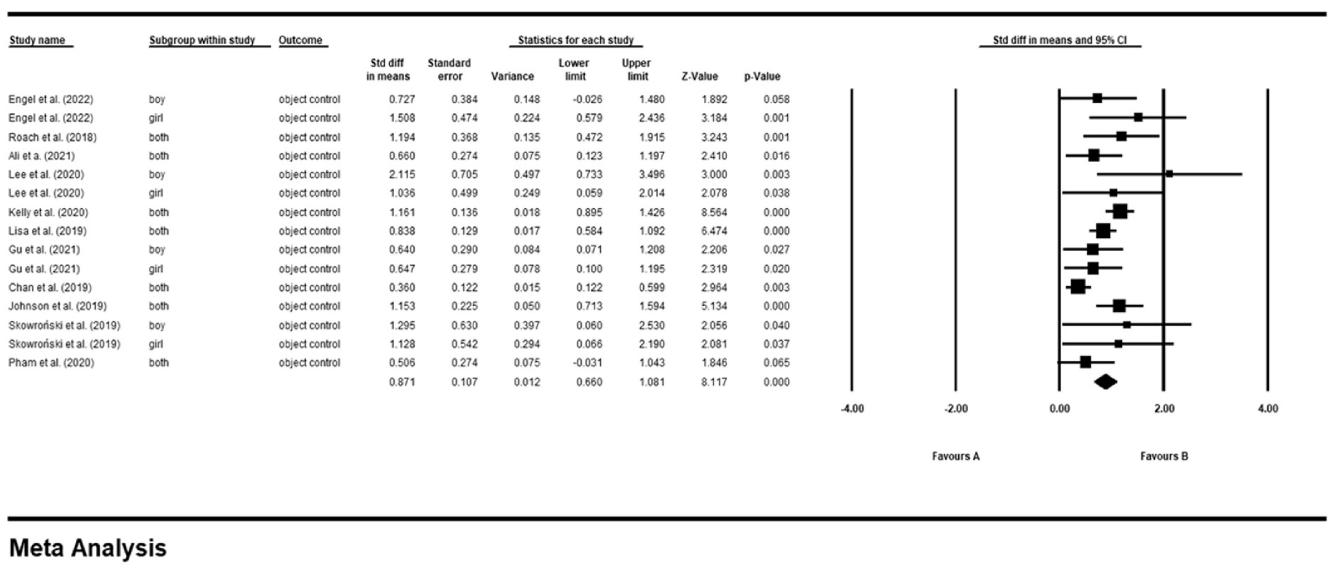

Fig. 4. Random effect size of object control skill.

0.662–1.117, P = 0.000; primary school: SMD = 0.876, 95 % [CI] 0.697–1.072, P = 0.000) (Table 4). Furthermore, boys tended to perform better than girls, and both showed a big effect size for object control skill (boys: SMD = 0.949, 95 % [CI] 0.418–1.480, P = 0.000; girls: SMD = 0.932, 95 % [CI] 0.538–1.326, P = 0.000) (Table 4), differing from locomotor skill. The findings indicate that object control skills may have played a more critical role in overall FMS proficiency.

4.5.4. Effects on balance skills

Data about the efficacy of balance skills are limited. Few studies evaluated it, and just four studies have provided testing results (Rudd et al., 2017; Hu, 2020; Hamilton and Liu, 2018; Branje et al., 2022). One of these studies employed a gymnastics training intervention that did not reveal significant improvement (Rudd et al., 2017). This study utilized the KTK test. The results revealed age as a significant covariate, whereas gender (p = 0.97) and BMI (p = 0.51) did not affect the result. In other studies, there was a significant positive change as the area, length, Anterior-posterior (A-P), and Medial-lateral (M−L) date changed significantly according to Tekscan foot-pressure measurements. The total balance score also increased ($p \leq 0.05$) according to the Preschooler Gross Motor Quality test (Hu, 2020). Although the current review is based on a small sample of studies, the findings suggest that FMS interventions can promote balance skills.

4.6. Heterogeneity analysis

In every *meta*-analysis, heterogeneity is to be expected. This review revealed moderate heterogeneity in overall FMS proficiency (I^2 = 50.183 %, P = 0.017), and object control skills (I^2 = 57.343 %, p = 0.003) (Table 3), but little heterogeneity in locomotor skills analysis (I2 = 9.998 %, p = 0.341) (Table 3). Subgroup analysis tested two priori hypotheses to explore the potential factors of the observed heterogeneity. Following gender grouping analysis, the heterogeneity of the boy and girl groups reduced in overall FMS proficiency (boy: I^2=0%, p = 0.598; girl: I2 = 0 %, p = 0.630), locomotor skills (boy: I^2=0%, p = 0.679; girl: I^2=0%, p = 0.606), and object control skills (boy: I^2=30.881 %, p = 0.227; girl: I^2=0%, p = 0.442) (Table 4), all of which were statistically significant. When analyzed by age group, the results still

Table 3
Summary of analysis results.

Groups	Effect size (ES) and 95 % confidence interval [CI]					Heterogeneity (HET)	
	No.	ES	Lower	Upper	p	I-squared	p
FMS	14	0.928	0.744	1.112	0.000	50.183	0.017
Locomotors	15	0.636	0.508	0.768	0.000	9.998	0.341
Object control	15	0.871	0.660	1.081	0.000	57.343	0.003

Table 4
Subgroup analysis of gender and age.

Groups	ES and 95 % [CI]	HET					
	No.	ES	Lower	Upper	p	I-squared	p
FMS							
Boy	3	0.795	0.368	1.233	0.000	0.000	0.598
Girl	3	0.789	0.363	1.214	0.000	0.000	0.630
Overall	6	0.792	0.490	1.094	0.000	0.000	0.856
Preschool	8	0.879	0.691	1.068	0.000	50.079	0.051
Primary	6	0.909	0.768	1.050	0.000	58.376	0.035
Overall	14	0.898	0.786	1.011	0.000	50.183	0.017
Locomotor skills							
Boy	4	0.620	0.223	1.017	0.002	0.000	0.679
Girl	4	0.327	−0.053	0.706	0.092	0.000	0.606
Overall	8	0.467	0.192	0.741	0.001	0.000	0.727
Preschool	7	0.710	0.488	0.932	0.000	54.720	0.039
Primary	8	0.604	0470	0.738	0.000	0.000	0.976
Overall	15	0.632	0.518	0.747	0.000	9.998	0.341
Object control skills							
Boy	4	0.864	0.457	1.271	0.000	30.881	0.227
Girl	4	0.932	0.538	1.326	0.000	0.000	0.442
Overall	8	0.899	0.616	1.182	0.000	1.213	0.420
Preschool	7	0.889	0.665	1.114	0.000	2.296	0.408
Primary	8	0.772	0.636	0.908	0.000	72.983	0.001
Overall	15	0.804	0.687	0.920	0.000	57.343	0.003

displayed heterogeneity in total FMS proficiency (preschool: I^2 =50.079 %, p = 0.051; primary: I^2 =58.376 %, p = 0.035), locomotor skills (preschool: I^2 =54.720 %, p = 0.039; primary: I^2 =0%, p = 0.976), and object control skills (preschool: I^2 =2.296 %, p = 0.408; primary: I^2 =72.983 %, p = 0.001) (Table 4). These results demonstrate that gender is responsible for the heterogeneity, while age is not. Sensitivity analysis yields another significant result. With the method of one study removed, the sensitivity analysis results did not contradict the initial analysis results, indicating that the original results are stable and

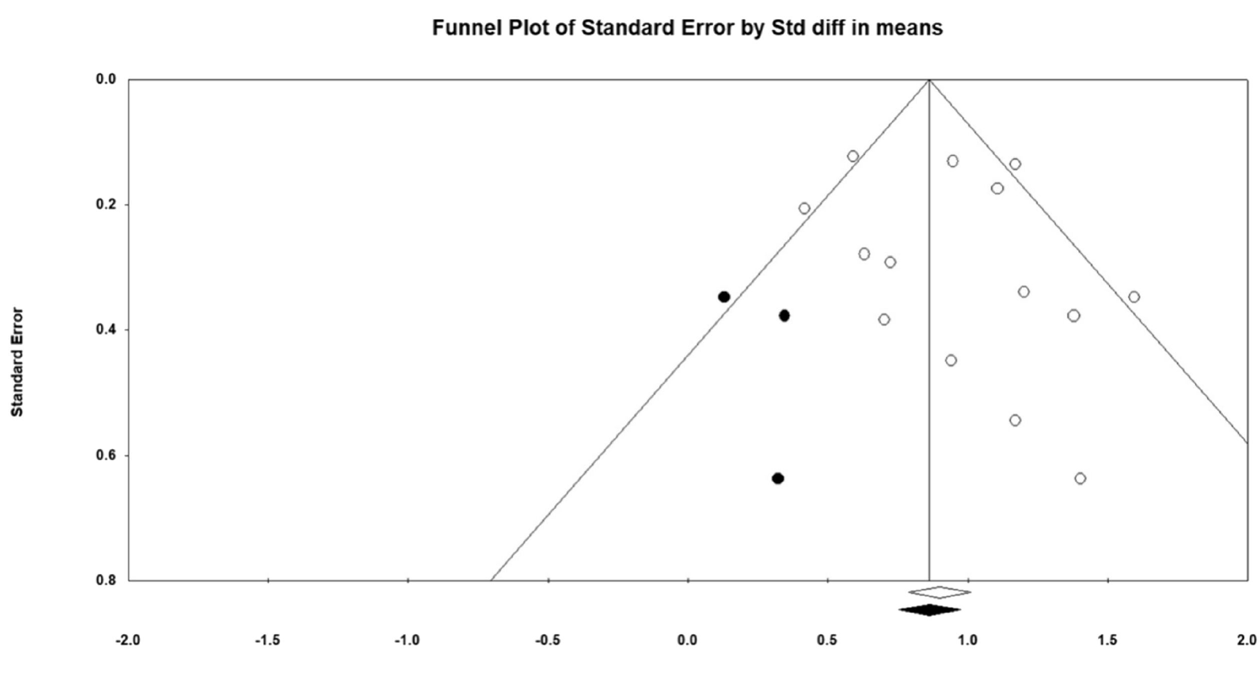

Fig. 5. Funnel plot of FMS proficiency.

reliable.

4.7. Publication bias analysis

Publication bias is another significant aspect that affects the value of the analysis. This study was analyzed using a funnel plot, the classic fail-safe number, and Egger's regression test. When observing the funnel plot, no apparent asymmetry was observed (Figs. 5, 6, 7). Concurrently, the classic fail-safe number for overall FMS (n = 642), locomotor skills (n = 294), and object control skills (n = 481) (Table 5) far exceeded the standard number of 5 k + 10 (Becker, 2005). These results indicate that there is no potential Publication Bias. Furthermore, Egger's regression is more reliable in evaluating the Publication bias. If the test results reveal $p > 0.05$, then there is no substantial publication bias (Lin et al., 2018). The final results: overall FMS (t = 1.159, p = 0.276), locomotor skills (t = 0.792, p = 0.448), and object control skills (t = 1.082, p = 0.307) (Table 5). In summary, multiple analyses revealed no publication bias in this *meta*-analysis.

5. Discussion

The evaluation of the effects of FMS interventions has been addressed in previous studies. However, the most recent review was published in 2013 (Morgan et al., 2013). In contrast, the significance of FMS has been widely acknowledged and stressed during the last decade. Unfortunately, children's FMS levels have persistently reduced in recent years (Bolger et al., 2021). Consequentially, various intervention designs to support the FMS development have emerged, particularly interdisciplinary and multidomain intervention strategies (Felzer-Kim, 2020). Such strategies include interventions integrating music and dance (Lykesas et al., 2014), employing psychological principles (Bandeira et al., 2017), or utilizing artificial intelligence equipment (Obrusnikova and Rattigan, 2016). These interventions enhance support for children who lack FMS proficiency, which also represent innovation and development of advanced science and technology and training theory in FMS intervention programs throughout the previous decade. Moreover, they might influence the development of FMS interventions in the next decade.

This study assesses the efficacy of FMS interventions and provides up-to-date research findings on FMS interventions over the past decade. The preliminary results demonstrated that intervention programs designed to improve FMS can positively affect children's FMS proficiency, object control, and locomotor skills. The *meta*-analysis offered quantitative evidence, and combined results revealed moderate to large effect sizes. Such positive results demonstrate that FMS cannot be acquired naturally but must be learned, practiced, and reinforced through suitable developmental programs (Mukherjee et al., 2017). Furthermore, this strongly reinforces Gallahue's hourglass model that the best age for FMS acquisition and development is between 3 and 12 years old (Barela, 2013). In advanced western countries, the fundamental goal of preschool health and PE courses is FMS development (Wu, 2014). In China, currently includes FMS development in their PE curriculum guidelines for primary schools (Liu, 2022). Such consensus also highlights the significance of early childhood interventions, and emphasizes the critical role that the school setting plays in facilitating the development of FMS. This setting should have dedicated teachers and instructors who are trained in FMS instruction and capable of providing guidance and support to students. Furthermore, it should ensure that children have ample opportunities for both formal and informal physical activities within the school environment.

This review confirms that FMS improvement is associated with the interventions implemented. It shares similarities with the findings of Capelle et al. (2016) (Van Capelle et al., 2017), Logan et al. (2012) (Logan et al., 2012), and Morgan et al. (2013) (Morgan et al., 2013). Furthermore, it is encouraging to compare these results with previous observations. The overall FMS effect size is more significant than most previous studies (Wick et al., 2017; Logan et al., 2012; Van Capelle et al., 2017). Positive outcomes imply that intervention programs and strategies for FMS are continuously evolving and improving. This outcome does not surpass that presented in Morgan et al.'s (2013) (Morgan et al., 2013) *meta*-analysis (SMD = 1.42, 95 % [CI] 0.68–2.16, $P < 0.0002$). However, their result may have had a potential bias from much heterogeneity ($I^2 = 93$ %), which is less present in the current study ($I^2 = 50.183$ %). According to the above data, it is possible to suggest that the review results are more reliable than Morgan et al.'s (2013) (Morgan et al., 2013).

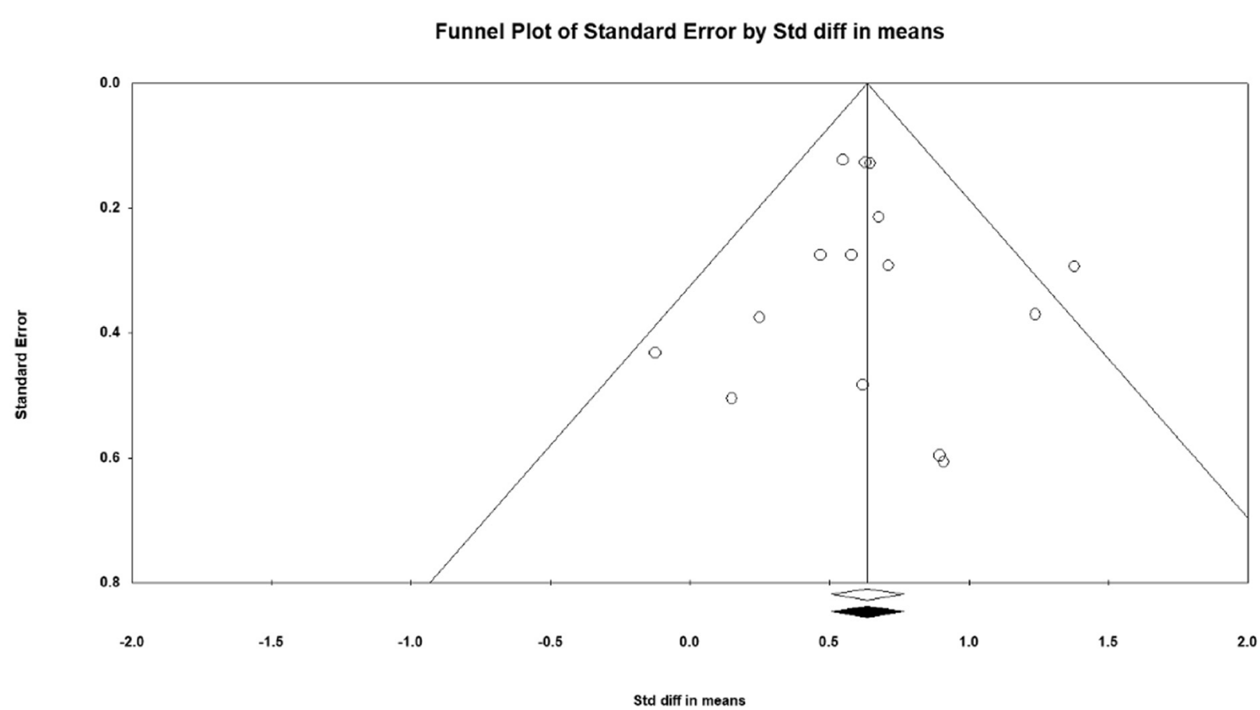

Fig. 6. Funnel plot of locomotor skills.

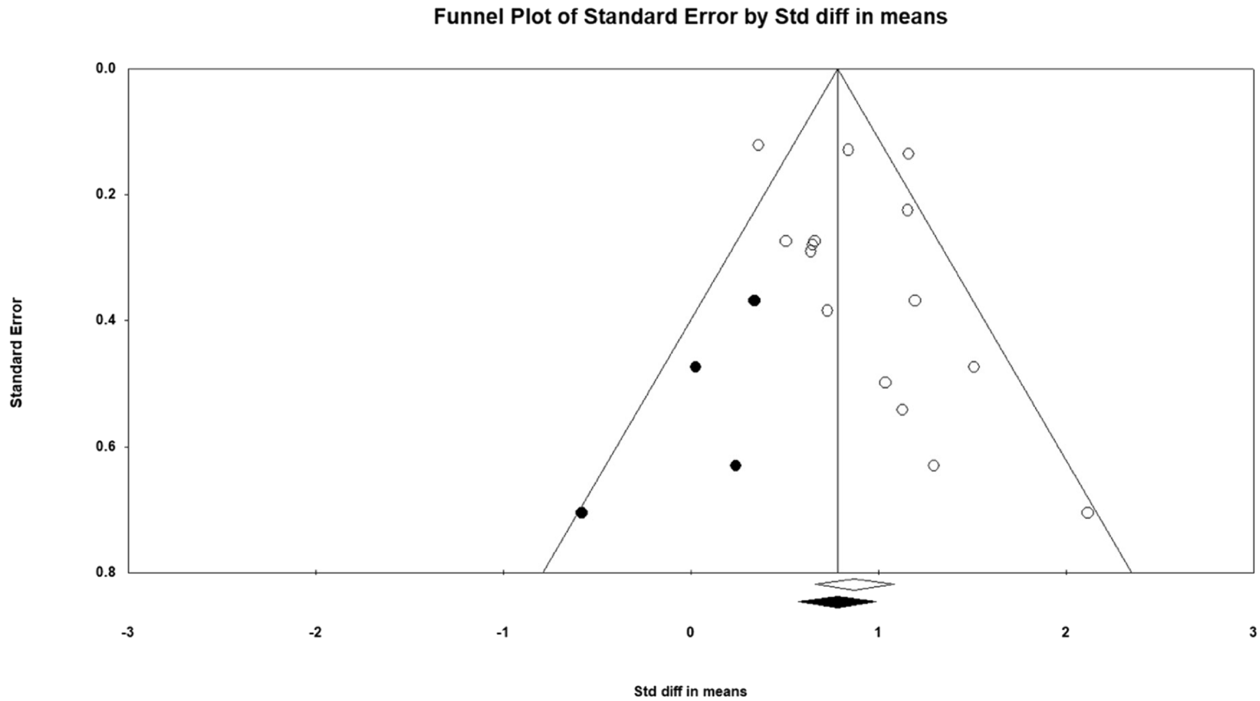

Fig. 7. Funnel plot of object control skills.

Table 5
Egger's regression date and Classic fail-safe number.

Groups	*Egger's regression*	*Classic fail-safe N*							
	Intercept	**SE**	**Lower**	**Upper**	**p**	**t**	**z**	**p**	**N**
FMS	0.717	0.819	−1.067	2.502	0.398	0.876	14.380	0.000	740
Locomotor	0.113	0.568	−1.114	1.340	0.845	0.199	9.506	0.000	338
Object control	1.090	0.759	0.549	2.730	0.174	1.435	12.767	0.000	622

The synthesis of results regarding locomotor (SMD = 0.636, 95 % [CI] 0.508–0.765, P = 0.000) and object control skills (SMD = 0.871, 95 % [CI] 0.660–1.081, P = 0.000) demonstrates that interventions on object control skills had a more significant effect size than locomotor skills. However, the discrepancy between locomotor and object control skills observed in this study was not unanimous in other studies (Logan et al., 2012; Morgan et al., 2013). The different results might be related to different participants and intervention settings. In contrast to the extensive literature on locomotor and object control skills, there is limited research reported about the influence on balance skills, and there were almost no results from relevant Meta-analyses. Therefore, no similar studies exist. This may be because no commonly used scales and tools are suitable for measuring balance skills. Besides, balance skills are the elemental when practicing new skills in all sports and physical activities. Its acquisition requires more complex neural and muscular control and more intensive skill instruction and practice (Atan, 2009). The comprehensive analysis still demonstrates that the interventions positively effect on balance skills.

Overall, the interventions undoubtedly had a positive effect. However, three significant findings that must be considered. It is difficult to evaluate which interventions are the most successful due to variances in experimental design, duration, and reporting details. Additionally, it shows that not all types of interventions yield beneficial outcomes for FMS development. This analysis could not identify a clear benefit of active play and unstructured training programs in FMS promotion. The previous systematic review confirmed the same results (Johnstone et al., 2018). The lack of statistical significance in the effect of control groups further reinforces this point of view. However, a recent study hypothesized that the unconstrained nature of free play or games is also likely to assist the development of children's motivation to participate in sports, which ultimately benefits FMS (Janssen, 2014). Therefore, the selected intervention types were a significant factor. In order to better promote the development of children's fundamental motor skills, it is necessary to choose appropriate intervention methods according to different participants.

Exploring the critical value of effective intervention duration is difficult. Contrary to expectations, this study found no correlation between the intervention duration and FMS performance. It is generally acknowledged that a longer intervention duration will result in a more significant improvement. However, in this review, no articles explored the relationship between intervention duration and effect. In the included studies, the shortest duration was four weeks (Costello and Warne, 2020), and the longest was 36 weeks (Johnson et al., 2019), with no significant difference in the final intervention effect between the two studies. Since this result has been found elsewhere, duration is probably not a factor influencing the effect. Some studies indicate probable reasons, Morgan et al. (2013) (Morgan et al., 2013) attributed this phenomenon to the ceiling effect. However, due to the limited research in this area, further study is required to establish the optimal duration of intervention for maximum effect.

In this *meta*-analysis, preschool and primary school intervention programs have positive effects, no statistically significant difference exists in effect size. Nonetheless, an unanticipated finding was that when the intervention strategy included professional FMS training programs for teachers, the intervention had a more significant effect. Previous research has demonstrated that professional instructors teaching FMS to children are more effective for developing their FMS (Goodway et al., 2003). Therefore, schools should offer FMS courses and involve experts in training teachers and designing effective FMS programs (Xin et al., 2021). Although school-based physical education is essential, other surroundings must be considered. To promote continual FMS development, after-school and family programs should be included as supplements, ultimately forming a systematic FMS intervention system.

5.1. Limitation

The current review has some limitations. Some studies employed a single-group experimental design, while others failed to provide the necessary experimental data. These studies were removed from the *meta*-analysis, and only a systematic analysis was conducted. Moreover, a smaller number of the studies included in this analysis implemented interventions targeting balance skill and performed statistical analyses. Consequently, the available sample size was inadequate to carry out a Meta-analysis specifically focusing on balance skills. According to the above restrictions, it is suggested that future studies should conduct more comprehensive research in these areas to gather more reliable data and evidence.

6. Conclusion

The analysis demonstrates that FMS development intervention programs in preschools and primary schools can be effective in promoting typically developing children's fundamental motor skills. This result synthesizes studies conducted over the past decade, and its conclusions contribute significantly to our knowledge and highlight the importance of providing children with opportunities to engage in FMS development in early childhood. Moreover, this study has important implications for educators and healthcare providers. They can use it to make better choices and plans for programs that help children build fundamental motor skills. These implications involve aspects such as promoting physical literacy, having a diverse FMS curriculum, providing training for physical education teachers, and engaging parents and guardians in supporting their children' FMS development.

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Authors' contributions

Conceptualization, D.Z. and K.S.; methodology, D.Z. and Z.Z.; software, Z.Z.; validation, D.Z, K.S. and Y.C.; formal analysis, D.Z.; investigation, D.Z.; resources, D.Z.; data curation, D.Z, K.S, Z.Z.; writing—original draft preparation, D.Z; writing—review and editing, K.S, Z.Z.; visualization, D.Z, Z.Z.; supervision, K.S.; project administration, D.Z, K.S and Y.C. All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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